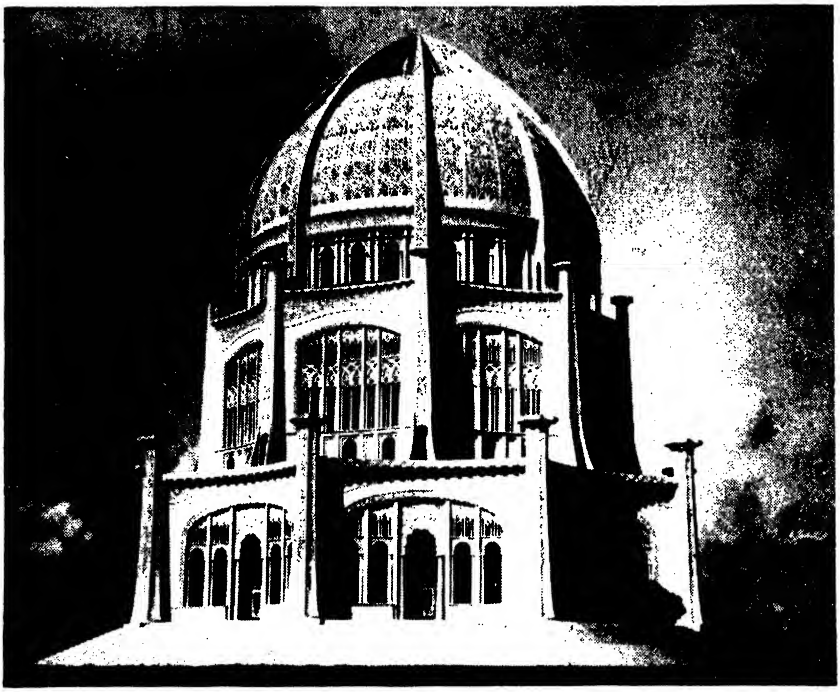
PLAIN CONCRETE



Frontispiece

The Bahai Temple at Wilmette, Ill., is an outstanding example of architectural concrete. The structural frame of the building is covered with an outer shell of ornamental concrete, consisting of hundreds of units joined together to form an unbroken surface. Each unit was made with white portland cement and crushed quartz.

PLAIN CONCRETE

BY

EDWARD E. BAUER
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University of Illinois

THIRD EDITION

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PLAIN CONCRETE

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VIII

PREFACE TO THE THIRD EDITION

Significant developments concerning concrete and concrete materials have occurred since the publication of the second edition in 1936. The discovery was made that the entrainment of a small amount of air in the cement paste produces a marked improvement in the durability of the concrete. Use of entrained-air concrete indicates that there is less segregation and bleeding during handling and placing and that the concrete is often much more plastic than concrete without air. Its use is increasing rapidly. Information is included in this edition concerning air-entraining portland cements, air-entraining admixtures, and the measurement of the amount of air entrained in concrete.

Discovery was also made that high alkali cements react unfavorably with certain siliceous aggregates causing disintegration of the concrete. Information is included concerning this cement-aggregate reaction and the means that are being taken to prevent its occurrence.

The American Society for Testing Materials has completely rewritten its specifications for portland cements, providing now for five types of non-air-entraining portland cement and three types of air-entraining portland cement. These are included in this edition. This Society has reorganized its specifications for the methods of testing portland cements, and has revised many of its specifications for concrete materials and methods of testing these materials. All instructions for the performance of laboratory tests have been revised in accordance with the latest available A.S.T.M. methods.

Most of the material in Part I has been rewritten and many new illustrations have replaced those of the previous edition. Statistical information has been brought up to date. Study questions for the benefit of students have been included following most of the chapters and methods of testing.

Grateful appreciation is expressed to the many individuals, organizations, and publications contributing information, statistical material, specifications, and illustrations for use in this edition. The American Society for Testing Materials, the Portland Cement Association, and the American Concrete Institute have been of special service.

Edward E. Bauer

Urbana, Ill.
April, 1949

PREFACE TO THE FIRST EDITION

A number of engineering colleges are now offering undergraduate courses in plain concrete and it is primarily to meet the needs of these classes that this volume has been prepared. Practicing engineers should also find it of value in the preparation of specifications, in the supervision of construction work, and in the testing of concrete and concrete materials.

The requirements of a college course in plain concrete call for a combination textbook and laboratory manual. This book being prepared for such use contains first material discussing the fundamental problems of concrete production and then instructions for the performance of laboratory tests.

In the text portion concrete materials are considered first. Methods of production are discussed briefly with special emphasis on items which affect the quality of the concrete in which they may be used. Purposes and values of the various tests are treated and specifications of the American Society for Testing Materials quoted wherever available. Following the discussion on materials the problems of proportioning, making, placing, finishing, and curing of concrete are considered. Other subjects covered are: field control methods, high-early-strength concrete, workability, waterproofing, estimating quantities of materials, specifications for concrete construction, sampling, and testing.

In the laboratory portion, instructions are given for the performance of all the usual tests on cement and aggregates, and for a number of research problems on concrete suitable for class use. Methods of testing prescribed by the American Society for Testing Materials are followed wherever available. The author has rearranged the instructions in such a way that the student can follow the operations in consecutive order, thus greatly facilitating the work in the laboratory. Forms are also given for the recording of laboratory data.

The author wishes to express his grateful appreciation to the many individuals, firms, and associations that have contributed information and pictures for use in this volume.

EDWARD E. BAUER

URBANA, ILL.
October, 1928

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Part I

CHAPTER 1

INTRODUCTION

Concrete is a mixture of a cementing material and a mineral aggregate. Cementing materials may be divided into two general classifications, bituminous and nonbituminous. Asphalts and tars compose the group of bituminous cements; and portland cement, aluminate cement, and natural cement make up the nonbituminous group. The mineral aggregate may be either crushed rock, gravel, slag, cinders, or burned shale.

Owing to the wide use of portland cement as the cementing material, the word "concrete" usually means portland-cement concrete. When the meaning is not clear, the kind of cementing material used should be designated, as portland-cement concrete or asphaltic-cement concrete. Occasionally it is desirable to designate the kind of aggregate used, and then the words indicating the kind of cement are omitted. Crushed-stone concrete or slag concrete are examples. The type of aggregate is usually designated only when slag, cinders, or burned shale are used.

This book deals largely with portland-cement concrete since portland cement is the nonbituminous cementing material most used. Natural cements are still produced but are not used extensively in concrete. Aluminate cement has been available on the American market since 1925, but the production has not been large as compared with that of portland cement.

History of Cement

The use of cementing materials dates back several thousand years. The early Romans and Egyptians used a variety of mortars and mortar-making materials.[1] Remains of some early structures indicate that the quality of the mortar used was good. No evidence is available, however, as to its composition or to the method of manufacture.

Natural Cement.—Natural cement is made by burning at a temperature between 1000 and 1300°C. a limestone containing a certain amount

[1] Lesley, "History of the Portland Cement Industry in the United States," p. 1.

of shale or clay. The limes and cements used previous to the building of the Eddystone Lighthouse in 1756 by John Smeaton, a noted British engineer, were not capable of setting under water.[1] Smeaton developed a cement that would set under water and, at the same time, contributed a valuable idea that the hydraulic properties of a limestone depended

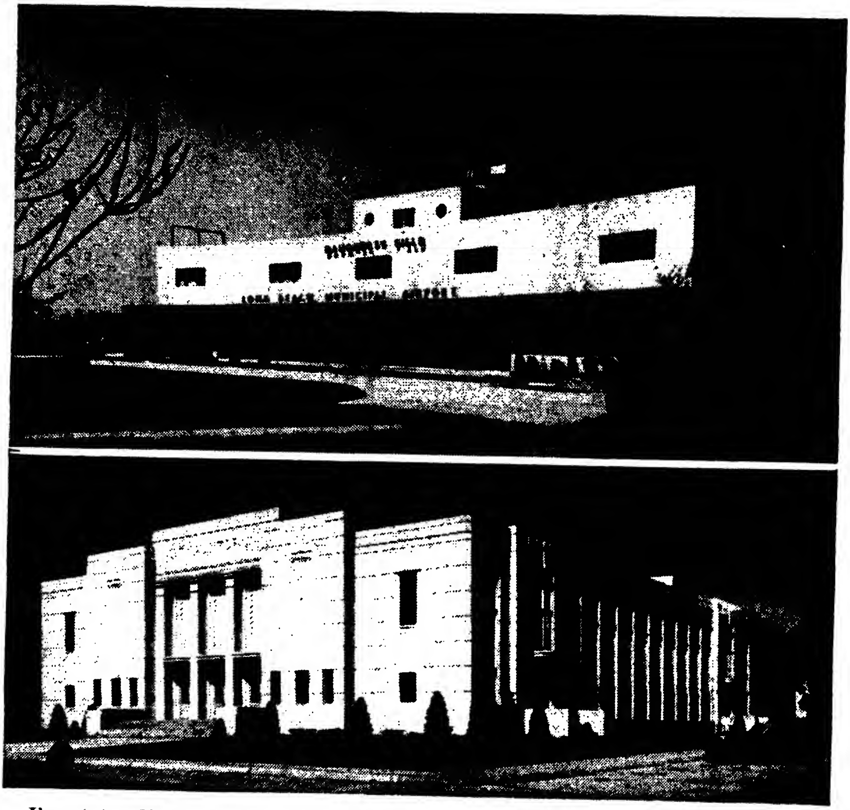

FIG. 1-1.—Examples of architectural concrete. *Top*, Terminal building Long Beach, Calif., municipal airport. *Bottom*, City auditorium, York, Nebr. (*Portland Cement Association.*)

upon the percentage of clay in its chemical composition and not upon its color and texture, as had been formerly supposed.

About 1791 Joseph Parker took out a patent for the production of a cement that he called Parker's cement. This later on became known as Roman cement. Parker had found certain rock deposits containing the proper elements necessary for the manufacture of a hydraulic cement.

[1] *Ibid.*, p. 12; DAVIS, "A Hundred Years of Portland Cement," pp. 13–24.

M. Vicat, the noted French engineer, introduced in 1818 a hydraulic lime, which, he said, was composed of ground chalk mixed with the proper proportion of clay. A plant was established outside of Paris but was not successful. Vicat was the first to experiment with the possibility of combining the raw materials in the production of cement. All cement produced prior to this time was made from a limestone containing sufficient clay.

The development of water transportation in the United States created a demand for cement, and the natural result was the development of the

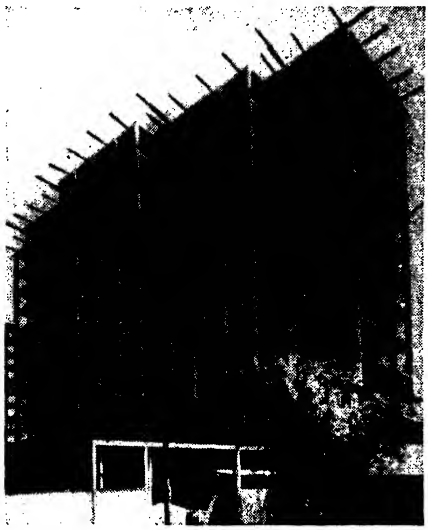

FIG. 1-2.—Reinforced-concrete skeleton for an office building. (*Portland Cement Association.*)

industry in this country. The Erie canal was started in 1817, and the following year saw the beginning of the cement industry in the United States. Table 1-1 indicates that much of the early natural cement was produced for the construction of canals.

Portland Cement.—To Joseph Aspdin, a bricklayer of Leeds, England, goes the credit for first producing portland cement. In 1824 he was granted a patent for his "improvements in the modes of producing an artificial stone." Aspdin called his new product *portland* because it resembled in color a building stone found on the Isle of Portland.

Aspdin's cement was, of course, not exactly what we have today. Aspdin was not trained in chemistry and, therefore, could not proceed to develop his new discovery on a scientific basis. The burning is the major difference between Aspdin's cement and our portlands. Aspdin calcined his raw material only until the carbonic acid was entirely removed. Today the raw materials are heated to incipient fusion.

I. C. Johnson, an English cement manufacturer, claims to be the real inventor of portland cement. Johnson was in charge of the works of J. B. White and Sons and in such capacity had the opportunity to experiment. On one occasion the raw materials were accidentally

TABLE 1-1.—DISCOVERY AND EARLY USES OF NATURAL CEMENT IN THE UNITED STATES*

Year	Locality	Construction
1818	Fayetteville, N.Y.	Erie Canal
1824	Williamsville, N.Y.	Erie Canal
1826	Kensington, Conn.	Miscellaneous
1828	Rosendale, N.Y.	Delaware and Hudson Canal
1829	Louisville, Ky.	Louisville and Portland Canal
1831	Williamsport, Pa.	Muncy and Lock Haven Canal
1836	Cumberland, Md.	Miscellaneous
1837	Round Top, Md.	Chesapeake and Ohio Canal
1838	Utica, Ill.	Illinois and Michigan Canal
1839	Akron, N.Y.	Miscellaneous
1848	Balcony Falls, Va.	Miscellaneous
1850	Siegfried's Bridge, Pa.	Easton and Mauch Chunk Canal
1850	Cement, Ga.	Miscellaneous
1863	Vallejo, Calif.	Miscellaneous
1867	Fort Scott, Kan.	Miscellaneous
1869	La Salle, Ill.	Miscellaneous
1869	Howe's Cave, N.Y.	Miscellaneous
1874	Buffalo, N.Y.	Miscellaneous
1875	Milwaukee, Wis.	Miscellaneous
1881	Canon City, Colo.	Miscellaneous
1893	Mankato, Minn.	Miscellaneous

* LESLEY, "History of the Portland Cement Industry in the United States," p. 32.

heated to semivitrifaction. Johnson decided to see what would happen if he pulverized this material. When made into a paste, this material became very hard and had the color of the Portland stone. The set cement fell to pieces, however, when it was immersed in water. He said: "I was so ashamed at this signal failure that I had the product of the kiln hidden away in an isolated cellar or vault at the outskirts of the works near the river out of sight." Johnson, however, out of curiosity came back to the cellar in a few weeks and found that the damp atmosphere had acted upon the free lime present and had slaked it. Johnson then tried this material again and found that it hardened and did not disintegrate when immersed in water. In 1845 shortly following this experiment Johnson's company began the production of portland cement essentially as we have it today.

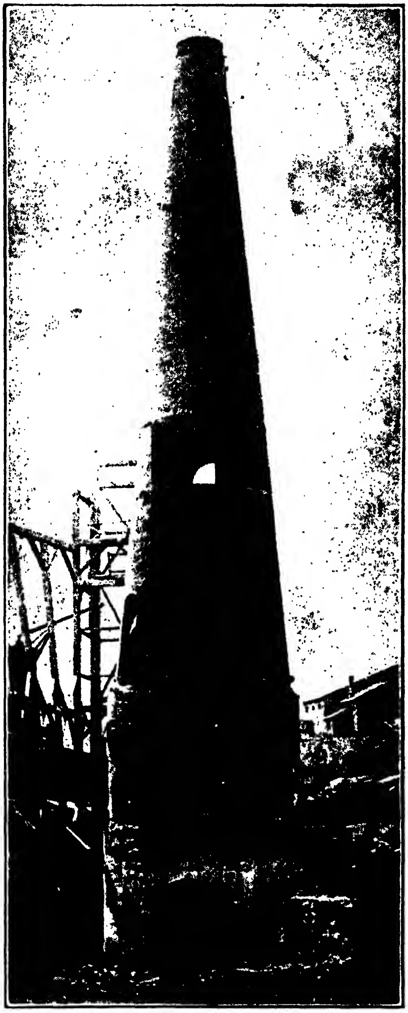

FIG. 1-3.—An old-time vertical kiln. This pioneer kiln used coke for fuel. The charge was arranged in alternate layers of coke and powdered rock made into bricks.

Introduction into the United States.—Portland cement was imported into this country first in 1865. European cement had acquired such a reputation for quality that it was difficult for American manufacturers to sell their product.

David O. Saylor, of Allentown, Pa., is generally given credit for being the first manufacturer of portland cement in this country.[1] He was granted a patent in 1871. The Coplay Cement Company, of which Saylor was the first president, shipped their first cement in 1874. Thomas Millen, of South Bend, Ind., and John K. Shinn, of Wampun, Pa., were other pioneer manufacturers who produced their first cements about the time that Saylor produced his.

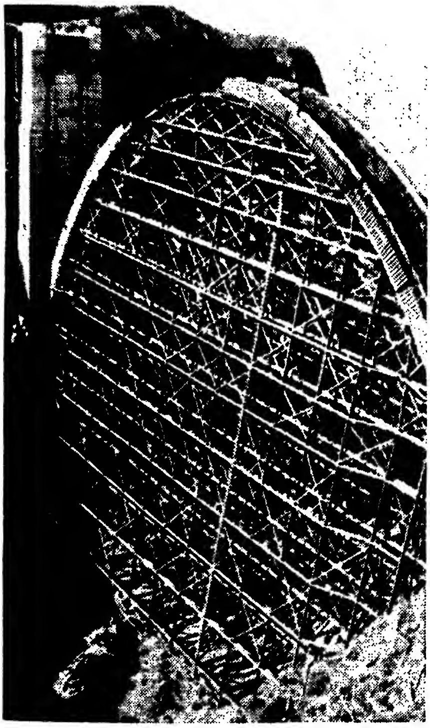

FIG. 1-4.—Construction form work for a reinforced-concrete bridge. (*Portland Cement Association.*)

The quantity of cement produced each year gradually increased until 1928 when over 176 million barrels were produced. Because of economic conditions beginning in 1929 consumption fell off until 1933 when only 63 million bbl. were produced. It is interesting to note that up to 1900—approximately the time of the adoption of a set of standard specifications—the amount of cement produced each year had not increased very rapidly. With the adoption and use of a standard specification the manufacturers were able to concentrate their efforts on quantity

[1] LESLEY, *op. cit.*, p. 50.

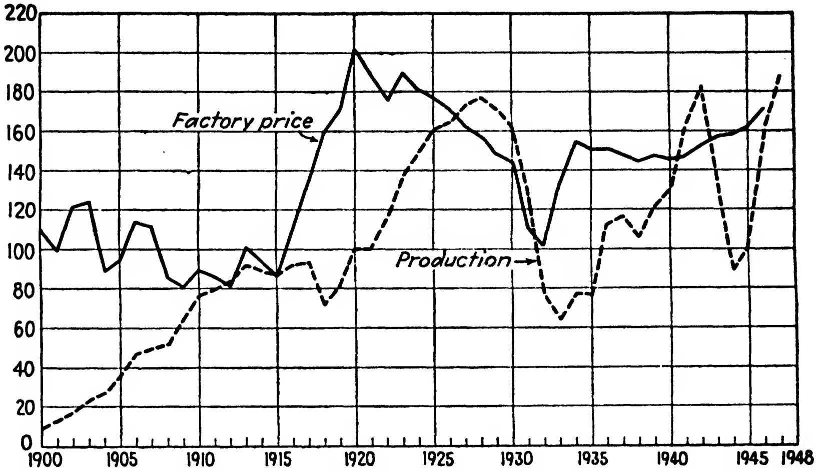

FIG. 1-5.—Production and average factory price of portland cement for the years 1900 to 1947.

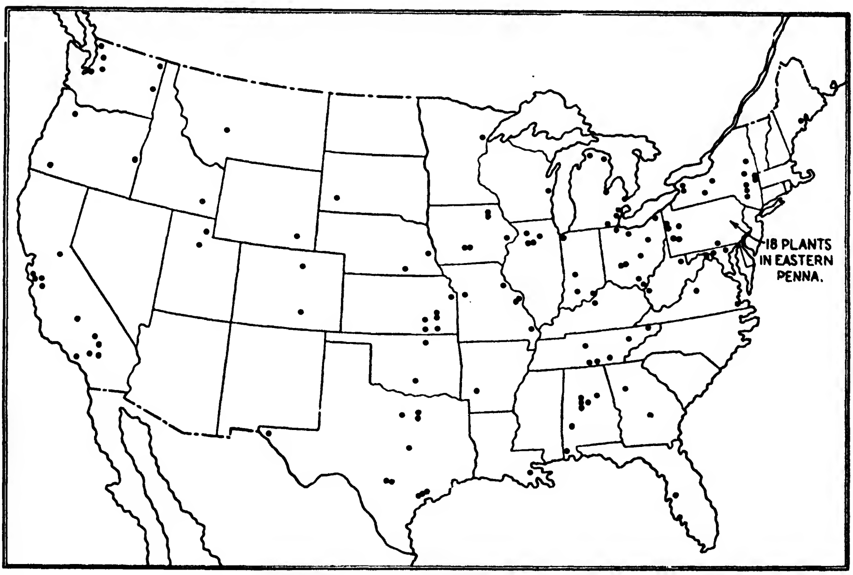

FIG. 1-6.—Location of cement plants in the United States, prepared from list supplied by the U.S. Bureau of Mines.

Table 1-2.—The Portland Cement Industry in the United States, 1870 to 1946*

Year	Production, bbl.	No. of producing plants†	Avg. factory value per barrel in bulk	Per capita consumption U.S.‡	Imports of hydraulic cement, bbl.§
1870–79	82,000		$3.00		198,000‖
1880	42,000		3.00	‡	187,000
1890	335,500	16	2.09		1,940,186
1895	990,324	22	1.60		2,997,395
1900	8,482,020	50	1.09		2,386,683
1905	35,246,812	79	0.94		896,845
1910	76,549,951	111	0.891		306,863
1915	85,914,907	106	0.86	0.83	42,218
1916	91,521,198	113	1.103	0.89	1,836
1917	92,814,202	117	1.354	0.84	2,323
1918	71,081,663	114	1.596	0.64	305
1919	80,777,935	111	1.71	0.77	8,931
1920	100,023,245	117	2.02	0.87	524,604
1921	98,842,049	115	1.89	0.87	122,317
1922	114,789,984	118	1.76	1.06	355,931
1923	137,460,238	126	1.90	1.21	1,767,264
1924	149,358,109	132	1.81	1.29	2,023,663
1925	161,658,901	138	1.77	1.38	3,667,458
1926	164,530,17	140	1.71	1.37	3,244,223
1927	173,206,513	153	1.62	1.44	2,065,730
1928	176,298,846	156	1.57	1.45	2,284,085
1929	170,646,036	163	1.48	1.41	1,745,345
1930	161,197,228	163	1.44	1.29	984,807
1931	125,429,071	160	1.11	1.06	457,238
1932	76,740,945	160	1.01	0.67	462,496
1933	63,473,189	152	1.33	0.50	477,794
1934	77,747,765	150	1.54	0.59	265,997
1935	76,741,570	150	1.51	0.58	619,404
1936	112,649,782	149	1.51	0.87	1,658,902
1937	116,174,708	150	1.48	0.87	1,803,932
1938	105,357,000	151	1.45	0.81	1,727,411
1939	121,934,911	149	1.47	0.95	1,413,853
1940	129,830,687	151	1.46	0.96	538,060
1941	163,567,931	154	1.47	1.25	42,405
1942	182,114,486	153	1.53	1.38	340
1943	132,445,838	151	1.57	0.95	13,658
1944	89,883,263	149	1.59	0.70	169
1945	101,340,500	142	1.63	0.77	323
1946	162,296,274	150	1.72	1.16	3,734

* Figures from U.S. Geological Survey and U.S. Bureau of Mines. Figures for Puerto Rico and Hawaii are not included.

† Number of plants active during year from 1905 on; previously, number of existing works.

‡ Based on shipments of domestic portland cement from mills to states.

§ Hydraulic cement imported for consumption; barrel of 376 lb. in 1920 to 1934 and 380 lb. in earlier years.

‖ Imports in 1878 and 1879.

production, and from 1900 to 1928 the production increased from 8 million to 176 million bbl.

Developments in the Manufacture.—The manufacturers of portland cement have ever been on the alert for the discovery of new methods to use in the production of their product. Their efforts have been for the most part to produce cement in greater quantities, resulting in lowered costs of production and lowered selling prices. Reduction in selling price has resulted in an increased volume of business. The quality of the cement was largely fixed by the user in his specifications.

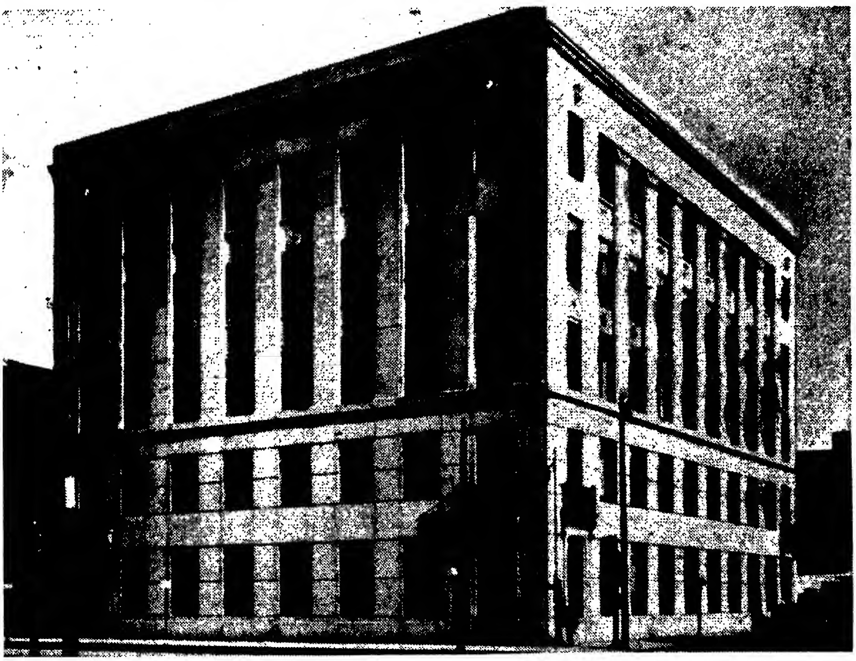

FIG. 1-7.—Precast concrete blocks were used instead of cut stone for the exterior walls of the Portland Cement Association building, Chicago, Ill. (*Portland Cement Association.*)

Probably the most noteworthy development has been made in the burning process. The first cements were burned in intermittent vertical kilns. The development of a horizontal rotary kiln, which could be operated continuously, meant much to the cement industry. The first British patent was issued to Thomas Russell Crampton.[1] The first rotary kiln in this country was erected in 1886 at Roundout, N.Y., by Jose F. de Navarro and his two sons.[2] It was 24 ft. long and 12 ft. in

[1] DAVIS, *op. cit.*, p. 163.
[2] LESLEY, *op. cit.*, p. 100.

diameter. In 1909 Thomas A. Edison was granted a patent for the use of kilns exceeding 150 ft. in length.[1] Today kilns vary in length from 150 to 475 ft. Inside diameters vary from 8 to 13 ft.

Particular attention has been paid in recent years to securing more uniformity in the mixtures of raw materials, which are prepared for burning in the kilns. Some manufacturers are mixing water with the

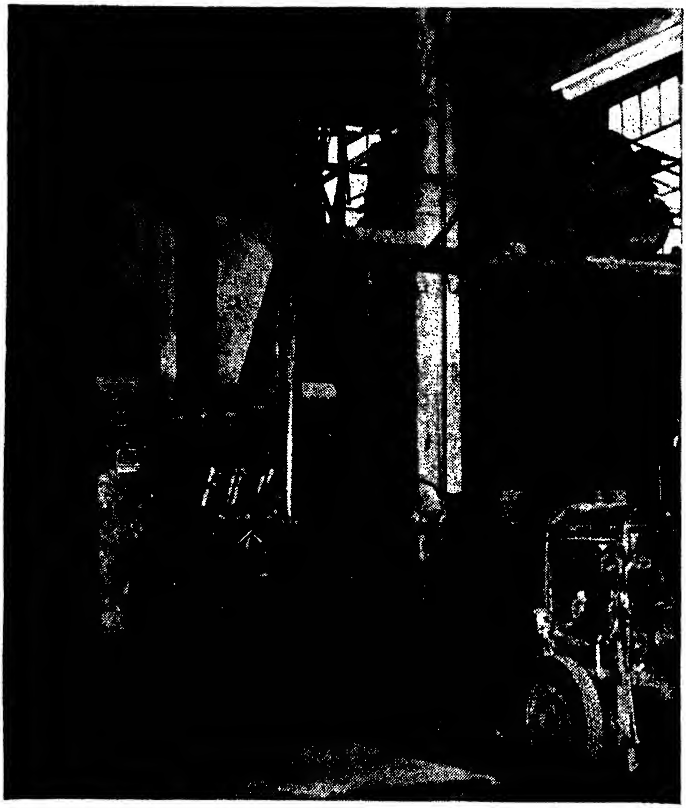

FIG. 1-8.—View in concrete-block manufacturing plant. Concrete mixer is on mezzanine platform above the block machine. Freshly molded blocks are being loaded on a special truck to be transferred to curing room. (*Courtesy of Rock Products.*)

limestone and shale to form a slurry, while others are securing the desired uniformity by means of blending bins where the dry materials are mixed or blended to the proper proportions of each. The former method is known as the wet process and the latter as the dry process. Most of the new plants being built now are for the wet process. The Olympic Portland Cement Company, Ltd., at Bellingham, Wash., was the first

[1] LESLEY, *op. cit.*, p. 123.

company to produce in 1915 portland cement from hard raw materials by the wet process.[1]

USES OF CEMENT AND CONCRETE

During the period beginning about 1900 the consumption of portland cement has been increasing (see Table 1-2 and Fig. 1-5) at the rate of about 10 million bbl. a year up to, and including, 1928. This rapid in-

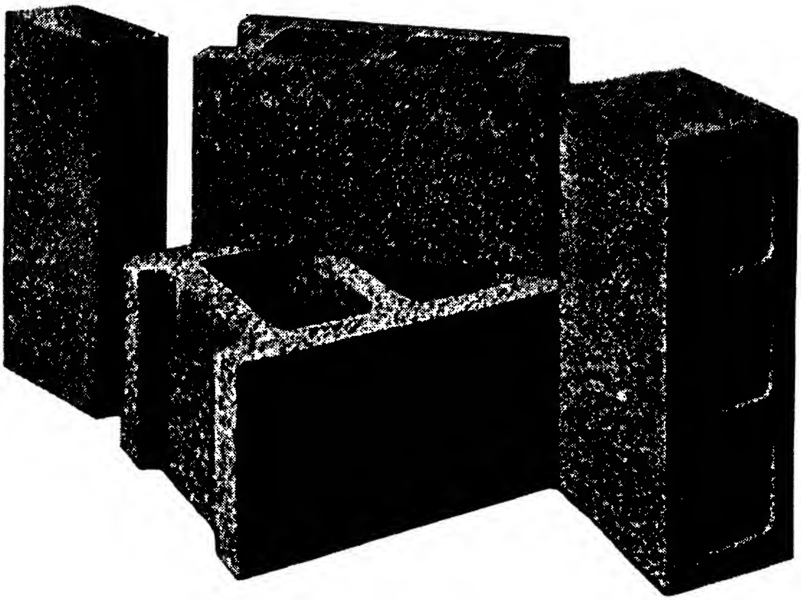

FIG. 1-9.—Various types of concrete building blocks. Other construction items made in concrete-products factories include sewer and drain pipe, ornamental light standards, precast concrete slabs, beams and columns, piling, fence posts, and blocks for building manholes. (*Besser Manufacturing Company.*)

crease has been brought about in part by finding new uses for cement and concrete. In 1902 the cement manufacturers formed an organization known as the Portland Cement Association, the purpose of which has been "to extend and improve the uses of portland cement," and to this association must go much of the credit for the development that has taken place. The public, too, has taken a natural liking to portland-cement concrete, and this has contributed much to the increased use of concrete. The public in its eagerness to find new uses for concrete has

[1] ROBERTS, "The Pioneer Wet Process Cement Plant on the North American Continent," *Pit and Quarry*, Vol. 11, No. 2, pp. 39*ff*. (Oct. 15, 1925).

sometimes misused it. A few of the more important uses of concrete will be briefly explained in the following paragraphs.

Reinforced Concrete.—Reinforced concrete is concrete in which steel bars have been placed to take the tensile stresses, since concrete is comparatively weak in tension as compared to its compressive strength. Reinforced concrete is used in the building of bridges, buildings, walls, floors, bins, reservoirs, etc.

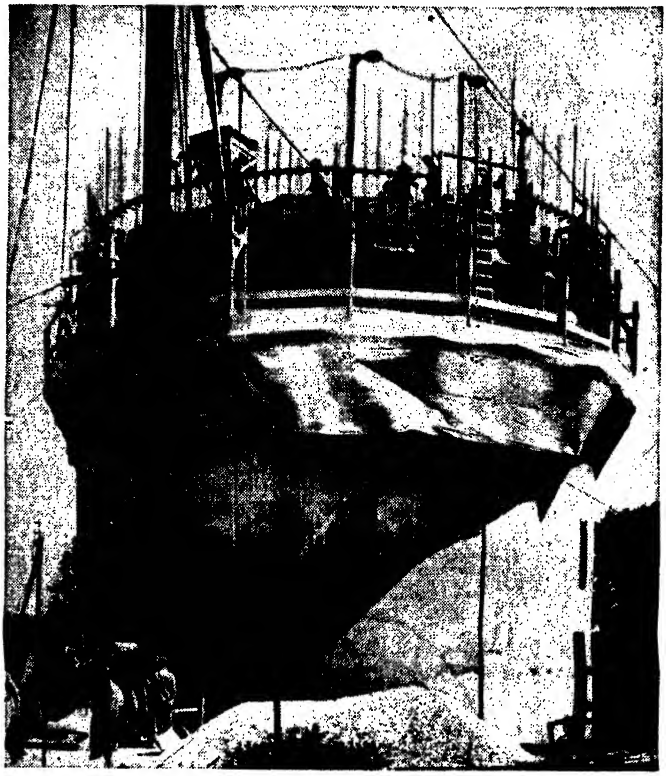

Fig. 1-10.—Reinforced-concrete water tank under construction using slip forms. (*Portland Cement Association.*)

Highway Construction.—In the period since the close of the First World War the use of concrete as the wearing surface of pavements greatly increased. There has been no general use of steel as a reinforcing material to take tensile stresses. Steel is used, however, to bond together the various parts of the slab when it cracks or has construction joints built in. Concrete is used also in constructing bases for other types of wearing surfaces, the building of bridges, culverts, drains, curbs and gutters, and sidewalks.

Sewage Disposal.—Concrete is being used extensively in the building of sewage-disposal plants and in the construction of sewers and is of the reinforced type mentioned above.

Concrete Products.—The more important concrete products include building blocks, brick, sewer and drain tile, light standards, telegraph, telephone and electric-wire poles, and fence posts. In order to remove the forms at once, the concrete is mixed to a relatively stiff consistency, which requires extra amounts of tamping, vibrating, or spinning. Lightweight aggregates are being used extensively in the building blocks.

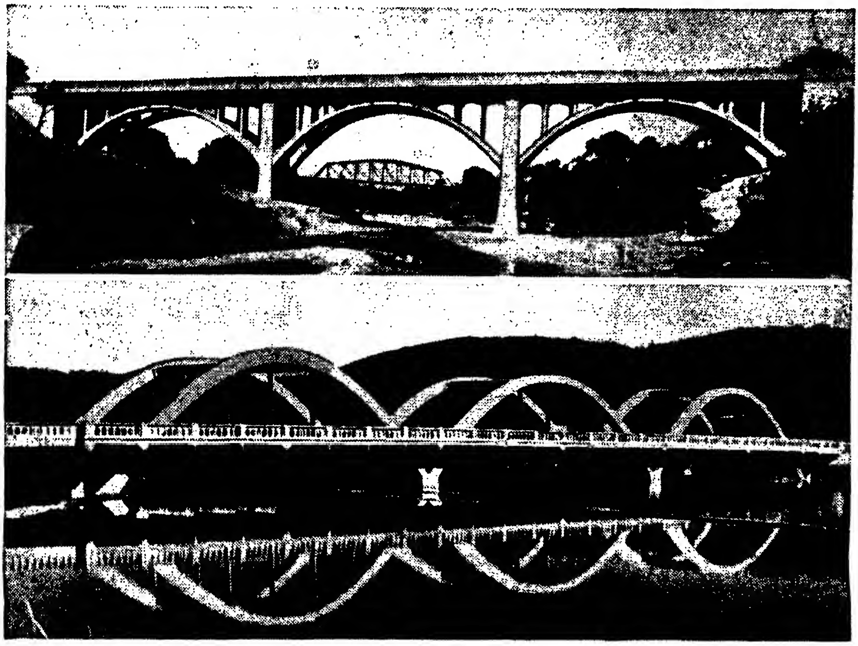

FIG. 1-11.—Two types of reinforced-concrete arch bridges. (*Portland Cement Association.*)

Decorative Concrete.—Concrete is also being used in various ways to develop the decorative scheme of a building. One method is to use colored aggregates near the surface and to expose these aggregates within 24 hr. by brushing away the mortar. Aggregates may also be exposed by grinding away the surface layer until the cross section of the aggregate is shown. Any desired pattern may be executed with almost any combination of colors. Colored designs may also be painted on the surface of the concrete. For a discussion of the methods used see Chap. 9.

Cast Stone.—Another recent development is the making of solid blocks of concrete that resemble cut natural stone and that are handled and used in the same manner. The aggregates are not exposed, and the cut-stone effect is secured by the use of sand molds.

Stucco.—Mixtures of cement and sand can be applied to the outside surfaces of walls of buildings. The aggregates may or may not show, the surface may be smooth or rough, and patterns may be worked in by molding the surface or by the use of aggregates. Stuccoed walls have a pleasing appearance and are durable.

FIG. 1-12.—A concrete house. (*Portland Cement Association.*)

FIG. 1-13.—A concrete stadium. (*Portland Cement Association.*)

Miscellaneous Uses.—Concrete is made to serve many other purposes around the home, on the farm, at the factory, in parks, etc.

Hassam Concrete.—Hassam concrete was a patented type used only in building pavements. A layer of crushed stone at least 4 in. in thickness is laid first, and then a 1:1 grout is flushed into the crushed stone. The grout normally penetrates to a depth of from 3 to 4 in. After the stone has taken all the grout possible, a thin layer of stone chips is spread over the surface and rolled until the grout comes through.

Interest in this type of concrete was revived in 1933 in an effort to secure a concrete pavement of lower cost than when the usual methods of construction were followed. This type is now known as cement macadam.

American Society for Testing Materials.—The American Society for Testing Materials, incorporated in 1902, is composed of persons interested in materials. The membership is divided into three classes—producers, consumers, and a general interest group, the last being engineers, scientists, educators, or research workers. The society holds an annual meeting in June, at which time reports are read of work done by

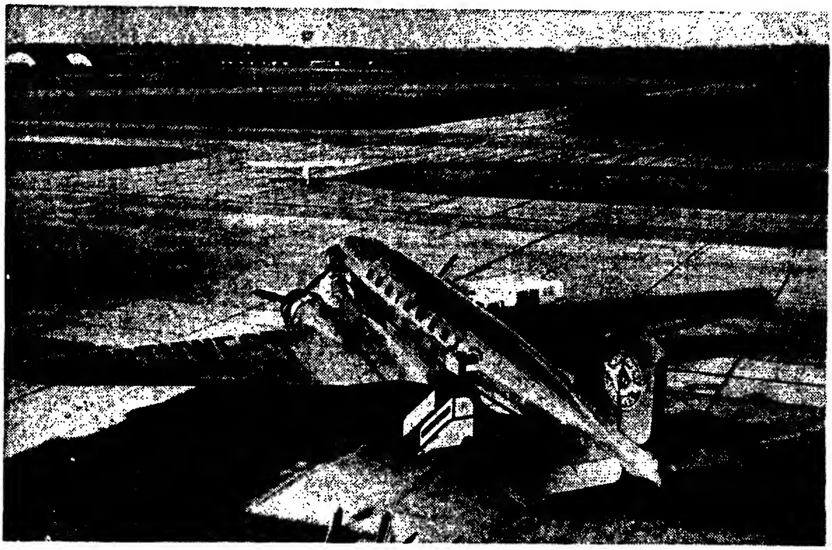

FIG. 1-14.—Use of concrete paving at an airport. (*Northwest Airlines.*)

individuals and committees. Specifications for materials and methods of testing are prepared by committees and submitted to the membership for adoption. Proposed specifications at first are issued as tentative. After the specification seems to be acceptable to everyone, it is advanced to a standard.

Each specification is given a serial designation, consisting of a letter and a number followed by the year of the last change or the year of adoption. For instance, the specification for cement has the designation C 150-47. Specifications in the tentative stage have a T after the year.

The A.S.T.M. specifications are used either by reference or by quoting part or in full. It is quite common, for instance, to say that the portland cement shall meet the requirements of the American Society for

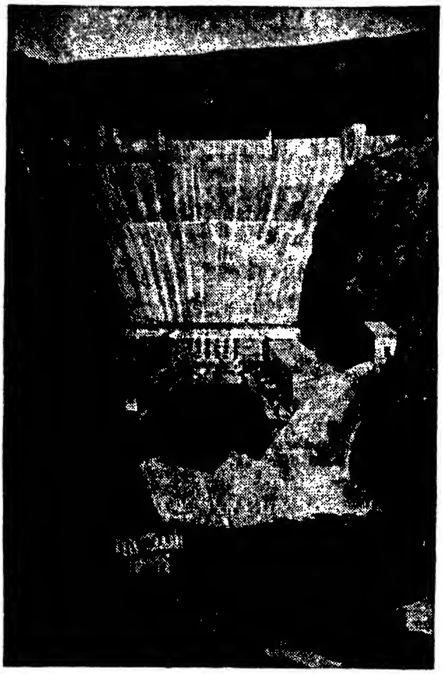

Fig. 1-15.—Concrete was used in the construction of Hoover Dam on the Colorado River. This was the first of the really large concrete dams to be built. Considerable research was carried on by the Bureau of Reclamation and others prior to its construction in order to secure information on cements, aggregates, and proportioning. (*Portland Cement Association.*)

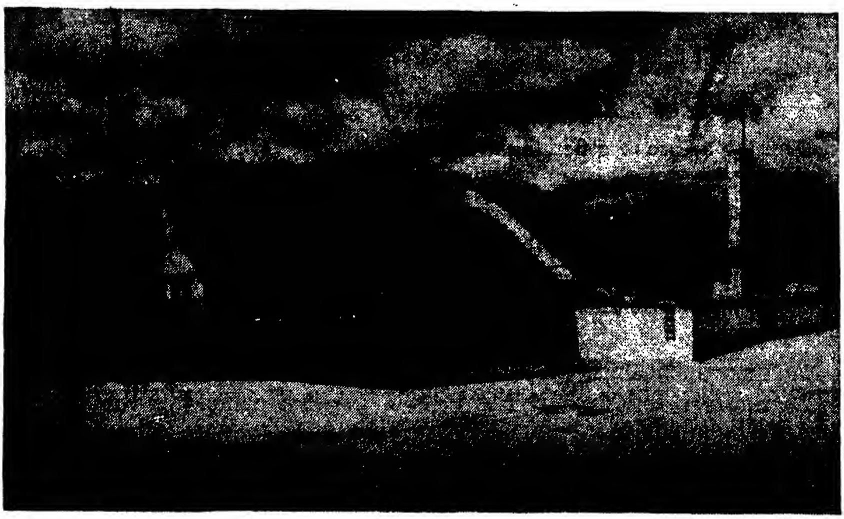

Fig. 1-16.—Use of concrete for swimming pool and stands at Fargo, N. D. (*Portland Cement Association.*)

Testing Materials as given in their Standard Specifications for Portland Cement, Designation C 150-47. Some engineers, on the other hand, prefer to include the whole specification verbatim. Frequently, only a part of a specification is desired, in which case that portion must be copied.

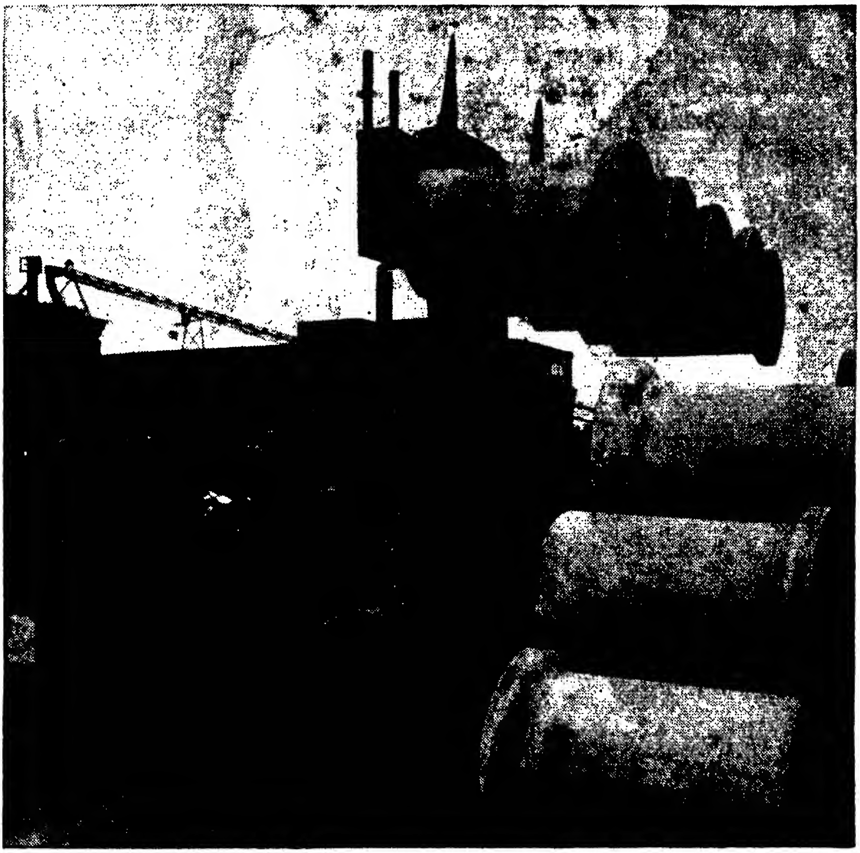

FIG. 1-17.—Handling of concrete pipe by a Ross Hilift truck. (*Courtesy of Rock Products.*)

The A.S.T.M. specifications are part of the copyrighted proceedings of that organization, but engineers are encouraged to use them in the preparation of specifications.

American Concrete Institute.—The American Concrete Institute is an organization composed of individuals who are interested in concrete. It was founded in 1905 and incorporated in 1906 as the National Association of Cement Users. The name was changed in 1913 to the American Concrete Institute. The principal function of the Institute is the dissemination of knowledge concerning concrete and concrete materials. The work is carried on through committees and subcommittees, an annual meeting, and the publication of papers and committee reports. The *Journal* is published bimonthly except during July and August. The annual *Proceedings* consist of the *Journals* for the year.

Portland Cement Association.—The Portland Cement Association is the promotion and research organization of the manufacturers of portland cement. Its function is to extend and improve the uses of cement. The headquarters and an extensive research laboratory are located in Chicago. Information is furnished the public through a series of pamphlets; the reports of research are made largely in the *Proceedings of the American Concrete Institute* or in the *Proceedings of the American Society for Testing Materials*.

Reference Material.—Much information concerning concrete and concrete materials is available in the following publications:

Journal of the American Concrete Institute

Proceedings of the American Society for Testing Materials. A number of special publications, such as *Symposium on Mineral Aggregates*, are also available.

Proceedings of the Highway Research Board of the National Research Council

Proceedings of the American Society of Civil Engineers

Pamphlets of the Portland Cement Association

Engineering News-Record

Pit and Quarry

Rock Products

Concrete

Civil Engineering

CHAPTER 2

STANDARD PORTLAND CEMENT

Portland cement is the product obtained by pulverizing clinker, consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that additions not to exceed 1.0 per cent of other materials may be interground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown to be not harmful by tests carried out or reviewed by Committee C-1 on Cement.[1]

The clinker mentioned in the definition is produced by heating to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, the usual argillaceous material being clay or shale and the calcareous material, limestone. The untreated calcium sulfate (gypsum) is added during the grinding of the clinker in order that the cement will not set too rapidly when used in concrete.

Prior to 1936 the American Society for Testing Materials had only one standard specification for portland cement. In 1936 a standard specification was adopted for high-early-strength portland cement. In June, 1941, both the specifications were discontinued and a single specification adopted, providing for five different types of cement, as follows:

Type 1. For use in general concrete construction when the special properties specified for types 2 to 5 are not required

Type 2. For use in general concrete construction exposed to moderate sulfate action or where moderate heat of hydration is required

Type 3. For use when high early strength is required

Type 4. For use when a low heat of hydration is required

Type 5. For use when high sulfate resistance is required

The new specifications provide that when no mention is made of the type of cement wanted it is to be type 1. Types 1 and 3 are rather

[1] From A.S.T.M. standard specification for portland cement (Designation C 150). Committee C-1 on Cement is the committee that has jurisdiction over the portland-cement specification.

generally available, type 2 in certain parts of the country, while types 4 and 5 are usually only made on special order.

Each manufacturer has a brand name for his cement. Some manufacturers have given the early-strength cement a name different from that used for the standard cement, while others retain the same name but designate the cement as early-strength. The specification provides that all packaged cement shall have the name of the manufacturer and the brand clearly marked on the package.

The manufacture of all portland cement is carried out in the same general way and from essentially the same raw materials. Certain variations are made, however, in order to produce the various types. In this chapter the general procedure will be discussed, mainly as it applies to type 1 cement. Variations in this procedure as are necessary to produce types 2 to 5, as well as air-entraining portland cement, will be given in Chap. 3, together with a discussion of their special properties. Discussion of the additions that are permitted during the grinding of the clinker will be given under that heading later in this chapter.

MANUFACTURE

Following the adoption of the first set of specifications by the A.S.T.M. in 1904, rapid strides were made in the development of quantity production of portland cement. The raw materials must be prepared, mixed in the proper proportions, burned into a clinker, the clinker ground into a fine powder and packaged for sale to customers. Freed of the requirement of making frequent changes in the manufacturing process due to different specification requirements of the customers, the manufacturers were able to increase their output and at the same time reduce the price at the factory.

There is not much variation from plant to plant in the exact methods of manufacture.

Raw Materials.—The raw materials from which cement is manufactured are divided into two general classifications, argillaceous and calcareous. The most common combinations of these are:

Argillaceous	*Calcareous*
Shale or clay	Limestone
Cement rock	Limestone
Blast-furnace slag	Limestone
Shale or clay	Marl

Cement rock is a limestone, found principally in Pennsylvania, containing more than 50 per cent clay. Marl is a soft deposit of clay and calcium carbonate found in the bottoms of shallow lakes, swamps, or extinct fresh-water basins. In 1945, 71.4 per cent of the portland cement was made from clay and limestone, 19.8 per cent from cement rock and limestone, 6.8 per cent from blast-furnace slag and limestone, and 2.0 per cent from clay and marl.[1]

FIG. 2-1.—General view in stone quarry from which limestone is secured.

PREPARATION OF RAW MATERIALS

The raw materials that are combined to produce portland cement must have the proper chemical constituents in order that the finished product will have the proper physical and chemical requirements as given in the A.S.T.M. specifications.[2] The composition of the raw materials varies from place to place in the deposits, thus necessitating frequent analyses as the materials are removed. Tests are also made on the mixture before it is burned and adjustments made until the proper proportions of the various materials are secured.

In the dry process of manufacture, the raw materials are dried before being ground and mixed for burning, while in the wet process they are mixed with water to be prepared for burning. The development of the long rotary kiln has made the use of the wet process economical, and from about 1915, most of the new plants have installed the wet process.

[1] *Minerals Yearbook*, 1945, U.S. Bureau of Mines.
[2] Given at the end of this chapter.

FIG. 2-2.—View of blast in stone quarry. Many tons of dynamite are used each year by the cement manufacturers in securing their supply of limestone.

FIG. 2-3.—Preliminary crushing of stone is accomplished in a giant gyratory crusher.

Dry Process.—The hard materials coming from the quarry must be crushed in order that all pieces will pass a 2- or 3-in. screen. Large, gyratory crushers are generally used. The materials are then dried in large hollow steel cylinders 50 ft. in length and 5 ft. in diameter. Waste gases are frequently used.

For proper burning about 85 per cent of the raw mixture should pass a No. 200 sieve. Two stages of grinding are necessary and are known as "preliminary" and "final grinding." Preliminary grinding is generally done in a ball mill, known as a "preliminator." The grinding is accom-

FIG. 2-4.—Ball mills in which the raw material or the clinker is ground.

plished by the action of 6 to 8 tons of steel balls, 2½ to 5 in. in diameter, as the cylindrical, steel drum revolves (see Fig. 2-4). The drum is 8 ft. in diameter and 5½ ft. in length. After preliminary grinding the materials should pass a No. 20 sieve.

At this point the argillaceous and calcareous materials are combined, proportions of each material being based on chemical analyses. Final grinding is usually done in a tube mill, which is 22 ft. in length and 5 or 6 ft. in diameter. The charge in a tube mill is about 15 tons of flint stone or steel balls. The material as it leaves the tube mill is ready for burning with about 85 per cent passing a No. 200 sieve.

Wet Process.—Prior to 1915 marl and clay were the only raw materials used in the wet process. Since then more and more plants have been installing the wet process, with limestone and shale as the raw materials. Manufacturers are not unanimous in the feeling that the wet process is better than the dry, and those believing in the latter have developed special blending bins for the purpose of securing more uniform raw mixtures.

To pass through a No. 20 sieve without being dried, the limestone and shale are first reduced in size. The materials are then mixed with water into a slurry and ground in order that 85 per cent will pass through a No. 200 sieve. Until about 1925 the slurry was introduced directly into the kiln, but since that date most manufacturers remove the water before introducing the raw mixture into the kiln. The removal of the water is accomplished by special driers using waste heat from the kiln.

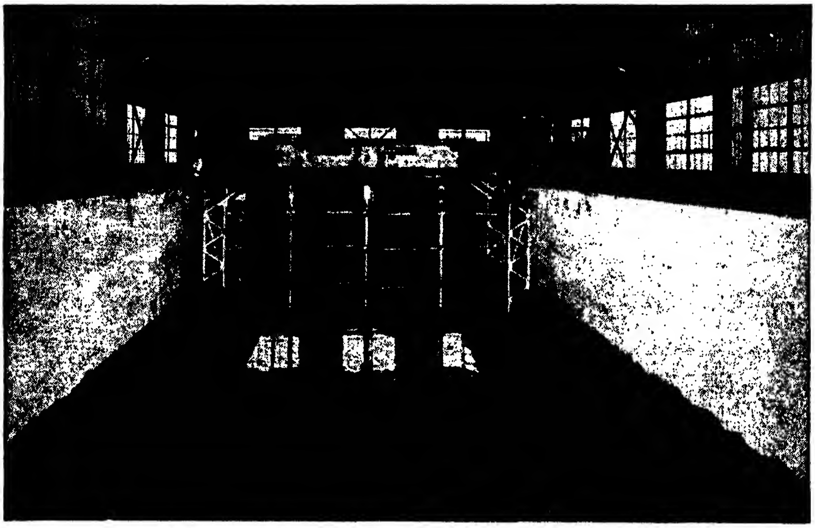

FIG. 2-5.—Traveling agitator in a slurry storage tank.

In 1945, 81 plants using the wet process produced 55.6 per cent of the portland cement that year while 60 plants using the dry process produced the remaining 44.4 per cent.[1]

Heating Raw Materials to Incipient Fusion.—Present-day practice is to burn the raw mixture in a long, horizontal rotary kiln, which may be from 150 to 475 ft. in length and 5 to 12 ft. in diameter. The average kiln is about 200 ft. long and 10 ft. in diameter. It consists of a steel drum that is supported on rollers at intervals and is lined with firebrick. The speed of rotation is about three-fourths of a revolution per minute, and the inclination with the horizontal is ½ to ¾ in. per ft. The longer kilns rotate at a higher speed and are on a flatter slope than the shorter

[1] *Minerals Yearbook*, 1945, U.S. Bureau of Mines.

ones. Fuel is introduced at the lower end while the raw materials are entering at the upper end. The smoke and gases pass out the upper end, which is connected to a chimney.

The fuel ordinarily used is coal, pulverized in order that 95 per cent will pass a No. 100 sieve. It is blown into the kiln by means of an air blast. Gas and oil are also used as fuels. The longer kilns have greater fuel economy than the shorter ones.

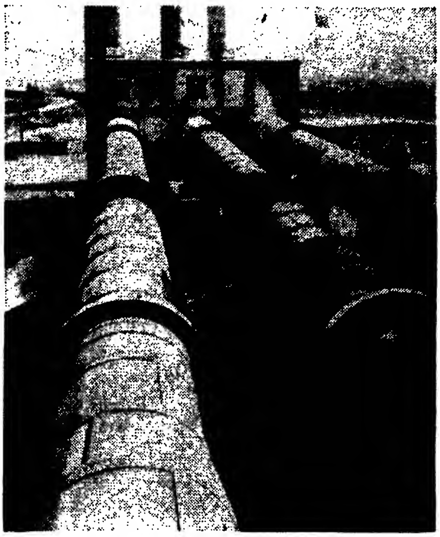

FIG. 2-6.—Battery of three long, horizontal rotary kilns in which the raw materials are burned into clinker. (*Portland Cement Association.*)

The U.S. Bureau of Mines reports that in 1945 fuels were used as follows in the cement industry:

Fuels	*Number of plants using*
Coal	84
Oil	13
Natural gas	12
Coal and oil	9
Coal and natural gas	15
Oil and natural gas	5
Coal, oil, and natural gas	3
Total	141

The raw materials gradually work themselves down through the kiln in from 1½ to 3½ hr. They are heated to a temperature of approximately 2700°F., at which temperature clinker of a black or a greenishblack color is formed. It has a vitreous luster and is quite hard. The output of a rotary kiln varies from 500 to 4,000 bbl. per day, depending upon its size. In producing a 376-lb. barrel of cement about 175 lb. of coal are burned, and 600 to 700 lb. of raw materials are used.

The introduction of the rotary kiln about 1900 was probably the most important development in the manufacture of cement and has made it possible to put cement on the market at a price sufficiently low to permit of its general use. At first the vertical kiln was used. Alternate layers

Fig. 2-7.—Tubular cooler through which the hot clinker is passed in order to recover much of the heat held by the clinker when it comes from the kiln. (*Portland Cement Association.*)

of the raw materials and coke or wood were put into place and fired. In order to remove the clinkers and recharge the kiln it was necessary to cool the kiln. The capacity of such a kiln was only about 100 bbl. per day.

Grinding the Clinker.—Conservation of heat is an important item in the reduction of operating costs. The clinker is heated in the kiln to a temperature of 2700°F., and much of this heat can be recovered as the clinker is cooled. Formerly, and in some cases still, the clinker was permitted to cool in air with a 100 per cent loss of this heat. Special cooling apparatus has been developed which recovers much of the heat.

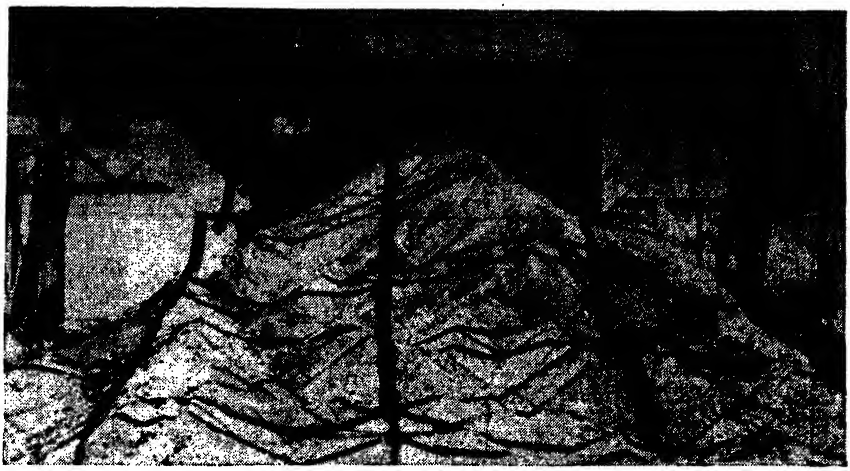

FIG. 2-8.—Clinker in storage, waiting to be ground into finished cement. (*Portland Cement Association.*)

FIG. 2-9.—Inside of ball mill used in grinding raw materials or the clinker.

The recovered heat is returned to the furnace to be used in burning more clinker.

The clinker is ground in much the same manner as the raw materials. Recent developments in grinding equipment permit of finer grinding of the clinker, and one piece of equipment is used instead of two as formerly.

The first specification for portland cement required that not more than 8 per cent be retained on the No. 100 sieve and not more than 25 per cent on the No. 200 sieve. Later, only the No. 200 sieve was included, and the value was 22 per cent. In 1937 the use of the sieve

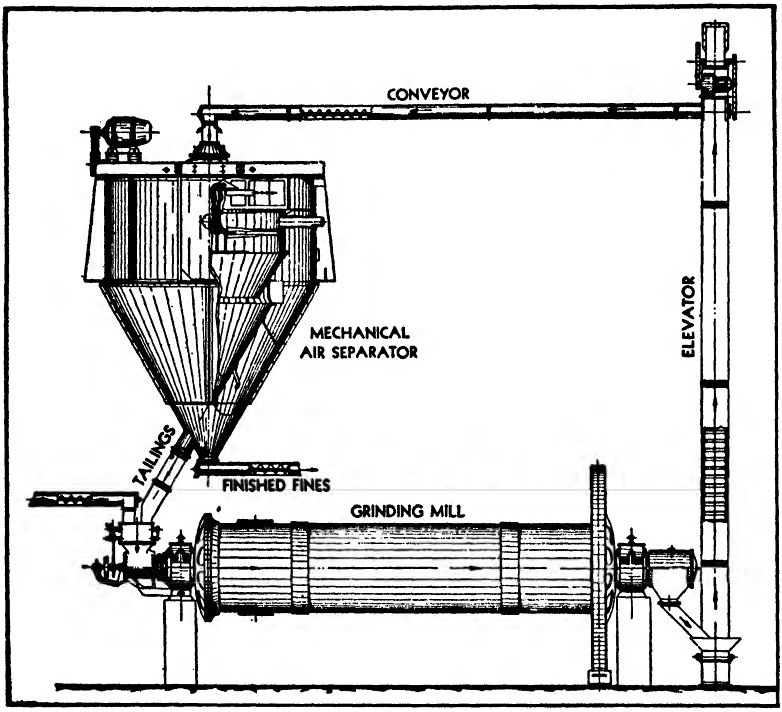

FIG. 2-10.—Diagram showing use of air separator in closed circuit with grinding equipment. Particles that are too coarse are returned to the grinder. Advantages of air separator are (1) close control over fineness and particle-size uniformity, (2) reduced grinding cost per unit of output, and (3) ability to make quick changes from one fineness specification to another. (*Raymond Pulverizer Division, Combustion Engineering Company, Inc.*)

was eliminated in checking fineness because very little was retained. From 1937 to 1941 there was no requirement for fineness. In 1941 when the present standard (C 150) was adopted, fineness of grinding was handled by means of a sedimentation test, relative fineness being expressed as specific surface values in square centimeters per gram of cement.

A gram of very finely ground cement has more particles than a gram of coarsely ground cement. The particles in 1 g. of the finely ground cement have a greater surface area than the equivalent weight of coarsely ground cement. The test is rather involved and for most persons it is sufficient to know that the cements with the high specific surface values are the finely ground cements.

Additions During Grinding.—The definition of portland cement calls for the addition of untreated calcium sulfate and permits certain other additions, provided that approval has been given by Committee C-1.

The calcium sulfate is added to retard the set of cement. The amount of calcium sulfate is usually about 2 per cent of the weight of the cement. The manufacturer adds the sulfate in amounts that will produce a cement meeting the A.S.T.M. requirements for time of setting. The limits have been established as a result of experience and are intended to produce a cement that will meet practically all construction requirements. The cement must not set until the concrete is in place and properly finished, but after the finishing operation is completed, the cement should set.

Committee C-1 has given approval for two other additions, known commercially as TDA and 109-B. They are sold to the cement manufacturer as grinding aids.

Bagging.—Practically all cement shipped prior to 1927 was in cloth bags, containing 94 lb. net. The original unit of measure was the barrel containing 376 lb. net. The first cements brought into this country and the first cements made in this country were shipped in wooden barrels. Cement is also shipped in bulk in gondola or boxcars.

Multiple-wall paper bags made similar to the cloth bags came into extensive use in 1927. The paper bags are made with five thicknesses of paper and prevent to a much greater degree the absorption of moisture from the air than do the cloth bags. Because of the smoother surface of the paper not so much cement remains in the paper bag as in the cloth bag. The price of cement in paper bags is 28 cents per barrel higher than in bulk.

When cement is shipped in cloth bags, the price is $1.05 higher than in bulk. The purchaser may recover $1 of the $1.05 upon return of the four bags. Cloth bags must be cleaned and put in bundles of 50 for return to the cement mill.

In 1946 bulk shipments constituted 29.8 per cent of all shipments, in cloth bags 15.9 per cent, and in paper bags 54.3 per cent.[1]

The first step in bagging is to wire shut the top of the cloth bag. A special device is inserted into the bottom of the bag for filling. The bag is then slipped over a nozzle, and the cement is blown in. When

[1] *Minerals Yearbook*, 1947, U.S. Bureau of Mines.

Fig. 2-11.—Bagging the cement. Cloth bags are tied at the top with wire while the paper bags are sewed or pasted shut across the top. In both cases the cement is forced into the bag through a self-closing valve at the bottom. Ninety-four pounds of cement is automatically weighed and fed into each bag. (*Portland Cement Association.*)

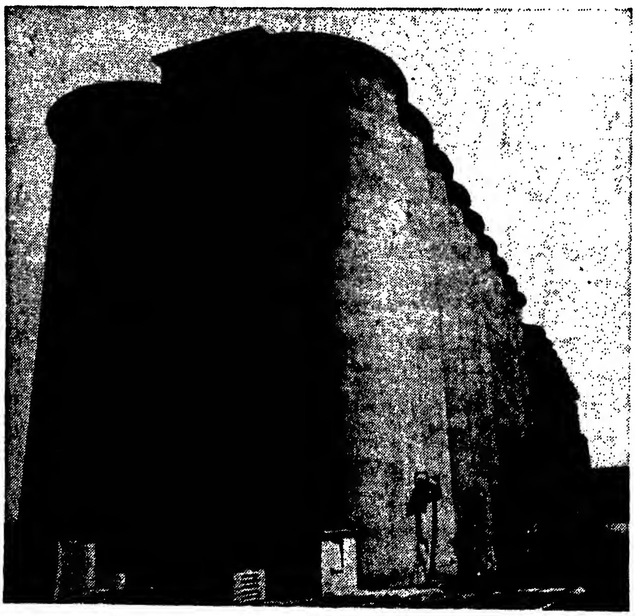

Fig. 2-12.—Concrete silos used for storage of cement at the factory. In the slack selling periods stocks of cement are built up to meet the heavier demands of

94 lb. are in the bag, an automatic cutoff stops the flow of cement, and the bag drops on a belt to be conveyed to the loading platform.

Attempts were made shortly after the First World War to ship cement in bulk, but the equipment available for unloading the cars and for measuring the cement on the job were unsatisfactory, and the practice nearly stopped until 1930. By that time the use of weighing equipment for measuring the aggregates had become general enough to indicate that it was practicable.

There is a saving to the contractor when he uses bulk cement in that the cement itself costs less and he can use his mixer at its full-rated capacity, which he cannot always do with bagged cement because of the usual limitation in the specifications that no fractional bags of cement can be used. For instance, a No. 28 mixer will handle 28 cu. ft. of mixed concrete plus a 10 per cent overrun, or 30.8 cu. ft. If a concrete is being mixed that runs 4.5 cu. ft. per bag of cement, the contractor is limited to a 6-bag batch, or 27 cu. ft., when he uses bagged cement. With bulk cement he can mix a batch right up to the capacity of the mixer.

Shipments of bulk cement in the United States, in per cent of all cement shipped in the years shown were:[1]

1928	2.4	1939	19.7
1929	11.4	1940	25.6
1930	13.6	1941	31.0
1931	15.4	1942	42.0
1932	24.2	1943	42.2
1933	20.6	1944	34.5
1934	20.0	1945	30.0
1936	18.0	1946	29.8

Normally, some time elapses between the grinding of the clinker and the shipment of the cement, during which much of the heat generated during the grinding of the clinker is lost. There are times, however, when fairly warm cement is used in the making of concrete, and the question has arisen as to the effect of this heat upon the properties of the resulting concrete. A special A.S.T.M. committee in 1932 reported on the effect of temperatures of cement at time of use as follows:

On account of the low specific heat of portland cement and its relatively small quantity in the usual mix, the temperature at the time of use of portland cement of normal properties appears to be a minor fac-

[1] Figures 1928–1933 furnished by H. Coffman, Hercules Cement Corp. Beginning with 1934, figures are from *Minerals Yearbook*, U.S. Bureau of Mines. Figures not available for 1935, 1937, 1938.

tor in producing high temperatures of freshly mixed concrete under usual job conditions.[1]

Chemical Composition.—Properly prepared portland cements (type 1) will have the following chemical composition:

Lime (CaO)	61.5–65.5
Silica (SiO_2)	19.5–23.0
Alumina (Al_2O_3)	5–8
Magnesia (MgO)	5 max.
Sulfur trioxide (SO_3)	2 max.
Iron oxide	0–4

The magnesia and sulfur trioxide values are maximum amounts permitted by the standard specifications.

High-alkali Cements.—When the chemical analysis of the cement indicates that the alkali content is greater than 1.0 per cent, the cement is known as a high-alkali cement. The compounds known as alkalis are sodium oxide, Na_2O, and potassium oxide, K_2O, both of which are not listed in the table in the preceding paragraph. The possible bad effect of using a high-alkali cement with certain siliceous aggregates is discussed in Chap. 10.

Specifications.—The specifications under which portland cement is produced in the United States are those adopted by the A.S.T.M. The first A.S.T.M. cement specification was adopted in 1904 and then revised in 1908, 1909, 1916, 1920, 1926, 1930, 1937, and 1938. In 1941 an enlarged specification was adopted, calling for 5 types of portland. On Mar. 31, 1922, the specification for cement became the first American Standard Specification.

Physical Tests

The engineer uses a small group of physical tests in controlling the quality and properties of portland cement, together with several chemical requirements. The physical tests are (*a*) fineness of grinding, (*b*) soundness, (*c*) time of setting, and (*d*) a strength test, either tension or compression. The specific-gravity requirement was eliminated in 1926. The instructions for the performance of the cement tests are given first in Part II of this book, and the reader is referred there for a detailed description of the tests.

Fineness of Grinding.—The principal result of finer grinding is to hasten the early development of strength. Final strengths may also be increased, provided favorable curing conditions are maintained over a period of time.

[1] *Proc. A.S.T.M.*, Vol. 32, Part I, pp. 298–301.

Another advantage of finer grinding is the reduction of the amount of bleeding of the concrete in which the cement is used. During the handling, placing, and finishing operations, and until the concrete has set, a portion of the mixing water may separate itself from the concrete. This loss of mixing water is known as bleeding and is considered undesirable by most engineers.

Those particles that are fine enough to pass through the No. 200 sieve are the ones that react with the water to give strength to the concrete. For many years it was considered sufficient to require that not more than a certain percentage be retained on the No. 200 sieve. The clear distance between wires of this sieve is only 0.0029 in. but even between 0 and 0.0029 in. there can be many variations in the shape of the particle-size curve.

In connection with the studies of materials for the Hoover (then called Boulder) Dam project, a turbidimeter[1] was developed for measuring the fineness of cement. The cement is placed in suspension in a suitable suspending medium, such as clear kerosene, in a glass container. The particles settle out over a period of time, the rate at which they settle depending upon their size, other items being kept constant. At certain intervals of time a beam of light is passed through the suspension, the intensity being measured after it has passed through the suspension. By proper calibration of the apparatus data can be secured with which to plot a particle-size accumulation curve similar to those plotted for aggregates.

Instead of specifying a particle-size accumulation curve between certain limits, a coefficient was developed known as specific surface. On the assumption that the particles are spheres it is possible to compute the surface area of any given weight of cement when the distribution of sizes is known. The specific surface value represents the surface area in square centimeters per gram of cement.

Soundness.—The purpose of the soundness test is to determine if there is anything present in the cement that will cause disintegration of the concrete in which the cement is used. In the manufacturing process occasionally free lime (CaO) is produced. This occurred much more often in the early years than now. As it absorbs moisture, free lime expands to many times its original volume and develops considerable heat, both of which are injurious to concrete.[2]

[1] WAGNER, L. H., "A Rapid Method for the Determination of the Specific Surface of Portland Cement," *Proc. A.S.T.M.*, Vol. 33, Part II, p. 553 (1933).

[2] See also paper by Lerch, "The Cause of Unsoundness in Portland Cement," *Paper* 20, Portland Cement Association Fellowship at the National Bureau of Standards.

Since 1941 the test for soundness has been the autoclave test (see Test 9); prior to that year it was the pat test (see Test 4). In the autoclave test, cement paste of normal consistency is molded into a bar 1 by 1 by 10 in. At the end of 24 hr. the bar is measured at 80°F. and placed in the autoclave where it is subjected to steam pressure of 295 p.s.i. for 3 hr. After cooling to 80°F., the bar is measured again and the per cent expansion calculated. Expansion is limited to 0.50 per cent.

Should the cement fail to pass on the first test, it may be retested any time within 28 days and accepted if it passes the retest.

Time of Setting.—The rate of setting is an important item in the handling and finishing of concrete. During the setting period the concrete loses its ability to be made into different shapes and becomes a hard mass. After the concrete has become sufficiently hard to hold its shape, the hardening period, as it is called, begins. As a concrete hardens, it gains in strength.

Sufficient time must elapse between the mixing and setting to permit the concrete to be placed. After the concrete is once in place, it is desirable that the setting and hardening action take place. The requirements for various jobs will be different, and sufficient latitude is given to include almost all construction work. It is necessary that any one using concrete plan his work in order that the concrete may be gotten into place before the setting action takes place.

Two stages of setting are defined in the specifications. They are known as initial set and final set. Initial set occurs when the cement paste will support the ¼-lb. Gillmore needle without appreciable indentation, or when the Vicat needle ceases to penetrate past a point 5 mm. above the bottom of the cement paste that is molded in the vulcanite ring. Final set occurs when the paste will support the 1-lb. Gillmore needle or the Vicat needle without appreciable indentation.

Bogue[1] in summarizing concerning the various theories on the setting action says:

> It is generally conceded that the alumina-containing compounds present in cements constitute the one important group of substances upon which the rate of set depends. . . . It is agreed that the alumina compounds or solid solutions, which we will refer to as calcium aluminate, combine with water with great avidity, and that it is this hydration which causes initial set. Consequently, the amount of calcium aluminate present, and the rate at which it hydrates, determine the rapidity of set.

[1] "A Digest of the Literature on the Nature of the Setting and Hardening Processes in Portland Cement," *Paper* 17, Portland Cement Association Fellowship at the National Bureau of Standards.

. . . It has been found, however, that the introduction of certain materials, notably some form of calcium sulfate does materially modify the rate of set. . . .

As previously indicated in this chapter, gypsum, which is calcium sulfate, is used to retard the setting.

Strength Tests.—As a final check on quality the specifications provide for a strength requirement, either in tension or compression. The purchaser is expected to indicate which type of test he prefers, but if no mention is made of the type of test to be used, the tension test requirements apply.

In the tension test (see Test 6) the cement is made into a mortar using standard sand (passing No. 20 sieve and retained on the No. 30 sieve). The amount of water to be used is based on the requirement to produce a cement paste of normal consistency (see Test 3). The mortar is made into briquets with a cross-sectional area of 1 sq. in. at midsection. At least three briquets must be tested at each age prescribed in the specifications.

In the compression test (see Test 7) the cement is made into a mortar using graded standard sand. The amount of water necessary is whatever amount is needed to produce a flow of a given amount, using a specified flow table. The test specimen is a 2-in. cube, and at least three must be made for each age given in the specifications for portland cement.

STANDARD SPECIFICATIONS FOR PORTLAND CEMENT

A.S.T.M. Designation: C 150-47

1. Scope.—These specifications cover five types of portland cement, as follows:

Type 1. For use in general concrete construction when the special properties specified for types 2, 3, 4, and 5 are not required.

Type 2. For use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required.

Type 3. For use when high early strength is required.

Type 4. For use when a low heat of hydration is required (Note).

Type 5. For use when high sulfate resistance is required (Note).

NOTE.—Attention is called to the fact that cements conforming to the requirements for type 4 and type 5 are not usually carried in stock. In advance of specifying their use, purchasers or their representatives should determine whether these types of cement are, or can be, made available.

2. Basis of Purchase.—The purchaser should specify the type or types desired. When no type is specified, the requirements of type 1 shall govern.

3. Definition.—For the purpose of these specifications portland cement is the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that additions not to exceed 1.0 per cent of other materials may be interground with the clinker at the option of the manufacturer, provided such materials in the amounts indicated have been shown to be not harmful by tests carried out or reviewed by Committee C-1 on Cement.[1]

NOTE.—Tests to determine whether a proposed addition is not harmful will be carried out or reviewed by Committee C-1 on Cement, for those making requests. In the year following that in which an addition has been declared not harmful by the committee, the name of the addition and the amount permitted shall appear as an addendum to Section 3 in a revision of the specifications.

4. Chemical Requirements.—Portland cement of each of the five types shown in Section 1 shall conform to the chemical requirements prescribed in Table 1.

5. Physical Requirements.—Portland cement of each of the five types shown in Section 1 shall conform to the physical requirements prescribed in Table 2.

6. Packaging and Marking.—When cement is delivered in packages, the name and brand of the manufacturer and the type under these specifications shall be plainly indicated thereon, except that in the case of Type 1 the type need not be indicated. Similar information shall be provided in the shipping advices accompanying the shipment of packaged or bulk cement. A bag shall contain 94 lb. net. A barrel shall consist of 376 lb. net. All packages shall be in good condition at the time of inspection.

7. Storage.—The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weathertight building that will protect the cement from dampness and minimize warehouse set.

8. Inspection.—Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be

[1] The committee has declared as not harmful the inclusion of the following materials:

(*a*) The material known commercially as TDA (composed of triethanolamine and highly purified soluble calcium salts of modified lignin sulfonic acids), manufactured by the Dewey & Almy Chemical Co., when added in an amount not exceeding 0.043 per cent by weight of the cement, except that in type 3 cement a maximum of 0.08 per cent by weight may be used.

(*b*) The material known commeicially as 109-B (composed essentially of 2 methyl 2-4 pentane diol), marketed by the Master Builders Co., when added in an amount not exceeding 0.03 per cent by weight of the cement, except that in type 3 cement a maximum of 0.05 per cent by weight may be used.

specified by the purchaser. The following periods from time of sampling shall be allowed for completion of testing:

1-day test	6 days
3-day test	8 days
7-day test	12 days
28-day test	33 days

TABLE 1.—CHEMICAL REQUIREMENTS

	Type 1	Type 2	Type 3	Type 4[a]	Type 5[a]
Silicon dioxide (SiO_2), min., per cent	......	21.0			
Aluminum oxide (Al_2O_3), max., per cent	......	6.0	......	......	4.0
Ferric oxide (Fe_2O_3), max., per cent	......	6.0	......	6.5	5.0
Magnesium oxide (MgO), max., per cent	5.0	5.0	5.0	5.0	4.0
Sulfur trioxide (SO_3), max., per cent	2.0[b]	2.0	2.5[c]	2.0	2.0
Loss on ignition, max., per cent	3.0	3.0	3.0	2.3	3.0
Insoluble residue, max., per cent	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate ($3CaO \cdot SiO_2$),[d] max., per cent	......	50	......	35	50
Dicalcium silicate ($2CaO \cdot SiO_2$),[d] min., per cent	......	......	......	40	
Tricalcium aluminate ($3CaO \cdot Al_2O_3$),[d] max., per cent	......	8	15	7	5

[a] See Note, Section 1.

[b] The maximum limit for sulfur trioxide content of type 1 cement shall be 2.5 per cent when the tricalcium aluminate content is over 8 per cent.

[c] The maximum limit for sulfur trioxide content of type 3 cement shall be 3.0 per cent when the tricalcium aluminate content is over 8 per cent.

[d] The expressing of chemical limitations by means of calculated, assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds.

The percentages of tricalcium silicate, dicalcium silicate, and tricalcium aluminate shall be calculated from the chemical analysis as follows:

Tricalcium silicate =
$(4.07 \times \text{per cent } CaO) - (7.60 \times \text{per cent } SiO_2) - (6.72 \times \text{per cent } Al_2O_3) - (1.43 \times \text{per cent } Fe_2O_3) - (2.85 \times \text{per cent } SO_3)$

Dicalcium silicate =
$(2.87 \times \text{per cent } SiO_2) - (0.754 \times \text{per cent } 3CaO \cdot SiO_2)$

Tricalcium aluminate =
$(2.65 \times \text{per cent } Al_2O_3) - (1.69 \times \text{per cent } Fe_2O_3)$

Oxide determinations calculated to the nearest 0.1 per cent shall be used in the calculations. Compound percentages shall be calculated to the nearest 0.1 per cent and reported to the nearest 1 per cent.

9. Rejection.—*a.* The cement may be rejected if it fails to meet any of the requirements of these specifications.

b. Cement remaining in bulk storage at the mill prior to shipment for more than 6 months, or cement in bags in local storage in the hands of a vendor for more than 3 months after completion of tests may be retested before use and

TABLE 2.—PHYSICAL REQUIREMENTS

	Type 1	Type 2	Type 3	Type 4[a]	Type 5[a]
Fineness, specific surface, sq. cm. per gram:					
Average value, min.	1,600	1,700	....	1,800	1,800
Minimum value any one sample	1,500	1,600	....	1,700	1,700
Soundness: autoclave expansion, max. per cent	0.50	0.50	0.50	0.50	0.50
Time of setting (alternate methods):[b]					
Gillmore test:					
Initial set, minutes, not less than	60	60	60	60	60
Final set, hours, not more than	10	10	10	10	10
Vicat test:					
Initial set, minutes, not less than	45	45	45	45	45
Final set, hours, not more than	10	10	10	10	10
Compressive strength, p.s.i.[c] The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C 109, shall be equal to, or higher than, the values specified for the ages indicated below:					
1 day in moist air	....	....	1,250		
1 day in moist air, 2 days in water	900	750	2,500		
1 day in moist air, 6 days in water	1,800	1,500	....	800	1,000
1 day in moist air, 27 days in water	3,000	3,000	....	2,000	2,200
Tensile strength, p.s.i.:[c] The tensile strength of mortar briquets composed of 1 part cement and 3 parts standard sand, by weight, prepared and tested in accordance with Method C 190, shall be equal to, or higher than, the values specified for the ages indicated below:					
1 day in moist air	....	....	275		
1 day in moist air, 2 days in water	150	125	375		
1 day in moist air, 6 days in water	275	250	....	175	175
1 day in moist air, 27 days in water	350	325	....	300	300

[a] See Note, Section 1.

[b] The purchaser should specify the type of setting test required. In case he does not so specify, the requirement of the Gillmore test only shall govern.

[c] The purchaser should specify the type of strength test required. In case he does not so specify, the requirements of the tensile strength test only shall govern. The strength at any age shall be higher than the strength at the next preceding age. Unless otherwise specified, the compressive and tensile strength tests on types 1 and 2 cement will be made only at 3 and 7 days. If, at the option of the purchaser, a 28-day test is required on type 3 cement, the strength at 28 days shall be higher than at 3 days.

may be reiected if it fails to conform to any of the requirements of these specifications.

c Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighting 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

10. Methods of Testing.—The cement shall be sampled and the properties enumerated in these specifications shall be determined in accordance with the following methods of the American Society for Testing Materials.

a. *Sampling.*—Designation C 183
b. *Chemical Analysis.*—Designation C 114
c *Fineness.*—Designation C 115
d. *Autoclave Expansion.*—Designation C 151
e. *Time of Setting.*—Designation C 191
f. *Compressive Strength.*—Designation C 109
g. *Tensile Strength.*—Designation C 190

Tentative Revision

A tentative revision of the above specification was made in 1948 to make the compressive and tensile strengths of type 5 cement at both 7 and 28 days the same as for type 2.

STUDY QUESTIONS

1. Define portland cement.
2. Name the raw materials normally used in the manufacture of portland cement.
3. What do the words "argillaceous" and "calcareous" mean?
4. What is meant by the dry process? the wet process? Which is more generally used? What advantages are claimed for each process?
5. What is done to prepare the raw materials for calcination? What does calcination mean? How fine are the particles when ready for calcination?
6. Name and describe the unit used for calcination. What is the maximum temperature in this unit?
7. Give the range of lengths and diameters for kilns used in the United States. What advantage does the long kiln have over the shorter ones?
8. What fuels are used in the kilns? Which one is used in most plants? How can coal be used in a cement kiln?
9. How fine is the clinker normally ground? How many openings per square inch in a No. 200 sieve? Why is the sieve not used any more to check fineness of cement?
10. Name the material that must be added during the grinding of the clinker. How much is normally added? What is the purpose of this addition?
11. Name the materials that may be added during the grinding of the clinker. What is the purpose of these additions? Who decides under the A.S.T.M. specifications whether or not to add any material?
12. What are the main advantages of finer grinding of the cement? How are fineness values given?

13. What chemical compounds are classed as alkalies? Under what circumstances are alkalies harmful in concrete? When is a cement classed as a high-alkali cement?

14. What is meant by the term "setting"? Can a fast-setting cement be used in normal construction operations? What tests are used to control the time of setting? Name the two stages of setting mentioned in the A.S.T.M. specifications, and give the time limits for each stage.

15. What is meant by a sound cement? What test is used in the A.S.T.M. specifications to control soundness?

16. What strength tests are used to control the strength-developing properties of cement? At which ages are strengths specified for the various types of cement?

CHAPTER 3

SPECIAL CEMENTS

Before discussing special cements, it would be well to consider briefly the chemical composition of cement and to indicate in a general way the effects of these compounds.

Chemical composition figures given in the previous chapter indicate that portland cement is a combination of lime (CaO), silica (SiO_2), alumina (Al_2O_3), magnesia (MgO), sulfur anhydride (SO_3), and iron oxide (Fe_2O_3). When these components are intimately mixed and burned to equilibrium, the following compounds are formed:

Tricalcium silicate ($3CaO \cdot SiO_2$)
Dicalcium silicate ($2CaO \cdot SiO_2$)
Tricalcium aluminate ($3CaO \cdot Al_2O_3$)
Tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot FeO_3$)
Uncombined magnesia (MgO)
Uncombined lime (CaO)
Calcium sulfate ($CaSO_4$)

Tests at the Bureau of Standards by Bogue lead to the following generalizations concerning the formation of the compounds:[1]

1. The ferric oxide (Fe_2O_3) reacts with the alumina (Al_2O_3) and lime (CaO) to form tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$).
2. The magnesia remains essentially in the form of uncombined MgO.
3. The alumina (Al_2O_3) remaining from combination as $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ reacts with lime to form tricalcium aluminate ($3CaO \cdot Al_2O_3$).
4. The lime (CaO) remaining from the above combinations reacts with the silica (SiO_2). The compound dicalcium silicate ($2CaO \cdot SiO_2$) is formed, and any CaO then uncombined reacts with the $2CaO \cdot SiO_2$ to form $3CaO \cdot SiO_2$. If CaO remains after converting all of the $2CaO \cdot SiO_2$ to $3CaO \cdot SiO_2$, it will be present as uncombined CaO.

The calcium silicate compounds are generally believed to be the ones most effective in developing strength. The others have little or no

[1] Bogue, R. H., "Calculation of Compounds in Portland Cement," *Paper* 21, Portland Cement Association Fellowship at the National Bureau of Standards, October, 1929.

cementing value. Heat is liberated by all the compounds during hydration of the cement. The rate of chemical reaction determines in a general way the total amount of heat developed. Tricalcium aluminate hydrates most rapidly, tricalcium silicate next, and dicalcium silicate and tetracalcium aluminoferrite least rapidly. The aluminate hydrates chiefly within the first day, the tricalcium silicate within the first week and the dicalcium silicate after the first week.[1]

TABLE 3-1.—COMPARISON OF CHARACTERISTICS OF MAJOR CEMENT COMPOUNDS*

Characteristics	Tricalcium silicate	Dicalcium silicate	Tricalcium aluminate	Tetra-calcium alumino-ferrite
Cementing value	Good	Good	Poor	Poor
Rate of reaction	Medium	Slow	Fast	Slow
Amount of heat liberated	Medium	Small	Large	Small

* CARLSON, R. W., "Development of Low-heat Cement for Mass Concrete," *Eng. News-Record*, Vol. 109, pp. 461–463 (1932)

TABLE 3-2.—QUANTITIES OF SPECIAL CEMENTS PRODUCED IN UNITED STATES*

Year	Type 3	Type 4	Type 5	White	Portland-puzzolan
1941	6,063,638	†	342,400	538,752	441,500
1942	7,523,647	†	79,835	345,613	234,002
1943	6,816,671	1,710,617	24,419	318,470	215,026
1944	5,135,264	441,368	100	302,543	290,013
1945	5,487,460	35,715	5,141	425,299	212,156
1946	6,716,488	139,966	65,880	774,215	1,092,607

* From *Minerals Yearbook*, U.S. Bureau of Mines.
† Information not available for these years.

Two theories have been advanced concerning what happens during the setting and hardening of portland cement. The crystallization theory was first advanced by Henri LeChâtelier and the colloidal theory by William Michaelis, Sr., their complete reports being published in 1887 and 1906, respectively.[2]

[1] CARLSON, R. W., "Development of Low-heat Cement for Mass Concrete," *Eng. News-Record*, Vol. 109, pp. 461–463 (1932).

[2] See BOGUE, "A Digest of the Literature on the Nature of the Setting and Hardening Processes in Portland Cement," *Paper* 17, Portland Cement Association Fellowship at the National Bureau of Standards.

For most engineers it is sufficient to consider that the reaction between the cement and the water forms an inorganic gel. The rate of setting of the gel is influenced by a number of factors such as temperature, amount of gypsum added during the grinding of the clinker, and the relative water content of the gel. Agitation of the concrete will prevent the setting of the gel, as will the presence of certain compounds such as sugar. The organic impurities test is made on fine aggregates to detect the presence of any organic compounds that might prevent the setting of the cement gel. (See Test 19).

HIGH-EARLY-STRENGTH PORTLAND CEMENTS

A high-early-strength portland cement is one that meets certain strength requirements at 1 and 3 days. At 1 day the tensile and compressive strength requirements are 275 and 1,250 p.s.i., respectively. At 3 days the values are 375 and 2,500 p.s.i., respectively. (See specifications at the end of Chap. 2 and Tests 6 and 7.) This is type 3 in the present A.S.T.M. specifications for portland cement.

The first American-made, high-early-strength portland cement was offered for sale in 1927. Since then there has been an increasing use of this type of cement until a peak was reached in 1942. (See Table 3-2 for quantities produced in recent years.)

The early-strength property is secured by finer grinding and by increasing the percentage of tricalcium silicate. More care is also exercised in the selection of the raw materials. In the specification for this type of cement there are no minimum values for fineness of grinding or tricalcium-silicate content, it being felt that the manufacturer will do whatever is necessary to meet the strength requirements. A limit of 15 per cent is placed on the content of tricalcium aluminate, however.

The amount of heat generated in hardening of this type of cement is higher than for types 1, 2, and 4, but there is little or no occasion to use this type of cement in massive structures, such as dams, large piers, and abutments where early strength is not essential.

The materials used in producing type 3 cement are the same as used in making the other types. One manufacturer gives the clinker a preliminary grinding and then runs it through the kiln a second time, after which it is given the usual grinding. The specific surface value of type 3 cement is often as much as a thousand greater than for the type 1 cement.

The retail price of type 3 cement is about 50 cents per barrel higher than for type 1 cement. By using the early-strength cement it is possible to remove forms at an earlier date, thus expediting construction. In the case of pavements it is possible to put them into use at an earlier date by using the early-strength cement in critical locations. In either case the expenditure of more money for the cement may not in the end mean a final, greater cost.

Low-heat-of-hydration Portland Cements

Low-heat-of-hydration portland cement was developed by the research in connection with the construction of Hoover Dam. Heat generated by hydrating cement raises the temperature in large concrete masses above that at which the concrete is placed. Shrinkage that then takes place as the concrete cools results in the cracking of the concrete.

Table 3-3.—Comparison of Early, Present-day, and Mass Concrete Cements*

Cement	Tricalcium silicate, per cent	Dicalcium silicate, per cent	Tricalcium aluminate, per cent	Fineness, pass No. 200 sieve, per cent	28-day strength, 1:2 mortar, p.s.i.	28-day heat generation, cal. per gram of cement
Probable average of 1890	31	36	18	80	1,500	90
Typical, standard portland 1932	55	23	11	90	4,000	100
Pine Canyon Dam 1932	30	46	5†	92‡	2,500§	75‖

* Carlson, R. W., "Development of Low-heat Cement for Mass Concrete," *Eng. News-Record*, Vol. 109, pp. 461–463 (1932).

† Specified to be not more than 6 per cent.

‡ Specified to be between 85 and 98 per cent.

§ Specified to be not less than 2,000 p.s.i.

‖ Specified to be not more than 80 cal.

Cracking is objectionable in any structure but is especially so in dams, since it may affect the permeability, appearance, and durability of the concrete.

Low-heat cement has a lower lime content and higher silica and iron contents than type 1 cement. It is ground slightly finer. The heat of hydration of type 4 cement is about one-third less than for type 1. The rates of heat liberation are different, since the heat is generated much more slowly in the low-heat cement. The net value is dependent to some extent on the shape and size of the mass and the rate of construction.[1]

[1] Meissner, H. S., and W. T. Moran, "The Field for Low-heat Cement," *Eng. News-Record*, Vol. 121, pp. 589–593 (Nov. 10, 1938).

In the specifications for type 4 cement, the tricalcium silicate content is limited to a maximum of 35 per cent, the tricalcium aluminate content to a maximum of 7 per cent, and the dicalcium silicate content to a minimum of 40 per cent. No heat-of-hydration requirement is written into the specifications. Some data on 1890 and 1932 cements are given in Table 3-3. The specifications for the Pine Canyon Dam cement called for a cement with a lower heat of hydration than do the specifications for a type 4 cement today. Requirements for type 4 are given at the end of Chap. 2. Production figures for recent years for type 4 cement are given in Table 3-2. Prior to 1943 low-heat cement production was not reported separately to the Bureau of Mines.

AIR-ENTRAINING PORTLAND CEMENT

After the discovery that a small amount of entrained air in concrete (3 to 6 per cent by volume) improved the resistance of the concrete to frost action and to the deleterious action of calcium chloride and sodium chloride salts sprinkled on the surface of concrete pavements, the practice started of intergrinding with the clinker a small amount of material that would cause entrainment of air in the concrete. Two compounds have been approved for intergrinding, known as "Vinsol resin" and "Darex AEA," produced by the Hercules Powder Company and Dewey & Almy Chemical Company, respectively.

Production figures are available beginning with 1945, as follows:[1] 1945, 5,075,332 bbl.; 1946, 13,765,384 bbl.

The first A.S.T.M. specifications for such a cement appeared in 1942, the cement being known as a treated portland cement for concrete pavements. In 1944 the name was changed to air-entraining portland cement for concrete pavements and in 1946 to air-entraining portland cement. Provision was made in the specifications for two types, known as types 1a and 2a, corresponding respectively to types 1 and 2 of the standard specifications for portland cement. In 1948, type 3a was added.

The amount of the air-entraining agent added is controlled by a mortar, air-content test (A.S.T.M. Method: C 185), in which mortar is made in a prescribed manner and tested for air content. The air content of the mortar must lie within the range of 15 to 21 per cent.

Only the compressive strength requirement appears in the air-entraining, portland-cement specifications. Strengths at 3 and 7 days are slightly less for the air-entraining cements than for the corresponding portland cements. The 28-day strength requirements are the same for types 1 and 1a and for types 2 and 2a.

[1] *Minerals Yearbook*, U.S. Bureau of Mines.

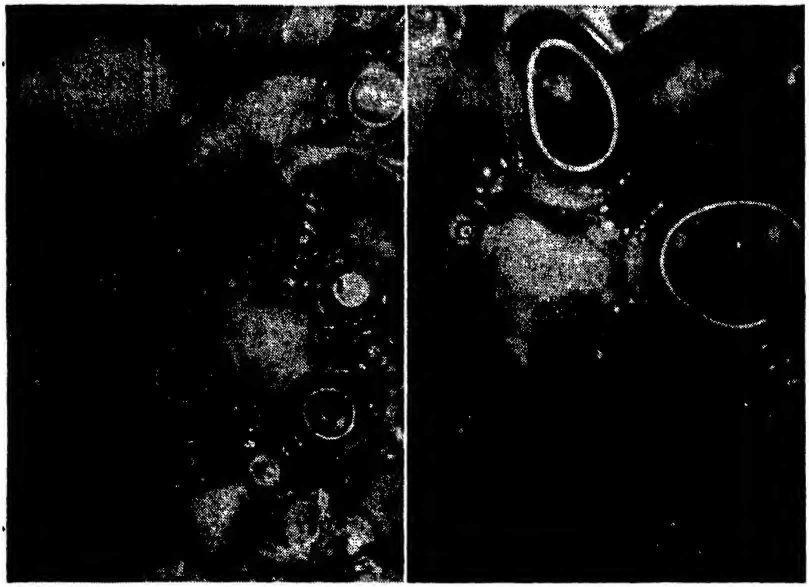

FIG. 3-1.—Showing relative sizes of entrained air bubbles: *left*, 50- to 100-mesh sand particles; and *right*, 30- to 50-mesh sand particles. There is no cement in the mixtures shown, the entrained air being produced by adding an air-entraining agent to the mixture of sand and water. (*Courtesy of Henry L. Kennedy.*)

FIG. 3-2.—Comparison of surface condition of pavement concretes using, *left*, air-entraining portland cement, and, *right*, nonair-entraining portland cement, with all other conditions the same. (*Portland Cement Association.*)

The A.S.T.M. specification (C 175-48T) for air-entraining portland cement follows. A discussion of air-entraining admixtures is given in the next chapter under admixtures.

TENTATIVE SPECIFICATION FOR AIR-ENTRAINING PORTLAND CEMENT

A.S.T.M. Designation: C 175-48T

1. **Scope.**—These specifications cover three types of air-entraining portland cement for use in concrete exposed to severe frost action. The three types shall be designated as types 1a, 2a, and 3a and shall correspond respectively to types 1, 2, and 3 of the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150).

2. **Basis of Purchase.**—The purchaser shall specify the type or types desired. When no type is specified, the requirements of type 1a shall govern.

3. **Definition.**—For the purpose of these specifications, air-entraining portland cement is the product obtained by pulverizing clinker consisting essentially of hydraulic calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulfate, except that there shall be interground with the clinker an addition shown to be acceptable, in the amounts indicated, by tests carried out or reviewed by Committee C-1 on Cement[1] (Note).

NOTE.—Tests to determine whether a proposed addition is acceptable will be carried out or reviewed by Committee C-1 on Cement, for those making requests. In the year following that in which an addition has been declared acceptable by the Committee, the name of the addition shall appear as an addendum to Section 3, and any definite limitation on the quantity to be used shall appear in the table of chemical or physical requirements in a revision of the specifications.

4. **Chemical Requirements.**

Author's note. The chemical requirements for types 1a, 2a, and 3a are the same as given for types 1, 2, and 3 of the standard specifications, given at the end of the preceding chapter. The Vinsol resin content is not limited, being governed by the requirement for air content of mortar prescribed in Table 1 of

[1] The committee has declared the following additions acceptable:

a. A material known commercially as "Vinsol resin," which is manufactured by the Hercules Powder Co. and consists substantially of the petroleum-hydrocarbon, insoluble fraction of a coal-tar, hydrocarbon extract of pine wood. When Vinsol resin is added, the Vinsol resin shall be added at the mill in the form of sodium resinate, produced by treating 100 parts of Vinsol resin with 9 to 15 parts of NaOH by weight. If the sodium resinate is added as an aqueous solution, the ratio of water to resinate shall not exceed 12:1 by weight.

b. A material known commercially as "Darex AEA," which is manufactured by the Dewey & Almy Chemical Co. and is substantially a triethanolamine salt of a sulfonated hydrocarbon.

this specification. The methoxyl test is required to identify the presence of Vinsol resin. Darex is limited to 0.05 per cent maximum for all types.

5. Physical Requirements.—Air-entraining portland cements shall conform to the respective physical requirements prescribed in Table 1.

TABLE 1.—PHYSICAL REQUIREMENTS

	Type 1a	Type 2a	Type 3a
Fineness, specific surface, sq. cm. per g.:			
Average value, min.	1,600	1,700	
Minimum value any one sample	1,500	1,600	
Soundness:			
Autoclave expansion, max., per cent	0.50	0.50	0.50
Time of setting:[a]			
Gillmore test:			
Initial set, min., not less than	60	60	60
Final set, hr., not more than	10	10	10
Vicat test:			
Initial set, min., not less than	45	45	45
Final set, hr., not more than	10	10	10
Air content of mortar, prepared and test in accordance with Method C 185, per cent by volume	18±3	18±3	18±3
Compressive strength, p.s.i.:[b]			
The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C 109, shall be equal to, or higher than, the values specified for the ages indicated below:			
1 day in moist air			1,100
1 day in moist air, 2 days in water	750	600	2,200
1 day in moist air, 6 days in water	1,500	1,250	
1 day in moist air, 27 days in water	3,000	2,500	

[a] The purchaser should specify the type of setting-time test required. In case he does not so specify, the requirements of the Gillmore test only shall govern.

[b] Unless otherwise specified, compressive strength tests will be made only at 3 and 7 days. The strength at any age shall be higher than the strength at the next preceding age.

6. Packaging and Marking.—Same as in Specification C 150 except that the type under these specifications shall be clearly indicated for all types.

7. Storage.—Same as in specification C 150.

8. Inspection.—Same as in specification C 150.

9. Rejection.—Same as in specification C 150.

10. Methods of Testing.—Same as in Specification C 150, except that tensile strength is omitted and Air Content of Mortar C 185 added.

PORTLAND-PUZZOLAN CEMENTS

Puzzolan is a term applied to a siliceous material that in itself has no cementing value but that, when mixed with lime, exhibits cementitious properties. Puzzolan was first discovered at Pozzuoli, Italy, near the base of Mt. Vesuvius. The original material was of volcanic origin, but today the name applies to any siliceous material that has the property mentioned above.

Although puzzolanic cements have been widely used abroad, their use has been rather limited in the United States. The outstanding project is the Los Angeles aqueduct, built in the years 1910 to 1912, in which more than 600,000 bbl. were used. Sand cements were used in the construction of the Arrowrock, Elephant Butte, and Lahontan dams (1913–1916) by the U.S. Bureau of Reclamation, but the silica content of the sand interground with the portland cement was small.[1]

Puzzolanic materials are mixed with standard portlands in order to change certain chemical reactions. The proportion of the portland-puzzolan cement that should be puzzolan lies between 10 and 30 per cent, depending upon the type of puzzolan, the composition of the portland-cement clinker, and the conditions under which the cement is to be used.[2]

Comparing the portland-puzzolans with portlands, Davis, Kelly, Troxell, Davis say:[3]

> The former are more grindable; produce more plastic concretes exhibiting less water gain; generate less heat of hydration; and produce more impermeable concrete; but require more water to produce mortars and concretes of a given consistency, and exhibit greater shrinkage of mortar upon drying. . . . In general, for the rich mixes, the compressive strength of concrete is less for portland-puzzolan cements than for the corresponding portland cements; but for the leaner mixes and active puzzolans the compressive strength of concrete at the later ages is greater for the portland-puzzolan cements than for the corresponding portland cements.

Most portland cements contain some free or uncombined lime. During the process of hydration additional uncombined lime is produced by hydrolysis of the silicates of the cement, the total running as high as 17 per cent, though usually much less. It is with this free lime that the puzzolanic material acts to form additional quantities of the ce-

[1] DAVIS, CARLSON, KELLY, TROXELL, "Properties of Mortars and Concretes Containing High-silica Cements," *Proc. Am. Concrete Inst.*, Vol. 30, pp. 369–389.

[2] DAVIS, KELLY, TROXELL, DAVIS, "Properties of Mortars and Concretes Containing Portland-Puzzolan Cements," *Proc. Am. Concrete Inst.*, Vol. 32, pp. 80–114.

[3] *Ibid.*

mentitious compounds (the calcium silicates).[1] The formation of these additional quantities of calcium silicate aids in reducing the void space in the cement paste, thus reducing the porosity and opportunities for corrosion. The additional strength secured aids in resisting the action of the salts in the alkaline waters, as explained under durability in Chap. 10.

No standard specifications are available for portland-puzzolan cements. Figures on the production of such cement for recent years are given in Table 3-2.

ALUMINATE CEMENT

Aluminate cements are made in practically the same manner as is portland cement but with different raw materials. The most common combination for portland cement is limestone and shale. In aluminate cements the shale is replaced by an aluminum ore called bauxite. Bauxite is an aluminum compound represented by the chemical formula $Al_2O(OH)_4$, but it is generally impure and may contain water, iron oxide, silica, or tannic acid. Bauxite is found in the United States in Arkansas, Georgia, and Tennessee. Most of the imported bauxite comes from the Guianas, Dalmatia, and France.

The French were the first to produce an aluminate cement on a commercial basis, under a patent issued in 1908. Their product is known as "Cement Fondu." Manufacture began in Germany in 1924. Several plants were started in England in 1923. The first, American-made aluminate cement was offered for sale in the United States in June, 1924.

Chemical Analyses.—Chemical analyses of Lumnite cement indicate approximately the following composition:

	Per cent
Silica	3–8
Iron oxide	14–18
Alumina	37–39
Lime	31–41
Magnesia	¾–1
Sulfur anhydride	½–1½

Physical Characteristics.—The chief advantage of the aluminate cement is the development of usable strengths in 24 hr. When it was first introducted in the United States, the 24-hr. strengths were about equal to the 28-day strengths of portland-cement concretes of the same

[1] SCRIPTURE, E. W., "The Possibilities of Puzzolans in Mortars and Concretes," *Eng. News-Record*, Vol. 115, pp. 563–567 (1935).

proportions. Improvements in portland cements have reduced this margin.

Another characteristic is the development of a large amount of heat during the setting period, which during cold weather is an advantage.

Combinations of the aluminate and portland cements usually give a flash set that makes them unusable. Aluminate cement alone has a longer initial setting period than most portlands, but the interval between initial and final set is often short.

The cost of the aluminate cement has been from three to four times the cost of the standard portland cement.

White Portland Cement

The gray color of portland cement is caused largely by the presence of iron oxide in the limestone and shale. Except for the impurities that exist in the raw materials, all portland cement would be colorless or white. Iron oxide occurs in the finished gray cement in quantity up to 4 per cent but is not an essential constituent.

Pure calcite limestone and white clay, from which two of the cement companies produce white cement, are found in Pennsylvania. This cement in combination with white aggregates produces white concrete and stucco. The chemical composition of the gray and white cement is essentially the same except that the iron oxide content of white cement is usually 0.5 per cent or less. The physical properties are much the same. The specific gravity is less, being 3.05 for the white cement. Specific gravity is no measure of quality, however.

Uses.—White cement is used principally (1) in stucco for external plastering of buildings, (2) for setting of fine building stone to avoid staining, (3) in the manufacture of ornamental concrete units, (4) for facing concrete blocks, and (5) in the manufacture of tile, mosaics, etc.

Natural Cement

Natural cement is the product obtained by finely pulverizing calcined, argillaceous limestone, to which nondeleterious materials, not to exceed 5 per cent, may be added subsequent to calcination. The temperature of calcination must be no higher than is necessary to drive off carbonic acid gas. Natural cements are not used as a rule in concrete, except when blended with portland cement in the ratio of one bag of natural to four or five bags of portland.

Requirements of A.S.T.M. Specification (Designation C 10-37) are as follows:

Fineness.—The residue on a standard No. 200 sieve shall not exceed 15 per cent by weight.

Soundness.—A pat of neat cement, about 3 in. in diameter and 0.5 in. in thickness at the center and tapering to a thin edge, shall be kept in moist air for a period of 48 hr. The pat shall then be placed in an atmosphere of steam at a temperature between 98 and 100°C. on a suitable support 1 in. above boiling water for 5 hr. and shall show no signs of distortion, cracking, checking, or disintegration upon removal from the steam chest.

Time of Setting.—The cement shall not develop initial set in less than 10 min. when the Vicat needle is used or in less than 20 min. when the Gillmore needle is used. Final set shall be attained within 10 hr.

Tensile Strength.—*a.* The average tensile strength of not less than three standard mortar briquets (A.S.T.M. Method: C 190), composed of 1 part of cement and 2 parts of standard sand, by weight, shall be equal to or higher than, the following:

Age at test, days	Storage of specimens	Tensile strength, p.s.i.
7	1 day in moist air, 6 days in water	75
28	1 day in moist air, 27 days in water	150

b. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

Natural cement is shipped in bags containing 94 lb. or in barrels containing 282 lb. net.

Waterproof Cements

Certain cements are available for which the manufacturers claim special waterproofing qualities. These generally are standard brands with the waterproofing material incorporated during the grinding of the clinker.

Some of the waterproofing cements are made by intergrinding with the clinker a small amount of stearate, approximately 0.2 per cent of the weight of the cement. Stearate is the salt of stearic acid, which is a fatty acid originally secured from animals. The sodium, potassium, and ammonium stearates are soluble in water while the calcium and most other ones are insoluble. When a soluble stearate such as sodium stearate (soap) is used for waterproofing concrete, the calcium in the water exchanges with the sodium of the stearate forming a calcium stearate, which is immediately precipitated out. It is insoluble, water repellent, and serves as a waterproofing agent. When the soluble stearate is used, there is danger of entraining more air in the concrete than is desirable.

Some of the waterproofing cements sold in the United States are manufactured under what are known as the "super" cement patents. Any manufacturer may produce a super cement upon securing the privilege from the owner of the patent. A special grade of tannin known as Gallo tannin, which is produced from oak gallnuts, is added at the same time as the retarder.

The addition of the waterproofing material may reduce somewhat the strength-producing properties of the cement. The desired concrete strengths may be secured, however, by using the proper amount of cement. Anyone using waterproof cement for waterproofing purposes should exercise just as much care in the production of the concrete as in any other case.

Waterproofing cements sell for about 75 cents to $1 more per barrel than the regular cements.

Oil-well Cement

Large quantities of cement are used by the petroleum industry in the cementing of oil wells for the purposes of (1) shutting off water from protective areas, (2) preventing blowouts from high-pressure oil and gas encountered in sands through which the casing passes, (3) protecting the casing from the corrosive action of waters, and (4) supporting some of the weight of the casing. The cement is mixed with water only at the rate of about 16 lb. per gal. of water to form a slurry.[1]

A special oil-well cement has been developed by cement companies with plants in the oil-producing areas. The setting must be retarded and the cement must function at temperatures as high as 350°F. In addition to the special oil-well cement the industry uses types 1, 3, and 5. In 1946 the Bureau of Mines reported that 1,329,462 bbl. of the oil-well cement was produced, while J. B. Clark,[2] in December, 1947, estimated that approximately 10 million barrels of cement of all kinds are used per year by the petroleum industry in the United States in cementing oil wells.

Study Questions

1. Name the four major compounds present in cement. Which are considered good for the development of strength? Which for the development of low heat of hydration? Which for the development of early strength?

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[1] MOELLER and ROBERTS, "Oil Well Cementing Practice," *Proc. Am. Concrete Inst.*, Vol. 43, pp. 893–911.

[2] *Proc. Am. Concrete Inst.*, Vol. 43, Part II, p. 912–1 (December, 1947).

2. Give briefly the special characteristics of types 2, 3, 4, and 5 cements.

3. What does the manufacturer do to make a type 3 cement as compared to a type 1 cement? Under what circumstances would a type 3 cement be used?

4. What does the manufacturer do to make a type 4 cement as compared to a type 1 cement? Under what circumstances would a type 4 cement be used?

5. What does the manufacturer do to make a type 5 cement as compared to a type 1 cement? Under what circumstances would a type 5 cement be used?

6. Define air-entraining portland cement.

7. Name the air-entraining additions that have been approved by Committee C-1. How much of each may be added, according to A.S.T.M. specifications?

8. Explain the test that is used to control the amount of air-entraining addition? What is the range of air contents for the mortar used in this test?

9. How many types of air-entraining portland cement are provided in A.S.T.M. specifications? How is each type designated?

10. What is a puzzolanic material? What is a portland-puzzolan cement? What proportion of the cement should be the puzzolanic material? Under what conditions in the United States would portland-puzzolan cements be used? Is there an A.S.T.M. specification for this type of cement?

11. What is an aluminate cement? What are the special characteristics of this cement? Can it be blended with portland cement? What happens when it is blended?

12. What is done differently by the manufacturer in making white cement as compared to the production of gray cement? What are the principal uses of white cement?

13. What is a natural cement?

14. What is a waterproofing cement?

CHAPTER 4

MINERAL AGGREGATES, ADMIXTURES, AND WATER

Mineral aggregates used in concrete are normally particles of rock, either naturally or artificially crushed or broken. The artificially crushed particles are angular while those produced by acts of nature are rounded.

Other aggregates include blast-furnace slag, cinders and Haydite, the latter being a lightweight, burned-shale material employed mainly where a lightweight concrete is desired.

Fine and Coarse Aggregates.—In the early days of concrete work, aggregates were used as they came from the pit or from the crusher, with no attempt to secure any particular gradation. Such aggregates were called bank-run gravel or crusher-run rock.

In 1907 Fuller and Thompson (see Chap. 5) pointed out the advantages that could be secured by combining two or more aggregates in order to produce a gradation that would come fairly close to an ideal gradation, which they had developed. Instead of the engineer combining aggregates of widely varying gradations, as they might be available from various producers, the practice became well established of requiring the producer to separate aggregate into two fractions, known as "fine aggregate" and "coarse aggregate." Such aggregates are now termed "separated aggregates." The dividing line today is the No. 4 sieve with a clear distance between wires of $\frac{3}{16}$ in.

The fine-aggregate particles range in size down to the No. 100 sieve, with from 2 to 10 per cent being required to pass this sieve. The coarse-aggregate particles range up to some size, called maximum size, varying from $\frac{1}{2}$ to 6 in., depending upon availability and the requirements of the work being done (see Chap. 6).

In 1927 the North Carolina highway department tried for the first time on a job the separation of the coarse aggregate into several sizes—a practice that is used quite generally now in concrete for large dams and to some extent in concrete for highway pavements and airport runways. When the coarse aggregate is separated into two or more sizes, the term "multiple-size aggregate" or "divided coarse aggregate" is used to indicate that this separation has been made by the producer and that the fractions are kept separate until the proper amount of each has been weighed out for a batch of concrete.

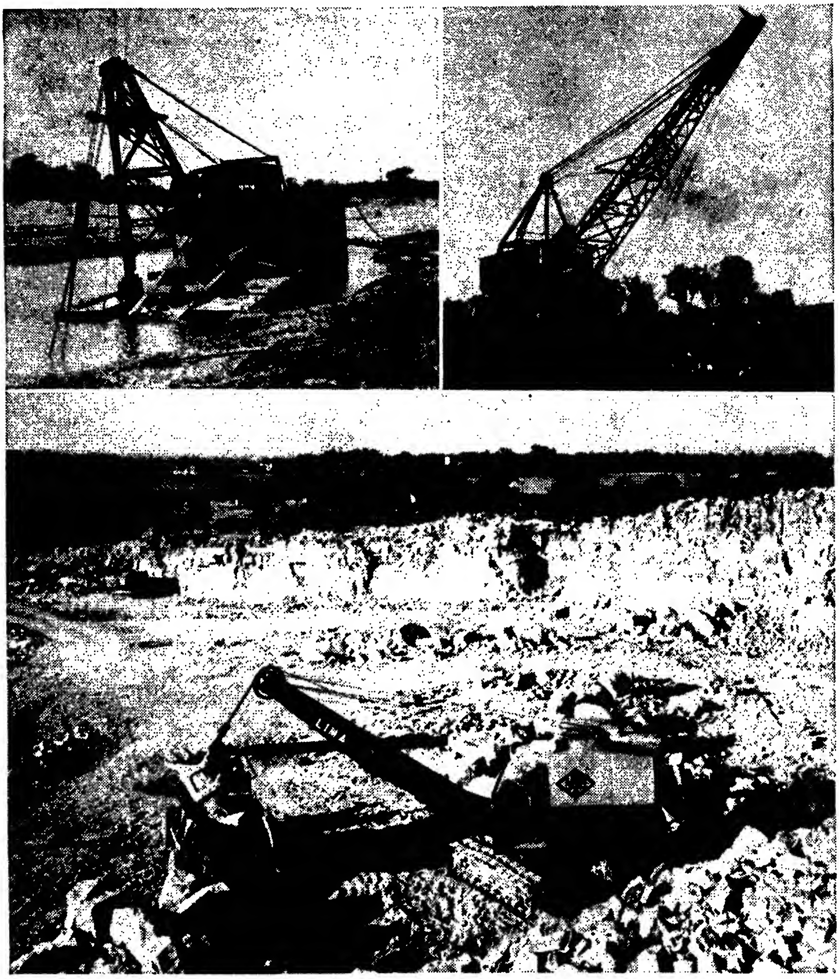

FIG. 4-1.—*Upper left*, a sand dredge. *Upper right*, a dragline with a 4-cu. yd. bucket removing sand and gravel from gravel pit. *Bottom*, a stone quarry with a ¾-cu. yd. dipper on the power shovel. (*Courtesy of Pit and Quarry and Rock Products*.)

The trend in A.S.T.M. specifications for fine aggregate has been to increase the required percentages passing the Nos. 50 and 100 sieves. In some instances the amount of material in a natural deposit passing these sieves has not been adequate, and contractors have found it necessary to secure a very fine sand to combine with the coarse sand that they normally use. The combining of the fine sand with the coarse sand is known as blending, the finer sand being the blending sand. The blending of the sands is accomplished by weighing out predetermined amounts of each at the batching plant as needed for batches of concrete.

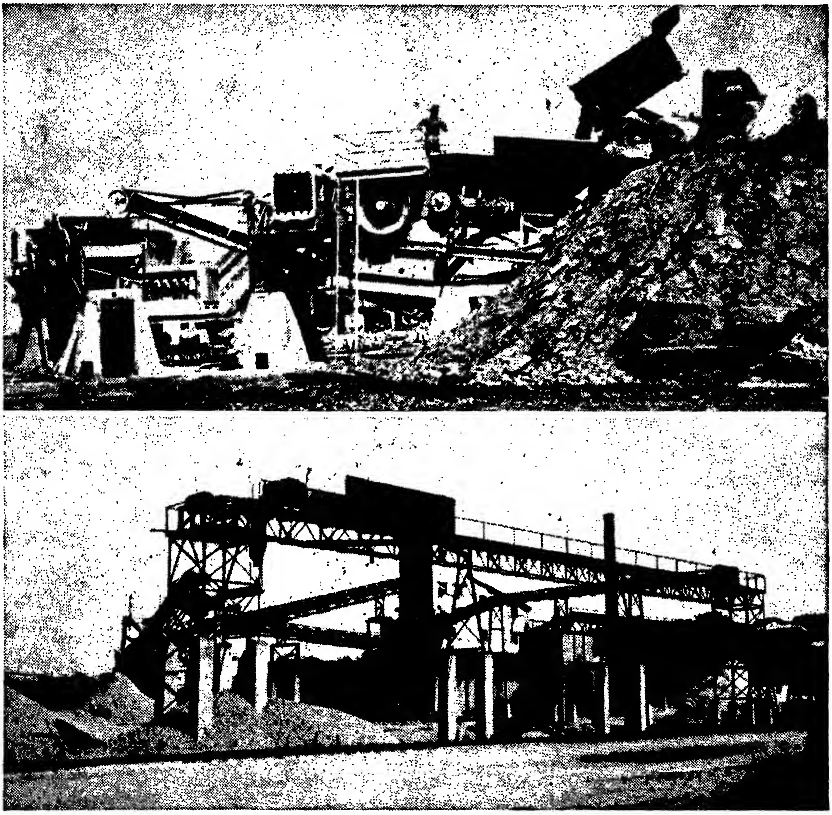

Fig. 4-2.—*Upper*, a rock-crushing plant with an hourly output of 110 tons. *Lower*, a sand and gravel plant. (*Courtesy of Rock Products and Pit and Quarry.*)

Fine aggregate is usually designated as sand. When no modifying word is used, sand means naturally disintegrated particles of rock. Stone sand is prepared by crushing rock, but because of the prevalence of natural deposits of sand it has not been used to any great extent. It was used in the construction of Norris Dam of the Tennessee Valley Authority.

Coarse aggregate may be either pebbles or crushed stone. Pebbles are the naturally formed particles and are sometimes known as gravel.

The former designation is better because it has only one meaning, whereas gravel is sometimes used to designate a combination of both sand and pebbles. Slag, cinders, and Haydite may be separated into both fine and coarse-aggregate sizes.

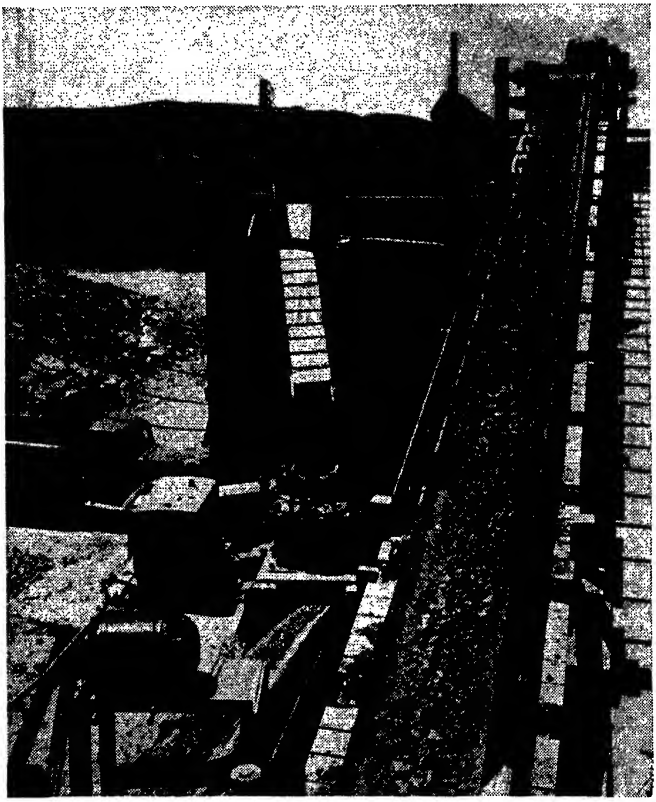

FIG. 4-3.—Use of belt conveyor in handling aggregates during their preparation. Aggregates for Shasta Dam in California were transported 9.6 mi. from the producing plant to the batching plant near the dam. Belts are also used at times in handling aggregates at the proportioning plant. (*Courtesy of Rock Products.*)

Sand and Pebbles.—At many places throughout the United States and Canada there are deposits of sand and pebbles. Gravel pits, as they are called, are found in many places in the northern half of the United States, which has been covered at various times by glaciers. The theory is that the glaciers pushed large masses of rock ahead of them as they moved south. As the rock was pushed along, it was broken up into smaller pieces and had the corners rounded off. Sand deposits are frequently found in and along streams and rivers. The proportions of sand and pebbles in a pit will vary considerably in the pit and from one pit to another. Some pits are nearly all sand while others contain very little.

Production consists in stripping off the overburden, excavating the material, and hauling it to a plant to be screened and washed. Practically all deposits are covered with earth, which may be removed by any of the ordinary methods of excavation, such as steam, gas, or electric shovels, dragline or sluicing. The excavation of the material is accomplished by means of power shovels or the dragline. When the

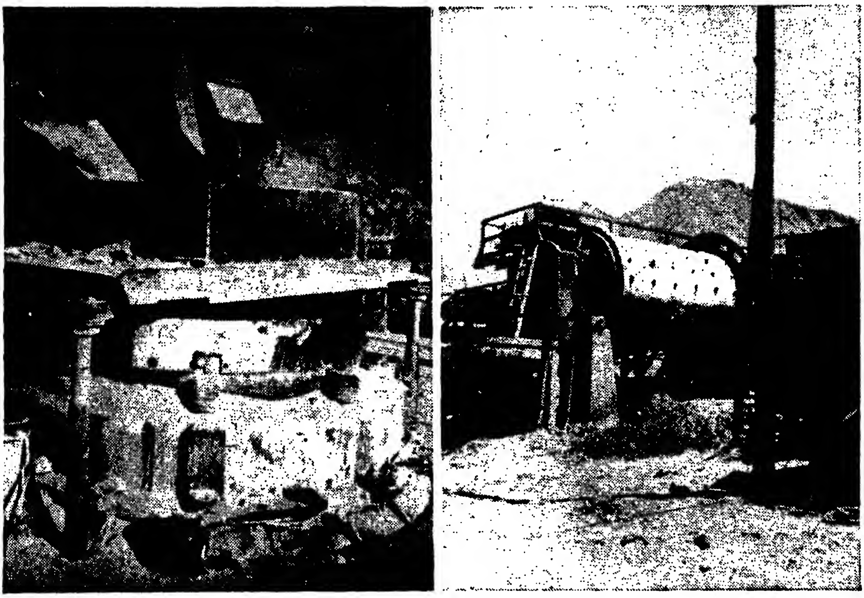

FIG. 4-4.—*Left*, a cone crusher being used to recrush plus 3½-in. stone before delivery to main plant. *Right*, a rod mill used for grinding pea gravel into sand (*Courtesy of Rock Products*.)

deposits are under water, it is not uncommon to use a suction pump to move the material to some point where it may be separated from the water.

In most pits are found pieces of rock too large to be used without crushing. Crushing machinery is generally installed for the purpose of reducing these boulders to such sizes that they may be incorporated with the pebbles.

At the plant the materials are elevated, and thus during the washing, screening, and loading they are moving by gravity. The material is separated into various sizes on rotary screens or horizontal, vibrating screens. During the screening, water is played on the materials, and by the time the screening operation is complete, they are practically clean. The various sizes are then recombined as the purchaser requires. In many cases, however, the requirements of the engineers are such that not all of the output can be used, and some must be wasted. In many of the pits there is a surplus of sand. The proportions for concrete are such that 1 part of sand is used for each 1½ or 2 parts of coarse aggregate. Unless there are other materials available in the territory as coarse aggregate, the sand must be wasted or other uses found for it.

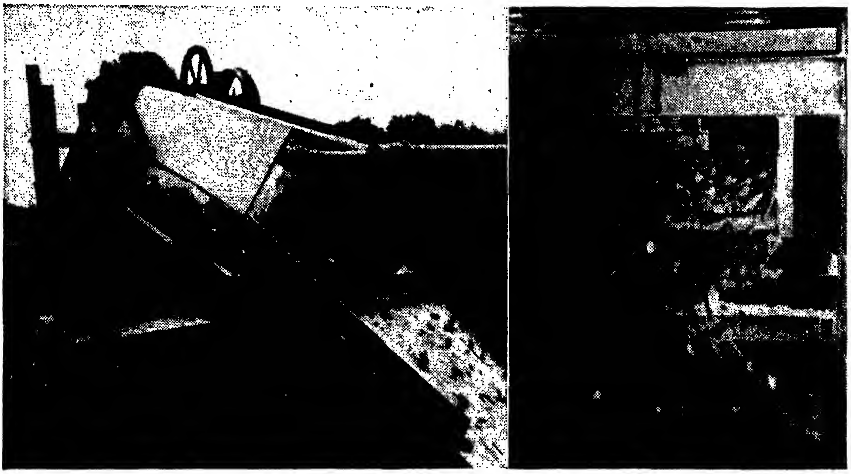

FIG. 4-5.—*Left*, a double-deck vibrating screen on which material is washed and sized. *Right*, a primary 2-deck vibrating screen over secondary crushing station receiving 3-in. material from primary crusher. (*Courtesy of Pit and Quarry and Rock Products.*)

Crushed Stone.—Crushed stone is prepared from solid rock. The words "stone" and "rock" are used more or less interchangeably, but stone more truly applies to pieces of rock. The word "rock" refers to the large natural masses.

There are three general classifications of rock—igneous, sedimentary, and metamorphic. *Igneous rocks* are those formed by the action of heat. They are generally hard and tough, granular, and have practically no bedding planes. Granite and basalt are examples. *Sedimentary rocks* are those formed by the consolidation of sediment deposited from water. Bedding planes are apparent. Limestone and sandstone are examples. *Metamorphic rocks* are either igneous or sedimentary rocks, which have been changed in structure and character by the action of heat, pressure, and movement. Marble is a metamorphic limestone and gneiss a metamorphic granite. *Trap rock* is the name that has been applied to any dark-colored, fine-grained igneous rock.

Granite, trap rock, and limestone are the most common rocks from which crushed stone is prepared for use in concrete. Some limestones are too soft, and only occasionally is a sandstone found that is sufficiently hard. Traps and granites are excellent materials.

Preparation of crushed stone for use is not so easy as that of pebbles. Overburden must be removed, holes drilled for charges of dynamite, the dynamite placed and set off, the broken rock loaded into cars and taken to a plant for crushing and screening. Air hammers are most generally used for drilling the holes and power shovels, for loading the large pieces into railroad cars. Crushing is usually accomplished in two stages known as "primary" and "secondary" crushing. Gyratory and jaw

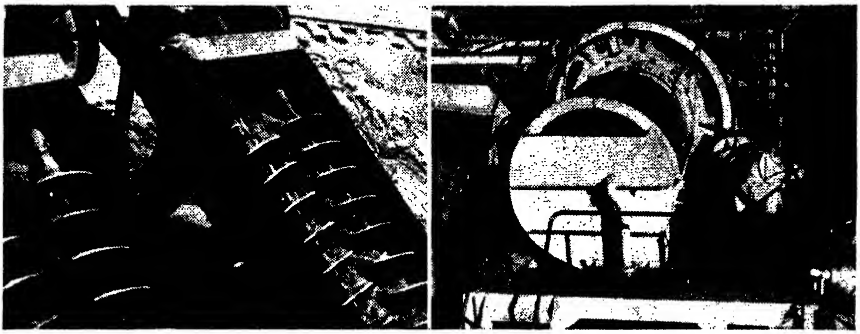

FIG. 4-6.—*Left*, two twin-screw washers in a sand and gravel plant. *Right*, a scrubber. (*Courtesy of Pit and Quarry and Rock Products.*)

crushers are the types most commonly used for both operations. Between the two crushings the material of proper size is removed by a screening operation.

The operations of screening are quite similar to those described for sand and pebbles. Not many plants, however, wash the crushed stone. Usually some dust is produced in the crushing and screening operations. The dust is objectionable when the stone is to be used in portland-cement concrete, and in some instances engineers have insisted that the stone be washed in order to remove this dust. Producers will install washing equipment only as the purchaser demands it. The various sizes are combined as the material is run into the cars for shipment.

Blast-furnace Slag.—Blast-furnace slag is the nonmetallic product consisting essentially of silicates and aluminosilicates of lime, which are developed simultaneously with iron in a blast furnace.[1] Blast-furnace

[1] As defined by American Concrete Institute Committee E-5 on Aggregates.

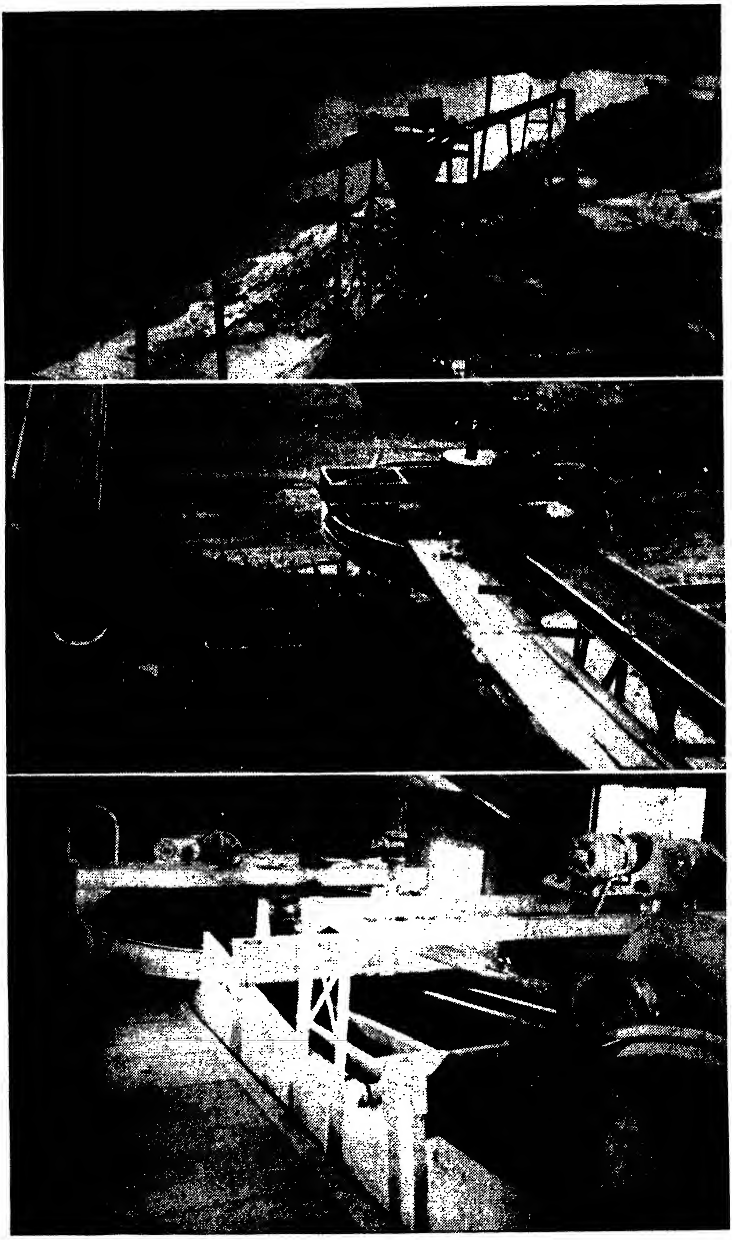

FIG. 4-7.—*Top,* an automatic sand-settling cone in which fine sands are recovered. *Middle,* sand drag and hydroseparator with sand belt at extreme left. *Bottom,* a Dorr bowl rake classifier used in the production of stone sand. The fine stone sand particles are discharged at the far end, where they are combined with coarser particles from screens. (*Courtesy of Pit and Quarry and Rock Products.*)

FIG. 4-8.—A sand and gravel plant from the rear, showing a car being loaded (*Courtesy of Pit and Quarry.*)

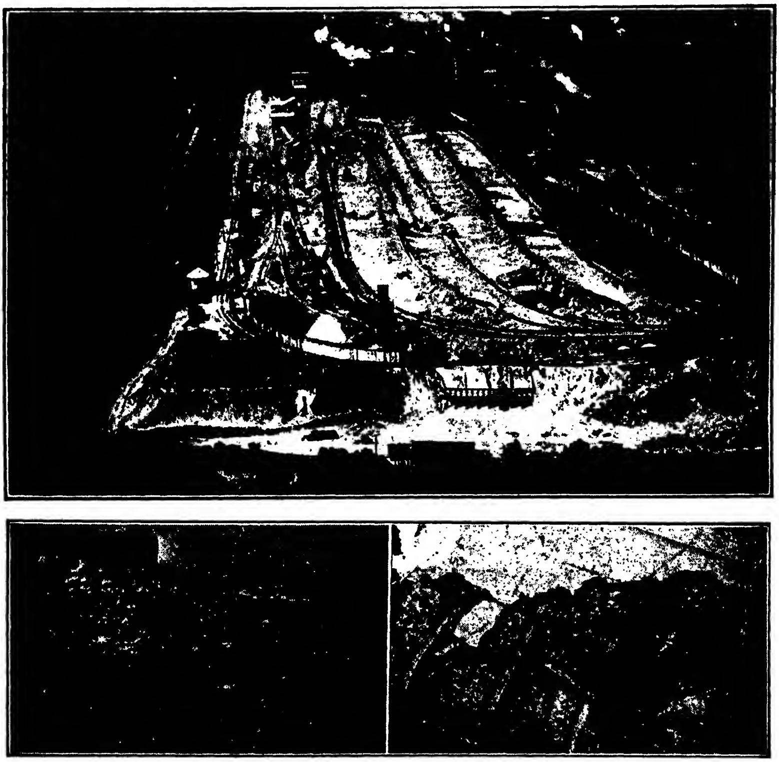

FIG. 4-9.—*Top*, airplane view of pit system at blast-furnace plant. *Lower left*, showing strata in slag pit. *Lower right*, 18-year-old slag concrete being removed

slag is produced in the kiln at the same time as the pig iron. In the furnace the slag rises to the surface of the molten mass and is drawn off at a higher level than the iron. The slag is placed in pits to cool. As drawn from the furnace it has a temperature of 3500°F. Granulated slag is produced by quickly cooling the molten slag with water. Air-cooled slag must be removed from the pit with a power shovel and taken to crushers to be reduced to the desired sizes as in a crushed-stone plant.

Chemical analysis limits for average blast-furnace slags are given in the following table:

	Per cent
Silica	32–48
Lime	17–45
Alumina	8–20
Magnesia	1–12
Iron	1–3
Sulfur compounds	0.5–2.5

The weight per cubic foot is usually at least 70 lb. for screened material between the 1½-in. screen and the No. 4 sieve. The percentage of voids varies from 38 to 46. Specific gravity is about 2.3.

Blast-furnace slag has been used as a concrete aggregate for many years in pavements, bridges, and buildings. Its use has been limited, of course, to the iron and steel manufacturing districts.[1]

Cinders.—Cinders are produced as waste material from steam boilers using bituminous coal. They are hard, vitreous, granular, porous, and light in weight. Cinders weigh about 45 lb. per cubic foot. They are used in buildings for floor and roof construction where there is no wetting and drying or freezing and thawing. They are commonly used in making a lightweight concrete building block. The cost is low since they are a waste material and may usually be had for the hauling.

Haydite.—Haydite is a patented lightweight aggregate made from shales ordinarily used in the manufacture of brick.[2] The shale is ground to a maximum size of 1 in. It is then burned in a rotary kiln of the same type as used in the manufacture of portland cement. The shale is fed in at one end and comes out at the other end finished except for crushing and screening. The temperature in the kiln at the discharge end is approximately 2000°F. When the shale reaches the zone of this high temperature, it becomes viscous, incipient fusion takes place, the carbon

[1] BARDSLEY, "Utilization of Blast-furnace Slag in Highway Improvement," a bulletin of the School of Mines and Metallurgy of the University of Missouri.

[2] Manufactured by a number of companies in various parts of the United States and Canada under patents issued to S. H. Hayde of Kansas City, Mo.

FIG. 4-10.—Views of Haydite manufacturing plant. *Top*, kiln and clinker conveyor. *Center*, handling from storage pile to loading chute. *Bottom*, grinding plant.

content is oxidized and formed into gas. As the gas escapes from the shale, the latter is expanded into a lightweight cellular structure.

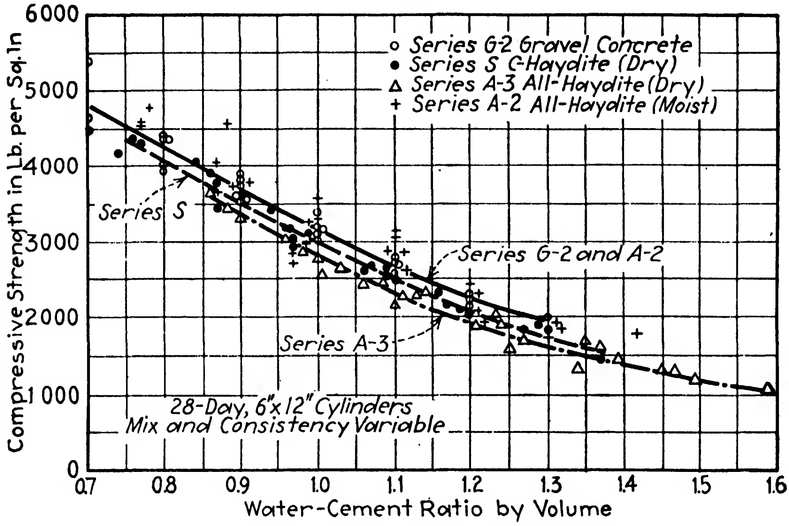

FIG. 4-11.—Relation between water-cement ratio and compressive strength for concrete using as aggregates: (*a*) natural sand and pebbles, (*b*) natural sand and *C* Haydite, and (*c*) All Haydite. (*Richart and Jensen, "Tests of Plain and Reinforced Concrete made with Haydite Aggregates," Bull. 237, Engineering Experiment Station, University of Illinois.*)

The product of the kilns is taken to a preparation plant where it is ground, screened, and graded into the commercial sizes. The available sizes are shown in the table at the top of page 67. Haydite aggregate concrete will weight from about 90 to 100 lb. per cu. ft. as compared to 150 lb. for sand and pebbles or crushed-stone aggregate. A typical chemical analysis:

	Per cent
Silica	59.48
Iron oxide	8.48
Aluminum oxide	16.14
Magnesium oxide	2.15
Lime	8.64
Alkalies	4.42
Loss on ignition	0.69

Figure 4-11 shows the results of some tests at the University of Illinois comparing the compressive strengths of concrete made with the following aggregates: (*a*) natural sand and pebbles; (*b*) natural sand and *C* Haydite; and (*c*) all Haydite. Haydite has a high absorption value,

Designation	Range of sizes	Weight per cubic foot, loose	Use
A or No. 6	0–3/16 in.	56 lb.	Fine aggregate
B or 1/2 in.	3/16–1/2 in.	47 lb.	Coarse aggregate for precast concrete units
C or 3/4 in.	3/16–3/4 in.	44 lb.	Coarse aggregate for larger precast units and in reinforced concrete.

The specific gravity is approximately 2.52.

the 1-hr. value for coarse material being about 7 per cent and for fine material about 14 per cent, and allowance must be made for this in figuring water-cement ratios.

Haydite is being used principally in concrete building units and in floor and roof slabs.

VALUE OF TESTS ON AGGREGATE

Concrete is a material that is put to many uses. Certain qualities in the aggregates are desirable and necessary in all cases while in others only special qualities are necessary. Clay and silt, for instance, may be tolerated in sand to the extent of 5 per cent by weight for structural concrete but must be limited to about 2 per cent for pavement concrete, while durability is necessary for all kinds of concrete exposed to the weather.

Aggregates should be hard to resist grinding action; tough to withstand impact; strong to stand up under heavy loads; sound to remain whole during freezing and thawing and other changes in weather conditions; clean to permit the cement paste to bond or in order not to contaminate the cement paste; free from organic impurities to permit setting and hardening of the cement; graded to make a workable concrete and one that is economical, or light in weight to make lightweight concrete. Further discussion of these qualities will be made in connection with each test.

Deval Abrasion Test.—It has been found that aggregates that show a low loss in this test will generally be hard, tough, resistant to abrasion, and strong.

For crushed stone a sample consting of 50 pieces weighing 5,000 g. is prepared, dried, weighed, and placed in a cylinder of the Deval abrasion machine. The cylinder is 20 by 33 cm. and is set at an angle of 30 deg. with a horizontal shaft. The shaft is rotated at a speed of 30 to 33 r.p.m.

TABLE 4-1.—PHYSICAL PROPERTIES OF SOME FINE AGGREGATES*

Reference number	Origin	Description	Sieve analysis, percentages passing							Specific gravity	Weight, lb. per cu. ft.	Voids	F.M.	Percentage absorption by weight
			100	48	28	14	8	4	3/8					
0	Ottawa, Ill.	Standard Ott. sand		0	1	100				2.65	105.4	0.363	2.99	0.05
1	Joliet, Ill.	Sand	34	75	100					2.76	107.0	0.380	0.91	0.16
2	Trap Rock, Pa.	Trap screenings	11	16	23	33	52	91	100	2.90	121.5	0.329	3.74	0.10
3	Algonquin, Ill.	Sand	5	19	46	67	84	100		2.71	116.6	0.309	2.79	0.36
4	Kansas City, Mo.	Kaw River sand	0	3	40	75	91	98	100	2.63	109.5	0.333	2.91	0.16
5	Chicago, Ill.	Lake sand	1	60	99	100				2.64	103.0	0.375	1.44	0.20
6	Milwaukee, Wis.	Limestone screenings	23	37	52	67	84	97	100	2.75	123.4	0.280	2.40	0.40
7	Joplin, Mo.	Chats	3	9	20	32	57	100		2.60	101.6	0.373	3.79	0.10
8	Ottawa, Ill.	Banding sand	43	99	100					2.65	106.1	0.358	0.58	0.00
9	Chicago, Ill.	Limestone screenings	3	3	3	3	6	100		2.77	96.9	0.440	4.82	0.16
10	Gary, Ind.	Dune sand	6	95	100					2.67	101.1	0.393	0.99	0.20
11	Chicago, Ill.	Slag	5	9	16	25	45	89	100	2.68	103.7	0.379	4.11	0.56
12	Berlin, Wis.	Crushed granite	15	21	28	39	61	96	100	2.61	114.1	0.300	3.40	0.20
13	Fremont, Neb.	Platte River gravel	3	19	42	57	71	88	98	2.63	121.0	0.263	3.23	0.10
14	Mapleton, Pa.	Glass sand	3	32	93	99	100			2.62	95.1	0.419	1.73	0.40
15	Lorain, Ohio	Crushed slag	9	15	24	34	55	93	100	2.59	91.3	0.435	3.70	0.44
16	Buffington, Ind.	Granulated slag	7	15	37	76	98	99	100	2.50	80.5	0.483	2.69	0.34
17	Atlantic City, N. J.	Sea sand	9	95	100					2.73	107.4	0.370	0.95	0.25
18	San Diego, Cal.	Sand	1	7	24	48	75	94	100	2.65	105.6	0.361	3.50	0.52
19	Janesville, Wis.	Sand	1	14	57	73	82	90	99	2.65	116.1	0.298	2.84	0.12
20	Elgin, Ill.	Washed sand	2	12	51	71	86	98	100	2.69	114.0	0.321	2.81	0.52
21	Medicine Hat, Can.	Sand	1	5	32	61	79	92	99	2.64	112.5	0.317	3.30	0.32
22	Elgin, Ill.	No. 20 Unwashed	1	7	37	57	72	95	100	2.69	116.0	0.309	3.30	0.36
23	Greenup, Ill.	Sand	6	48	39	100				2.63	101.5	0.382	1.47	0.65
24	Attica, Ind.	Sand	4	10	25	51	78	97	100	2.67	112.1	0.332	3.33	0.63

* Compiled from Tables 4 and 5 in TALBOT and RICHART, "The Strength of Concrete—Its Relation to the Cement, Aggregates and Water," *Univ. Illinois Eng Exp. Sta. Bull.* 137, pp. 48–49.

TABLE 4-2.—TYPICAL RESULTS OF PHYSICAL TESTS ON SOME ROCKS*

Name of rock	Location	Crushing strength, lb. per sq. in.	Weight per cubic foot, lb.	Absorption lb. per cu. ft.	Percentage of wear	French coefficient of wear	Hardness	Toughness
Granite	Massachusetts	18,260	166	0.71	2.6	15.4	18.0	9
Granite	Georgia	15,325	163	0.51	4.7	8.5	17.8	6
Granite	Wisconsin	....	164	0.25	2.4	16.7	18.7	7
Basalt	Virginia	....	180	0.39	3.2	12.5	17.7	10
Limestone	Indiana	15,330	166	1.00	4.5	8.9	13.3	6
Limestone	Pennsylvania	19,470	161	0.88	4.2	9.5	15.3	6
Limestone	Colorado	....	168	0.45	4.6	8.7	13.3	6
Sandstone	Ohio	....	142	1.84	6.2	6.5	14.7	9
Sandstone	Texas	....	135	6.62	5.8	6.9	13.0	9
Volcanic sandstone	Washington	....	....	....	3.0	13.3	19.3	
Gneiss (granite)	Massachusetts	....	162	0.75	3.0	13.3	18.7	11
Gneiss (biotite)	Pennsylvania	21,530	165	0.58	....	....	19.0	7
Marble	Vermont	7,380	168	0.39	10.6	3.8	6.7	3
Marble	Georgia	11,340	171	0.37	10.6	3.8	10.3	2
Dolomite	Ohio	16,480	167	1.12	3.4	11.8	16.7	6

* Chosen from "The Results of Physical Tests of Road Building Rock from 1916 to 1921, Inclusive," *U.S. Dept. Agr. Bull.* 1132.

for 10,000 revolutions. The sample is washed, dried, and weighed again. The wear value is taken as the percentage of the material that is finer than 1/16 in. at the conclusion of the test. When gravel is to be tested, it is sieved into one of four combinations, depending on size range, and a charge of six small cast-iron spheres from the brick rattler are used. Otherwise the method is the same.

The French coefficient of wear, or the "French coefficient" as it is often called, is found by dividing 40 by the percentage of wear. American practice is favoring the use of the percentage value rather than the French coefficient.

Los Angeles Abrasion Test.—A number of years ago engineers of the city of Los Angeles, Calif., developed a machine for determining the abrasive resistance of aggregates.[1] The apparatus is known as the Los Angeles rattler or abrasion machine. It is taking the place of the Deval machine.

The Los Angeles rattler consists of a cylindrical drum 28 in. in diameter and 20 in. in length, mounted longitudinally on a horizontal shaft, and having a 3½-in. shelf extending from end to end on the inside.

The test sample consists of 5,000 g. of graded, broken stone or pebbles. A charge of 6 to 12 cast-iron or steel spheres 1⅞ in. in diameter is included in the drum during the test. The number of spheres depends upon the gradation of the test sample. The drum is revolved at a speed of 30 to 33 r.p.m. At the end of 500 revolutions the percentage loss is determined, that portion passing a No. 12 sieve being considered as loss.

The Los Angeles abrasion machine is reported as having certain advantages over the Deval machine:[2] greater speed of operation; more severe action, thus emphasizing the poorer aggregates; adaptability for testing both natural and crushed aggregates; no effect from variations in volume of sample due to specific gravity; no cushioning effect from the dust; and tests can be made on material as prepared for use during construction.

Dorry Hardness Test.—The hardness test consists of grinding both ends of a core of solid rock for 1,000 revolutions each on the Dorry hardness machine. The loss in weight per 1,000 revolutions is taken as a measure of its hardness. The French, who originated the test, de-

[1] McKesson, "Selection of Rock and Gravel for Highway Construction," *Calif. Highways*, Vol. 3, No. 4 (April, 1926).

[2] Woolf and Runner, "The Los Angeles Abrasion Machine for Determining the Quality of Coarse Aggregate," *Public Roads*, Vol. 16, pp. 125–133 (September, 1935).

veloped a coefficient of hardness that is found by subtracting one-third the loss in weight per 1,000 revolutions from 20. Concrete used in highway surfaces, sidewalks, and warehouse floors may be subjected to considerable grinding at times.

Toughness Test.—The toughness test is made by dropping a 2-kg. weight from various heights on a cylinder of the rock, which is 1 in. in diameter and 1 in. long. The first blow falls 1 cm., and each succeeding blow falls 1 cm. more than the preceding one. The height of the blow causing failure is taken as the toughness value. This test is still used. Concrete in pavements, driveways, and warehouse floors is subject to con-considerable impact at times, and therefore it is necessary to have an aggregate that will not shatter easily under impact.

FIG. 4-12.—Spalling caused by a piece of chert in the aggregate.

Crushing Strength.—Crushing strength determinations are made on cylinders 2 in. in diameter and 4 in. long or on 2-in. cubes. The former is easily prepared with a diamond set, core drill and a high-speed cutting tool to trim up the ends. Except for informational purposes, it is not necessary to make this test, as most rocks have crushing strengths far in excess of anything that may be secured with concrete.

Soundness.—An important quality of aggregates is their ability to withstand changes in weather conditions, such as freezing and thawing, wetting and drying, and temperature changes not involving freezing and thawing. Some rocks have good test values in all other respects but do not weather satisfactorily. Accelerated soundness tests may be divided into two groups: (1) actual freezing and thawing and (2) alternate soaking in a saturated solution of either sodium sulfate or magnesium sulfate and then drying in an oven at 230°F. for five or more cycles. The A.S.T.M. has a tentative method of test for the second group (Designation C 88).

In the sodium and magnesium sulfate tests the disintegration takes place due to the formation of crystals during the soaking periods. The amount of sodium sulfate that will go into solution varies considerably, depending on the temperature of the solution, and the effectiveness of the solution in producing disintegration is considered to vary with the concentration of the solution. The amount of magnesium sulfate going into solution does not vary to any extent in the range of temperatures likely to be found in the average laboratory (see Fig. 4-13). As a result some consider it to be the better solution. There is some disagreement as to the effectiveness of the two solutions, some securing more disintegration with one than with the other on the same material.

Freezing and thawing tests require much more time than do the salt-solution tests, but some feel that they are more in line with what is

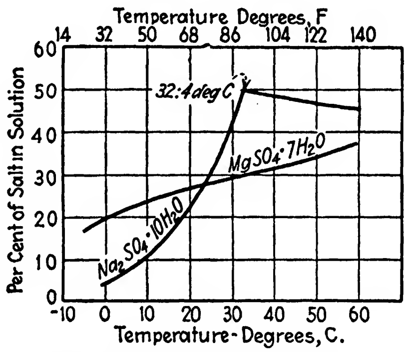

FIG. 4-13.—Solubility curves for sodium and magnesium sulfates, for temperatures from 0 to 60°C.

actually happening under field conditions. Soaking of the test specimen is normally done in air under average conditions of temperature and air pressure, with the result that not all the pore space in the aggregate particles is filled with water. There are indications that when more than 85 per cent of this pore space is filled with water, disintegration of the rock takes place in a relatively small number of cycles of freezing and thawing.

Organic Impurities.—Deposits of sand and pebbles sometimes contain organic matter, which if left in the aggregate might delay considerably the setting of the cement. It is the usual procedure to wash the gravels from the deposits before using them as aggregate in concrete, but occasionally washing is omitted. In such cases the sand should be checked for organic impurities. The test as prepared by A.S.T.M. provides that the sand be placed in a 12-oz. prescription bottle to the 4½-oz.

mark and that a 3 per cent solution of sodium hydroxide be added until the bottle is filled to the 7½-oz. mark. It is shaken and set aside for 24 hr. Sands free from organic impurities will have a clear liquid above them in the bottle.

American Society for Testing Materials specifications for aggregates provide that sands showing colors darker than the standard color may be used, provided that in the test for measuring the mortar-making properties of fine aggregate (A.S.T.M. Designation: C 87) the strengths are not less than a certain percentage of the strengths specified. The percentage is left blank by A.S.T.M., however, to be filled in by the engineer to suit local conditions.

Deleterious Substances.—The presence of clay and other fine particles in concrete aggregates has always been a source of concern. These very fine particles are easily carried in suspension in the mixing water, and when there is an excess of mixing water, they are brought to the surface or remain in the concrete near the surface. When the concentration of these fine particles is great, concrete of inferior quality results. On the other hand, when they are uniformly distributed through the concrete, there may be a beneficial effect.

In pavement concrete the fine particles are worked to the surface during the compacting and finishing operations where they may contribute to scaling or produce a surface easily worn away. In structural concrete, where the concrete is usually mixed wetter than for pavements, the fine particles are more easily worked to the surface. If one lift is allowed to harden before the next one is added, the surface of the hardened concrete should be cleaned of the layer containing the fine particles.

When these fine particles are so firmly attached to the aggregate particles that they are not removed during the mixing operation, a satisfactory bond may not develop between the cement paste and the aggregate.

The amount of material finer than the No. 200 sieve is limited in the A.S.T.M. specifications for aggregates to 2 per cent for concrete subjected to surface abrasion and to 3 per cent for all other concrete. The amount in the coarse aggregate is limited to 0.5 per cent. Clay lumps in sand are limited to 1 per cent and in the coarse aggregate to 0.25 per cent.

Coal and lignite are limited to 0.25 per cent in both fine and coarse aggregates. In some coarse aggregates there may be a fair amount of soft fragments, the limit being placed on the average at 2 per cent. In concrete subject to surface abrasion these soft fragments may be completely pulverized, producing holes in the surface of the concrete.

Gradation.—Gradation is measured by the sieve-analysis determination. A representative sample is passed through a series of sieves, the larger sieves being on top. Material retained on the largest sieve is weighed first; then the material on the next sieve is added to that retained on the first sieve and weighed; and so on until all the material is weighed. This is known as a cumulative analysis, and the value for

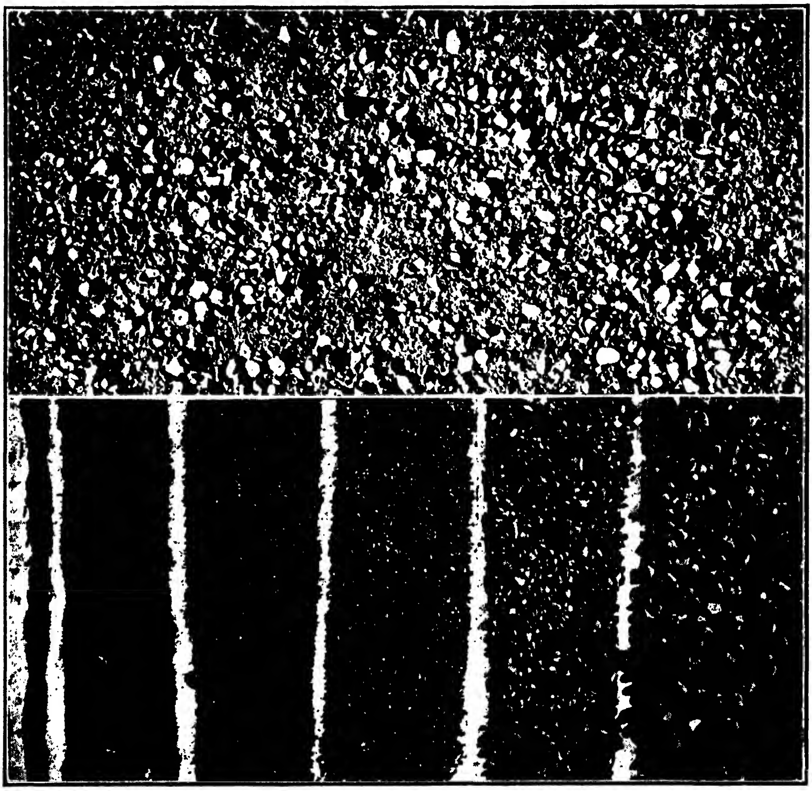

FIG. 4-14.—*Top*, appearance of a well-graded concrete sand ranging in size up to ¼ in. *Bottom*, appearance of same sand when separated into six different sizes. The width of the strips indicates the relative amounts of each size.

each sieve is called the total per cent retained. If total percents passing are desired, the total per cents retained are subtracted from 100. Another method of procedure not often used in the concrete field is to determine the fractions between each two sieves. These values are designated as fractional per cents.

A graded aggregate is one that contains all sizes of particles between the extreme limits for that kind of aggregate. For fine aggregate the range extends from the No. 100 sieve to the No. 4 sieve and for coarse aggregate from the No. 4 sieve to any maximum size required by the work in hand. When all of the particles are of one size, it is known as a one-size material. A well-graded aggregate is one containing the proper amounts of the various sizes.

A *sieve-analysis curve* is a graphic presentation of a sieve analysis. The diameters of the openings of the sieves are plotted to a direct scale

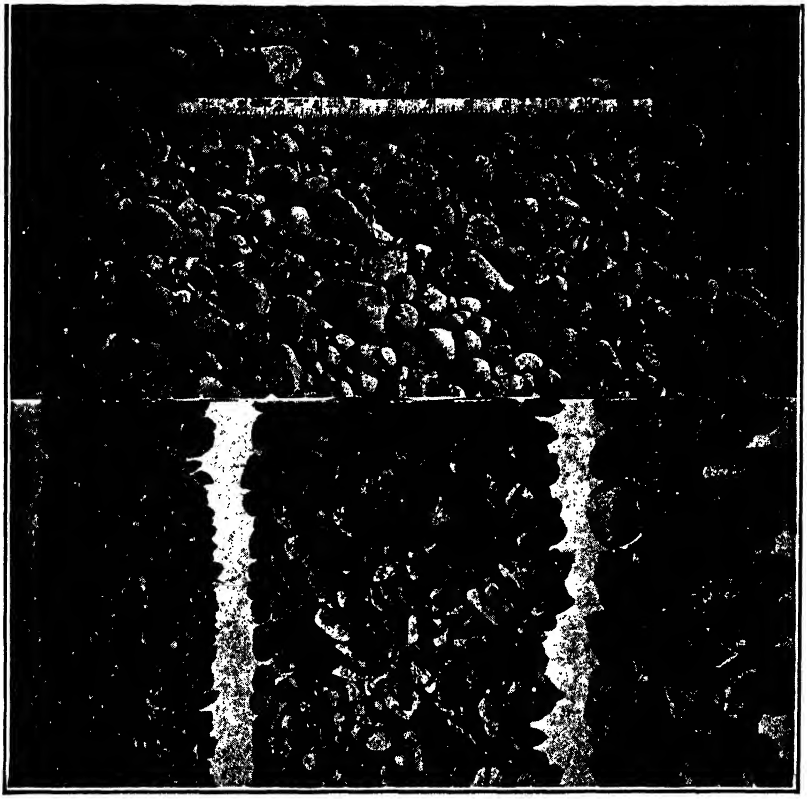

FIG. 4-15.—*Top*, appearance of a well-graded coarse aggregate ranging in size from ¼ to 1½ in. *Bottom*, appearance of same aggregate when separated into three sizes: ¼ to ⅜ in.; ⅜ to ¾ in.; and ¾ to 1½ in. Width of material indicates amount of each size.

as the abscissas and the percentages passing, as ordinates. Typical, sieve-analysis curves are shown in Fig. 5-2. In some instances the diameters are plotted to a logarithmic scale, and in other cases the percentages retained are plotted instead of the percentages passing. Most engineers now are accustomed to the percentages passing and diameters of opening plotted to a direct scale.

Maximum size of aggregate is designated as the smallest sieve through which all the aggregate will pass. There are various interpretations of this general rule, some engineers excepting 5 per cent while others except as much as 15 per cent.

The percentage of voids in a well-graded aggregate decreases as the maximum size is increased, and, therefore, it is advisable to use a maximum size as large as conditions will permit. The maximum size should be limited to about one-fourth the minimum thickness of concrete used or to about two-thirds the minimum spacing between reinforcing bars.

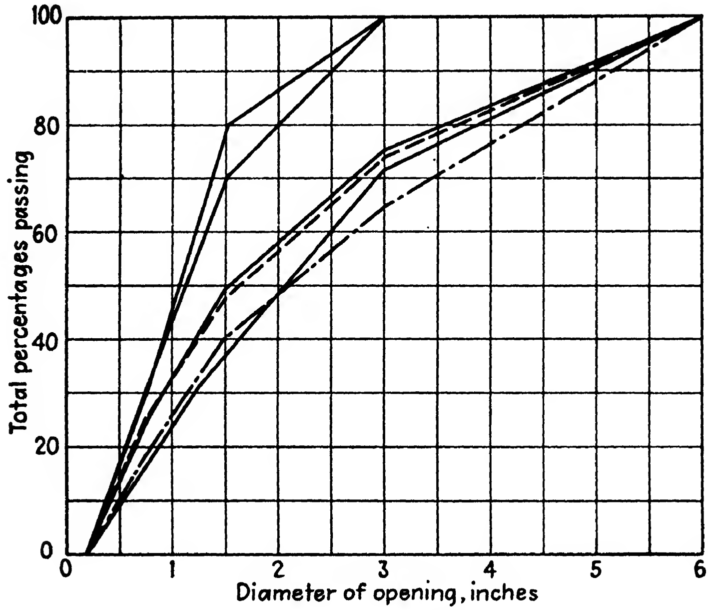

FIG. 4-16.—Some typical gradation curves for 3-in. and 6-in. maximum size coarse aggregates. In these cases the coarse aggregate was separated into the following fractions: No. 4 to ¾ in.; ¾ to 1½ in.; 1½ to 3 in.; and 3 to 6 in.

In pavements the maximum size used is about 2 to 2½ in. In concrete structures of large mass the practice today is to use 6 in. as the maximum size. For the concrete in Hoover Dam the maximum size was 9 in., but it was felt that the benefits were not sufficient as compared to the cost of preparation and handling another size of coarse aggregate.

Specific Gravity.—Specific gravity is not a measure of any quality, but values for various materials are necessary in making certain calculations. Specific gravity is defined as the ratio between the weight of a material at a designated temperature and the weight of an equal volume of water at a designated temperature. Workers in the concrete field are inclined to ignore the item of temperature for both the material and the water. In some instances this produces no significant differences while in others it does. The fundamental basic definition should be kept in mind at all times. In connection with discussions concerning concrete it is much better not to substitute the term density for specific gravity, since density has come to mean only one thing in connection with concrete.

Unit Weight.—Unit-weight values are always expressed in the United States in terms of pounds per cubic foot (p.c.f.). Unit weight is also not a measure of quality, but values are necessary for certain calculations. The volume involved always includes both the volume of the solids and the volume of the voids.

Unit-weight values must always be secured by actual test, there being no way to compute them. Because they are always test values, it is implied that the sample has been tamped into the test measure in some standard manner.

The term unit weight is applied to cement, fine aggregate, coarse aggregate, combinations of fine and coarse aggregate, and to mortar and concrete. The unit weight of a combination of fine and coarse aggregate is greater than the unit weight of either separately, and the unit weight of concrete is greater than that of the materials separately. The unit weight of water is often taken as 62.355 lb. per cu. ft., which is the weight at 62°F. Unit weights at other temperatures are given in the appendix.

Density and Voids.—The term density is used quite generally in the concrete field to indicate the proportion of a unit volume (*e.g.*, 1 cu. ft.) of concrete that is occupied by the particles of cement and aggregates. The part of the unit volume that is not occupied by the particles of cement and aggregates is known as voids, and these include both water and air.

Density values are always less than one, values rarely ever being expressed as percentages. On the other hand, voids values are more often given as percentages than as decimals.

In the case of the cement and aggregates, density values as such are normally not used, although the Talbot-Richart value b_0 is really a density value. The voids values are normally given for the aggregates rather than the density values, although when either is given the other is immediately known.

Voids values for cement and aggregates are normally secured by calculation, using the specific-gravity and unit-weight values of the material, as explained in Test 14. Calculation of voids values for concrete is illustrated in Chap. 6, being the value *v* in the Talbot-Richart set of values.

ADMIXTURES

Admixtures are materials other than the usual cement, water, and aggregates that are added to the concrete at the mixer. They should not be confused with the materials called "additions," which are added during the grinding of the cement clinker and mentioned in the chapters on cements. Admixtures may be grouped into the following classes according to purpose of use:

1. Workability
2. Air entrainment
3. Color
4. Cement dispersion
5. Early strength
6. Waterproofing

Workability Admixtures.—Workability admixtures are fine materials added to the batch to aid in securing a concrete that may be handled and placed more easily with less segregation of the regular ingredients. A certain amount of fine particles is needed in order to produce a sticky paste to hold together the aggregate particles. In concretes in which the amount of the cement used or the amount of the sand passing the Nos. 50 and 100 sieves is small, there may not be enough sticky paste to prevent segregation.

Concrete must also be worked into the forms and around reinforcing steel, either or both of which may be fairly intricate. The presence of these fine particles in the concrete aids materially in increasing the ease of working the concrete into place.

The presence of these fine, workability particles in the concrete may reduce the amount of bleeding. The effectiveness of any particular admixture in the matter of reducing bleeding will depend upon certain characteristics of the material itself. In other words, all materials of equal fineness will not produce the same results in the matter of bleeding.

A mass of freshly made concrete is held together compactly by the film of water that is developed continuously around the outside of the mass. Fine particles are necessary for the formation of this film, and certain kinds of particles seem to be more effective than others. For each combination of cement, aggregates, and admixture there is some amount of mixing water that develops the maximum strength of the film. In general, this amount of mixing water is too small for ease and convenience in placing the concrete in the forms, and a larger amount is used.

A number of workability admixtures are on the market, such as hydrated lime and diatomaceous silica. At times a small amount of additional cement is used as a workability admixture.

Hydrated Lime.—Hydrated lime is quicklime that has been mixed with about one-third of its weight of water. Quicklime is produced by heating limestone to a temperature of 1500°F. or over. Pure limestone corresponds in composition to calcium carbonate ($CaCO_3$), and when heated to 1500°F., it is separated into lime (CaO) and carbon dioxide (CO_2).

Most limestones contain some magnesia, which is then evident in the limes produced. Limes containing less than 5 per cent magnesia are marketed as high-calcium limes; most magnesian limes contain about 30 per cent magnesia. The latter are slower slaking and cooler than the high-calcium limes, and less plastic or smooth.

There are three stages in the process of hydrating lime: (1) grinding of the lump quicklime, (2) mixing with water, and (3) sieving. Approximately 55 lb. of water are necessary per 100 lb. of high-calcium lime and 30 lb. per 100 lb. of magnesian lime. Following the slaking operation the hydrated lime is placed in bins for 48 hr. or more, after which it is ready for use. It is shipped in either heavy, closely woven burlap or duck bags containing 100 lb. each or in paper bags containing 40 lb.

Diatomaceous Silica.—Diatomaceous silica is composed of the remains of the simplest form of plant life called "diatoms," which are found in both fresh and salt waters. The diatoms perpetuate themselves by dividing into two complete diatoms every day or two. The microscopic material that forms the body of the deposits of diatomaceous silica is pure silica secreted from the water in which the diatoms lived.

It is thought that the diatoms that form the principal deposit of diatomaceous silica, which is located at Lompoc, Calif., were grown in much colder waters to the north and that the sudden change in temperature that took place as a result of their movement by ocean currents to southern waters caused them to die in large numbers. This deposit covers many square miles and varies in depth from 900 to 1,400 ft.

The diatomaceous silica is ground so that 95 per cent will pass through a No. 200 sieve and is mixed in such a proportion that over 90 per cent of any quantity sold will be pure silica. The deposit contains varying amounts of foreign materials. The prepared material is extremely light, weighing about 10 lb. per cu. ft.

When used as a concrete admixture, the amount of diatomaceous silica varies from 2 to 5 lb. per bag of cement, the smaller amounts being used with the richer mixes. Inclusion of this admixture without any change in the quantities of the other materials will result in a concrete of a much drier consistency, and in many cases too dry to use.

Air-entraining Admixtures.—Both the materials that have been approved for addition to portland cement for the purpose of producing an air-entraining portland cement are available for use as air-entraining admixtures for concrete and are being used. Some engineers prefer to use the air-entraining portland cement, taking whatever air content is produced under job conditions, while others prefer to secure air entrain-

FIG. 4-17.—A deposit of diatomaceous silica.

ment by the addition of an admixture at the mixer. The amount of this admixture can be changed as may be necessary to secure the desired air content.

When air entrainment is secured by the use of air-entraining portland cement, there is no extra cost. When the admixture is used, there is the cost of the material itself as well as the cost of handling and adding it to the batch. Automatic dispensing machines are available, however.

When an air-entraining admixture is added to concrete that has had none in previous batches, the concrete will be of a wetter consistency. If the amount of the mixing water is reduced to bring the consistency to that prevailing before the admixture was added, it will in most cases be found that the concrete is more workable. In some cases engineers are reducing the proportion of the aggregate that is sand because the entrained air acts much like the finer particles of sand. The substitution of air-entraining portland cement for standard portland cement produces the same effects as the use of the admixture.

Darex AEA admixture is sold by the manufacturer in liquid form ready to use. It is dark brown in color and freezes at approximately 27°F., but it is claimed that the air-entraining properties are restored upon thawing. The amount used ranges between 1 to 1½ fl. oz. per bag of cement, but the exact amount must be determined by trial with full-size job batches under actual working conditions.

Vinsol resin is sold by the manufacturer in powder form. It is advisable to dissolve this powder in a 3 per cent sodium hydroxide solution at the rate of 1 g. of powder per 10 ml. of solution and to use the solution rather than the powder. Vinsol resin prepared in this way is known as neutralized Vinsol resin. The liquid is dark brown in color.

The determination of the exact amount of Vinsol resin solution to use is made by trial on full-size batches of concrete under actual job conditions. The amount of Vinsol resin powder needed for average conditions to produce from 3 to 5 per cent air in the concrete is 0.01 per cent by weight of cement. A set of typical calculations is given at the end of Chap. 6.

Color Admixtures.—Occasionally it is desirable to give the surface of concrete some special color. Normally, because of the cost of the color admixture, just a relatively thin layer is colored, and usually it is a mortar coating. Colored powders are sometimes used to produce the desired color, the powder being added to the batch as an admixture.

The materials need to be chemically inactive with the cement and should not fade when exposed to sunlight. Colors used are black, red, green, yellow, and blue. The University of Illinois used a black-color admixture in the building of some tennis courts about 1930 to reduce the glare that is normally present on a newly laid concrete surface.

Cement-dispersion Admixtures.—Under certain conditions, when fine-grained particles are mixed with some liquids, there is a tendency for the particles to gather together in clusters or flocs. This phenomenon is known as flocculation. By the addition of certain chemicals the amount of the flocculation may be lessened considerably. Any chemical that is used to lessen flocculation is known as a dispersing agent.

Cement particles in water flocculate to a high degree. Some engineers visualize that this cement floc is wetted only on the outside at first and that it may be a long time before cement particles on the inside of the floc are hydrated. Powers feels that there is no question but that the cement particles in a normal paste are flocculated but questions the necessity of adding anything to the concrete to disperse the cement.[1] There are some admixtures on the market for which cement dispersion is claimed.

Early-strength Admixture.—The early-strength admixture is calcium chloride, which is normally used at the rate of 2½ lb. per bag of cement. The calcium chloride crystals should always be dissolved in water and added to the batch in solution form.

Waterproofing Admixtures.—Waterproofing admixtures may be divided into two general groups—those that are water-repellent and those that are not. In the first group are the stearates, discussed in connection with waterproofing cements in the previous chapter. In the second group are those that use calcium chloride to hasten the development of the cement gel and those that are essentially workability admixtures, previously discussed in this chapter.

The ability of the concrete to resist the movement of water depends upon the ability of the cement paste to resist movement of water and upon the thoroughness with which the paste is distributed through the aggregate. Any material used as an admixture that aids in getting a better cement paste and in distributing the paste through the aggregate may be classed as a waterproofing admixture, even though it can be classed otherwise also.

MIXING WATER

Mixing water for concrete is often restricted to water that is suitable for drinking purposes. Not all water, unsuitable for drinking is unsatisfactory for mixing water in concrete, however. No special tests have been developed for determining the quality of mixing water, and hence it is difficult for the man in the field to judge the fitness of water. If there is any question about the water, samples should be sent to a laboratory where they may be compared with water that is known to be satisfactory. The comparison would be made by means of strength tests at 7 and 28 days on mortar or concrete, although there may be other important considerations.

Some of the waters that are known or considered to be harmful are are those containing sugar, tannic acid, most sulfates, humic acid, free carbonic acid, sodium salts above certain concentrations, and effluents from sewage, gas, paint, and artificial-fertilizer works. There is some discussion about the suitability of sea water, with certain persons reporting to have used it with no detrimental effects and others blaming deterioration on the use of sea water.

[1] POWERS, T. C., "Should Portland Cement be Dispersed?" *Proc. Am. Concrete Inst.*, Vol. 42, p. 117.

Tests were made at Lewis Institute, Chicago, Ill., on a large number of samples of water. The report on these tests says in part:[1]

. . . in spite of wide variations in the origin and type of waters used, and contrary to accepted opinion, most of the samples gave good results in concrete. . . . The following samples gave concrete strengths below the strength ratio of 85 per cent which was considered the lower limit for acceptable mixing waters: acid water, lime soak from tannery, refuse from paint factory, mineral water from Colorado, and waters containing over 5 per cent common salt.

STANDARD SPECIFICATIONS FOR CONCRETE AGGREGATES

A.S.T.M. Designation: C 33-46

1. **Scope.**—These specifications cover fine and coarse aggregates suitable for use in concrete.

NOTE. *Quality of Aggregates.* It is recognized that for certain purposes satisfactory results may be obtained with materials not conforming to these specifications. In such cases, the use of fine and coarse aggregates not conforming to these specifications may be authorized only under special provisions, based upon laboratory studies of the possibility of designing a mixture of materials to be used on the job that will yield concrete equivalent in quality to the specified mixture made with material complying with these specifications in all respects.

FINE AGGREGATE

2. **General Characteristics.**—Fine aggregate shall consist of natural sand or of sand prepared from stone, blast-furnace slag, or gravel, or, subject to the approval of the engineer, other inert materials having similar characteristics.

3. **Deleterious Substances.**—*a.* The amount of deleterious substances in fine aggregate shall not exceed the limits prescribed in Table 1.

TABLE 1.—PERMISSIBLE LIMITS FOR DELETERIOUS SUBSTANCES IN CONCRETE AGGREGATES

	Recommended permissible limits, max. per cent by weight	Maximum permissible limits, per cent by weight
Clay lumps	1	1.5
Coal and lignite	0.25	1
Material finer than No. 200 sieve		
In concrete subject to surface abrasion	2	4
All other classes of concrete	3	5
Other deleterious substances (such as shale, alkali, mica, coated grains, soft and flaky particles)	As specified	As specified

[1] ABRAMS, DUFF A., "Tests of Impure Mixing Waters for Mixing Concrete," *Proc. Am. Concrete Inst.*, Vol. 20 (1924), reprinted as *Structural Materials Research Lab.*, *Bull.* 12, Lewis Institute.

NOTE.—The recommended limits should be specified on all work where it is economically practicable to obtain materials conforming thereto.

b. Organic Impurities.—All fine aggregate shall be free from injurious amounts of organic impurities. Aggregates subjected to the colorimetric test for organic impurities and producing a color darker than the standard shall be rejected unless when tested in accordance with the Standard Method of Test for Measuring Mortar-making Properties of Fine Aggregate (A.S.T.M. Designation: C-87), the mortar develops a compressive strength at 7 and 28 days of not less than. . .[1] per cent of that developed by the mortar specified in that method as the basis for comparison.

4. Grading.—*a.* Fine aggregate shall be well graded from coarse to fine and when tested by means of laboratory sieves shall conform to the following requirements:

Sieve	*Percentage passing*
⅜ in.	100
No. 4	95–100
No. 16	45–80
No. 50	10–30
No. 100	2–10

NOTE 1. At the approval of the engineer, when the fine aggregate is to be used in concrete mixtures containing five or more sacks of cement per cubic yard, the limitations on the material passing the No. 50 and No. 100 sieves may be 5 to 30 and 0 to 10 per cent, respectively.

NOTE 2. Fine aggregate failing to pass the minimum requirements for the material passing the No. 50 or No. 100 sieve or both may be used, provided a satisfactory, inorganic fine material is added to correct for the difference in grading.

NOTE 3. Attention is called to the fact that the relatively wide range in grading, which is shown in the above table, should be permitted only when it is economically impracticable to obtain materials meeting more restrictive requirements. The most desirable grading will depend upon the type of work and the class of concrete. For the leaner mixes, or when a small-size coarse aggregate is used, in cases where the degree of workability is important, it is desirable to further restrict the allowable ranges in sizes shown so as to insure a grading approaching the maximum percentage passing each sieve. On the other hand, for the richer mixes, in the interests of maximum strength and economy, a grading as coarse as is consistent with the requirements for workability should be specified. However, in no case should a range in grading be required more restrictive on any one sieve than indicated below:

Sieve	*Percentage passing*
No. 16	20
No. 50	15
No. 100	5

[1] A percentage should be inserted by the engineer to suit local conditions.

b. Uniformity of Grading.—The above gradation for fine aggregate represents the extreme limits, which shall determine the suitability for use of fine aggregate from all sources of supply. The gradation of fine aggregate from any one source shall be reasonably uniform and not subject to the extreme percentages of gradation specified above. For the purpose of determining the degree of uniformity of a fine aggregate, a fineness-modulus determination shall be made upon representative samples of fine aggregate from such sources as are proposed for use. Fine aggregate from any one source, having a variation in fineness modulus greater than plus or minus 0.20 from the fineness modulus of the representative sample submitted by the contractor, shall either be rejected or may be accepted subject to such adjustment in proportions as may be necessary by reason of changes in grading of fine aggregate. Fine aggregate from different sources of supply shall not be mixed or stored in the same pile nor used alternately in the same class of construction or mix without permission from the engineer.

c. In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not of a workable character or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine material, or a coarse aggregate having a sufficiently smaller percentage of fine material shall be used.

5. Mortar Strength.—Fine aggregate shall be of such quality that when made into a mortar and tested in accordance with the Standard Method of Test for Measuring Mortar-making Properties of Fine Aggregate (A.S.T.M. Designation: C 87), the mortar shall develop a compressive strength at 7 and 28 days of not less than . . .[1] per cent of that developed by the mortar specified in that method as the basis for comparison.

NOTE.—The graded standard sand mentioned in Section 5 may be obtained with a mixture of approximately equal parts by weight of standard Ottawa sand conforming to the requirements prescribed in the Standard Method of Test for Tensile Strength of Hydraulic-cement Mortars (A.S.T.M. Designation: C 190) and graded Ottawa sand conforming to the requirements specified in Section 4 of of the Standard Method of Test for Compressive Strength of Hydraulic-cement Mortars (A.S.T.M. Designation: C 109).

6. Soundness.—Fine aggregate shall pass a sodium, or magnesium sulfate, accelerated soundness test, except that aggregates failing in the accelerated soundness test may be used if they pass a satisfactory freezing-and-thawing test.

COARSE AGGREGATE

7. General Characteristics.—Coarse aggregate shall consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials of similar characteristics, or combinations thereof, having hard, strong, durable pieces, free from adherent coatings and conforming to the requirements of these specifications.

[1] A percentage should be inserted by the engineer to suit local conditions.

8. Deleterious Substances.—The amount of deleterious substances in coarse aggregate shall not exceed the following limits:

	Recommended[a] permissible limits, max. per cent by weight	Maximum permissible limits, per cent by weight
Soft fragments	2	5
Coal and lignite	0.25	1
Clay lumps	0.25	0.25
Material finer than No. 200 sieve	0.5[b]	1[b]
Other deleterious substances	As specified	As specified

[a] The recommended requirements should be specified on all work where it is economically practicable to obtain materials conforming thereto.

[b] When the material finer than the No. 200 sieve consists essentially of crusher dust, the recommended and maximum permissible limits specified above may be raised to 0.75 and 1.5 per cent, respectively.

9. Grading.—*a.* Coarse aggregate shall be well graded between the limits specified and shall conform to the requirements prescribed in Table 2.

b. Designation of a given coarse aggregate as aggregate of a certain maximum size shall be understood to mean that more than 5 per cent must be retained on the next smaller of the sieves appearing in Table 2.

c. In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not a workable character or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine material or a coarse aggregate having a sufficiently smaller percentage of fine material shall be used.

10. Weight of Slag.—Blast-furnace slag that meets the grading requirements of these specifications shall conform to the following weight requirements:

	Unit weight, min., lb. per cu. ft.
General concrete	65
Concrete subject to abrasion	70

11. Soundness.—Coarse aggregate shall pass a sodium or magnesium sulfate accelerated soundness test, except that aggregates failing in the accelerated soundness test may be used if they pass a satisfactory freezing-and-thawing test.

NOTE.—Many engineers believe that an abrasion test for coarse aggregate to be used in concrete subject to abrasion is important, but no test limits are specified due to the status of knowledge concerning suitable specification limits for this test. The committee believes that the abrasion tests when applied to blast-furnace slag do not meet the requirements for a desirable test. This recommendation is made after consideration of the results of a study to determine the value of the abrasion test as to the concrete-making properties of slag.

12. Methods of Sampling and Testing.—The aggregates shall be sampled and the properties enumerated in these specifications shall be determined in accordance with the following methods of the American Society for Testing Materials (except as specified in Paragraph *j.*):

TABLE 2.—GRADING REQUIREMENTS FOR CRUSHED STONE, GRAVEL, AND BLAST-FURNACE SLAG

Designated size	Percentages passing laboratory sieves having square openings							
	2½ in.	2 in.	1½ in.	1 in.	¾ in.	½ in.	⅜ in.	No. 4
2 in. to No. 4	100	95–100		35–70		10–30		0–5
1½ in. to No. 4		100	95–100		35–70		10–30	0–5
1 in. to No. 4			100	90–100		25–60		0–10
¾ in. to No. 4				100	90–100		20–55	0–10
½ in. to No. 4[a]					100	90–100		0–15
2 to 1 in.	100	90–100	35–70	0–15				
1½ to ¾ in.		100	90–100	20–55	0–15			

[a] Not more than 5 per cent passing the No. 8 sieve.

a. Sampling.—Tentative Method D 75
b. Sieve Analysis.—Standard Method C 136
c. Amount of Material Finer than No. 200 Sieve.—Standard Method C 117
d. Organic Impurities.—Standard Method C 40
e. Mortar Strength.—Standard Method C 87
f. Compressive Strength.—Standard Method C 39
g. Soundness.—Tentative Method C 88
h. Clay Lumps.—Standard Method C 142
i. Coal and Lignite.—Standard Method C 123
j. Shale.—American Association of State Highway Officials Method T-10
k. Moisture.—Standard Method C 70
l. Weight of Slag.—Standard Method C 29
m. Abrasion.—If abrasion tests are made, the following methods of test are recommended:

(1) *Abrasion of Gravel.*—Standard Method D 289

(2) *Abrasion of Rock.*—Standard Method D 2, except that for material having specific gravities lower than 2.2, a 4,000-g. sample shall be used.

(3) *Abrasion of Coarse Aggregate.*—Standard Method C 131 (Los Angeles rattler test)

n. Fineness Modulus.—The fineness modulus is the sum of percentages in the sieve analysis divided by 100 when the sieve analysis is expressed as cumulative percentages coarser than each of the following sieves: Nos. 100, 50, 30, 16, 8, and 4.[1] The sieve analysis shall be made in accordance with Standard Method C 136.

Study Questions

1. What is meant by each of the following terms:

Aggregate	Blending sand
Admixture	Blended sand
Bank-run aggregate	Stone sand
Separated aggregates	Graded aggregate
Multiple-size aggregates	Segregation
Divided coarse aggregate	Maximum size of aggregate
Fine aggregate	Sound aggregate
Coarse aggregate	Tough aggregate
Combined aggregate	Hard aggregate

2. What material is most commonly used as aggregate in concrete?
3. What materials are available as lightweight aggregates?
4. When is it advisable or necessary to use a blended sand?
5. Why is it better to use separated aggregates rather than bank-run aggregate?
6. Why is it better to use divided coarse aggregate with the fine aggregate rather than just the separated aggregates? Under what conditions would the divided coarse aggregate be used?
7. Why should the maximum size of the coarse aggregate be as large as conditions will permit? What factors affect the choice of maximum size? What is the greatest maximum size in use at the present time?
8. Name the three general classifications of rock, and define each.
9. Name and describe briefly the two abrasion tests for aggregates. Which one is the newer? Which requires the shorter time of operation? Which one gives the greater test losses?
10. Describe briefly the hardness, toughness, and crushing strength tests.
11. Name two methods of testing for soundness of aggregates. Describe briefly the methods involved. Which method requires the shorter testing time?
12. What is the critical value for saturation of aggregate in the freezing-and-thawing method?
13. What ill effect might organic impurities in sand produce in the concrete in which the sand is used?
14. What substances other than organic impurities are rated as deleterious?
15. Name the six classes of admixtures.
16. What are workability admixtures? Name several.
17. Name two widely used air-entraining admixtures. Are they liquids or crystals? What advantage does the use of air-entraining admixture have over the use of air-entraining portland cement? What disadvantages are there?

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[1] Author's note. Only six sieves are mentioned in the above specification because fineness modulus of fine aggregate is covered. When coarse aggregate is involved, three additional sieves must be included. They are 3/8 in., 3/4 in., and 1½ in.

18. What properties should color admixtures have?

19. Explain the terms "flocculation" and "dispersion." Do cement particles flocculate when wetted with water?

20. What chemical compound is used as an admixture to hasten the early development of strength? What is the rate at which it is used?

21. What is a good criteria for deciding if water is suitable for use in concrete? What kinds of water should be avoided?

CHAPTER 5

THEORIES OF PROPORTIONING

Concrete is a material composed of cement, water, and mineral aggregate, which develops strength with age. Strengths are influenced by many factors, such as quality and quantity of cement, water, and aggregates; thoroughness of mixing; temperature of unmixed materials and of the concrete during and after placing; and the method and duration of curing. The determination of the proper amounts of given materials needed to produce, at a certain age, concrete of a given strength, under given conditions of mixing, placing, and curing, is known as proportioning. From the number of factors enumerated above it is apparent that no mathematical formula can be developed from which the strength of concrete may be predicted for any combination of conditions.

In the early days of concrete, strengths were low at 7 to 10 days, with the result that all strength tests were made at ages of 28 days or greater. The tendency has always been to develop greater strengths at earlier ages, but until recently the practice has been to make the tests only at 28 days. Since the First World War special efforts have been made to develop what is known as high-early-strength concrete, and hence today many strength tests are being made at ages under 28 days.

In this chapter are presented brief summaries of the scope, the methods used, and the results of major investigations of concrete proportioning, as well as information concerning empirical and trial proportioning. Since the studies were all made under laboratory conditions and, as indicated before, not all the variables present in the field were included, it is not possible to predict field strengths accurately from these results. Certain information of value may be secured from each investigation, and if conditions under which the tests were made are borne in mind, no great conflict of ideas will result. The quality of the cement has been improved since the last of the investigations were made, and the strength curves are lower than can be expected today. Revised curves are shown in the next chapter.

Empirical Proportioning.—The oldest and most used form of proportioning is that in which the amounts of the dry materials are arbitrarily selected. This method has in a general way proved satisfactory and is likely to be extensively employed for some years to come because of the simplicity of its application and because more people are familiar with it than with any other method. On larger and more important work where money is available for supervision, strengths are being specified and tests made. Where empirical proportioning is used, the qualities and quantities of the cement and aggregate are specified for each. The exact amount of water, however, is not given, it being intended that the desired consistency shall be obtained by varying the amount of mixing water. Some control over the amount of mixing water is exercised when the consistency of the concrete is specified. On jobs where

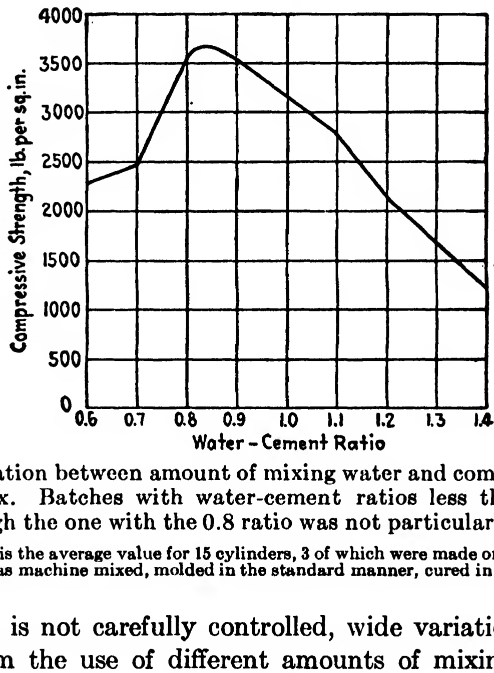


FIG. 5-1.—Relation between amount of mixing water and compressive strength for a 1:2½:4 mix. Batches with water-cement ratios less than 0.9 were not workable, although the one with the 0.8 ratio was not particularly so.

Each point plotted is the average value for 15 cylinders, 3 of which were made on each of five different days. The concrete was machine mixed, molded in the standard manner, cured in a moist room at 70°F., and tested at 28 days.

the consistency is not carefully controlled, wide variations in strength may result from the use of different amounts of mixing water. The curve in Fig. 5-1 shows how much the strength of a 1:2½:4 mix may be varied by the use of different amounts of mixing water. The batches with water-cement ratios less than the one giving maximum strength are too dry and are not considered workable. For arbitrary proportions the amount of mixing water should be kept at a minimum in order to secure the greatest amount of strength.

Proportions commonly used for various classes of work are

Reinforced concrete............................	1:2:4	or 1:2½:4
Mass concrete..................................	1:3:5	or 1:3:6
Pavement concrete..............................	1:2:3	or 1:2:3½
Pavement bases.................................	1:2½:4	or 1:3:5
Sidewalks......................................	1:2:3	or 1:2:4

FULLER AND THOMPSON'S STUDIES

William B. Fuller made some tests in 1901 at Little Falls, N.Y., to determine factors affecting the transverse strength and density of concrete. He came to the conclusion that transverse strength varied with the percentage of cement in the concrete and with density. The percentage of cement was computed on the combined weight of cement and aggregate. Fuller came to the conclusion also that there was a gradation of aggregate that gave highest breaking strength. The mechanical-analysis curve for this ideal gradation was tentatively established as a parabola.

Fuller and Sanford E. Thompson carried out additional tests in 1903 and 1904 at Jerome Park Reservoir in New York City.[1] In these early discussions of concrete great emphasis was placed on density, or the proportion of the freshly made concrete that was cement and aggregate particles. The idea was that the denser the concrete, the better it was. Much of the early concrete was used in the construction of works where the concrete was continuously in contact with water. Such concretes should be watertight, and a watertight concrete should be dense.

In view of later investigations it appears that this emphasis on density was not warranted, especially in connection with its influence on strength. A general plotting, for instance, of strength against density without regard to variables, does not reveal any direct relationship between them. Fuller and Thompson made a number of series of tests in which some one item was varied in each series, thus producing an effect on density and strength. It was therefore reasoned that strength depended upon density.

What was actually happening was that as the density increased the amount of mixing water used decreased. The water occupied practically all the void space in the concrete, and as the void space decreased, there was consequently a decrease in mixing water, or water-cement ratio as suggested by Abrams.

The work of Talbot and Richart brings out the same idea but in a different way. They indicate that there is a relationship between strength and cement-space ratio. The latter is the ratio between the volume of the cement particles and the volume of these particles plus the volume of the voids in the concrete. Any increase in the density of the concrete means a decrease in the volume of the voids, which in turn increases the cement-space ratio.

[1] FULLER, W. B., and S. E. THOMPSON, "The Laws of Proportioning Concrete," *Trans. Am. Soc. Civil Engrs.*, Vol. 59, pp. 67–143.

Plottings of strength against either water-cement ratio or cement-space ratio indicate a definite relationship regardless of variables introduced.

Fuller-Thompson Tests.—Tests were run first on the density of concrete, using different mixtures of aggregate and cement to determine the laws of proportioning for maximum density. Concrete test specimens were then made to determine the relationship between the laws of strength and the laws of density. The amount of mixing water used was enough to give the proper consistency.

Aggregate was sieved into 21 different fractions and recombined to give over 400 different sieve-analysis curves. In most of the tests for density the weight of cement used was 10 per cent of the combined weight of cement and aggregate. This cement content is very low in contrast to today's values.

In making the density tests the concrete was tamped into a strong cylinder in which its volume could be measured.

Fuller and Thompson present a large number of conclusions in their A.S.C.E. report, and we quote a few of the more significant ones:

1. Keeping the percentage of cement constant, aggregate graded artificially to secure maximum density of the concrete produced greater strength than naturally graded aggregate.
2. Keeping the percentage of cement constant and using a graded aggregate, the aggregate with the largest maximum size gave the greatest density and strength.
3. With a given fine aggregate, coarse aggregate, and percentage of cement, the densest and strongest concrete is secured when the volume of the mortar (cement, water, and fine aggregate) just fills the voids in the coarse aggregate. In other words, it is best to use as small a percentage of fine aggregate as possible without producing visible voids in the concrete.
4. The best mixture of cement and aggregates has a mechanical-analysis curve which is a combination of an ellipse and a straight line, the former for the fine-aggregate and cement portion, and the straight line for the coarse-aggregate portion. The curve varies slightly depending upon the materials used. The form is nearly the same for all maximum sizes of coarse aggregate, that is, the curve may be described by an equation in which maximum size is the only variable.

A number of the ideas brought out by Fuller and Thompson are in use today. The idea of artificially grading the aggregate is widely used. Fuller and Thompson evidently had in mind that the engineer in making concrete for a large project might combine a number of aggregates, depending upon what was available, to produce a gradation closely approximating the ideal curve. Instead, the engineer requires that aggregate producers prepare fine and coarse aggregates to meet certain gradation requirements and then combines these aggregates in fixed proportions. In this way the gradation curves for the aggregates used from day to day agree at the ends and at least one intermediate point, which is at a diameter approximately 0.185 in. (No. 4 sieve). When divided coarse aggregate is used, additional points of agreement are secured.

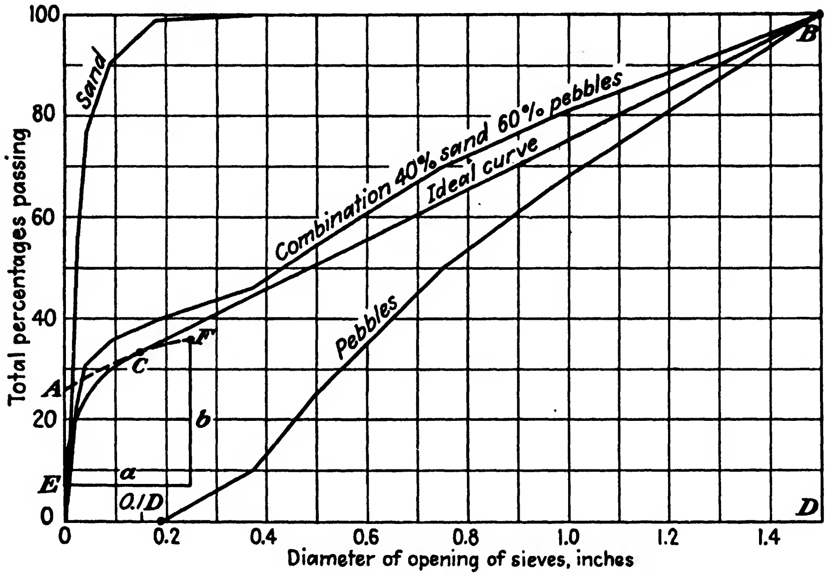


FIG. 5-2.—Illustrating the drawing of a Fuller ideal gradation curve, together with the sieve-analysis curves for a fine aggregate, a coarse aggregate, and a combination of the two, using 40 per cent fine and 60 per cent coarse. By decreasing the percentage of fine aggregate a small amount, a better agreement with the ideal curve can be secured.

The data plotted here for sand, pebbles, and the combination are given in columns 2, 3, and 7 of Table 5-2. Diameters of opening for the numbered sieves are:

4	0.185 in.	30	0.023 in.
8	0.093 in.	50	0.0116 in.
16	0.046 in.	100	0.0058 in.

No attempt is made to grade aggregate artificially to agree exactly with the Fuller and Thompson ideal curve. The idea that the gradation curve should follow roughly some curve is in use. Concrete mixes today are much richer in cement than at the time of this investigation. We are using also on construction percentages of sand that are higher than are secured when the Fuller-Thompson recommendations were followed.

The idea of using as large a maximum size of aggregate as possible is used today. Recommendations are given in Table 6-4.

The idea of using as small a percentage of sand as conditions will permit is good practice today. Recommendations are given in Table 6-5 and Fig. 6-4.

Example of Use of Ideal Curve.—The maximum size of the aggregate and the kinds of aggregate to be used are the first decisions to be made. For the illustration we will use a maximum size of 1½ in. and sand and pebbles for the aggregates.

Plot the ideal curve on the graph sheet. Data for the plotting of the curve are given in Table 5-1. Draw first the straight line from *A* to *B*. Point *A* is at 26 per cent and 0 diameter. Point *B* is at 100 per cent and 1½ in. diameter. The ellipse is drawn from point *E* to point *C*. Point *E* is always at 7 per cent and 0 diameter. Point *C* is at the per cent shown in column 3 of Table 5-1, and at 0.1 the maximum diameter. Values for the major and minor axes of the ellipse are given in columns 4 and 5 of Table 5-1. A fairly good ellipse can be drawn with an irregular curve by using points *E* and *C* and a third point *F*. *F* is on the ellipse extended to the right of *C*. It is located at the diameter indicated in column 4 and the per cent given in column 5 plus 7. The ideal curve is the curve *ECB*; segments *AC* and *CF* are only construction lines and are not further needed.

TABLE 5-1.—DATA FOR PLOTTING FULLER'S IDEAL CURVE

Materials	Intersection of tangent with vertical at zero diameter, point *A* in Fig. 5-2	Height of tangent point, point *C* in Fig. 5-2	Axes of ellipse	
			a	*b*
(1)	(2)	(3)	(4)	(5)
Crushed stone and sand....................	28.5	35.7	0.150D*	30.4
Pebbles and sand.........	26.0	33.4	0.164D*	28.6
Crushed stone and screenings..............	29.0	36.1	0.147D*	30.8

* *D* is the maximum diameter.

In columns 2 and 3 of Table 5-2 are given the sieve-analyses values for the sand and the pebbles to be combined. Probably the easiest way to find the combination that agrees best with the ideal curve is to figure several sets of values, plot the results, and by visual inspection decide which one is the answer.

For the first trial, try a combination of 40 per cent sand and 60 per cent pebbles. Tabulate the sieve-analysis values for each material, as shown in Table 5-2. To figure the sieve analysis of the combination assume that a batch of 100 lb. is being used, of which 40 lb. are sand and 60 lb. pebbles. Based on the sieve analyses of each material, figure the weights of sand and pebbles passing each of the sieves, as given in columns 4 and 5. Add values in columns 4 and 5 and record as in column 6. Figure percentages for values in column 6 and record as in column 7.

TABLE 5-2.—COMPUTATION OF SIEVE ANALYSIS OF COMBINED AGGREGATE

Sieve designation	Sieve analysis, individual materials, per cent passing		Combined aggregate, total weight 100 lb.—40 lb. sand and 60 lb. pebbles, weights passing, lb.				Ideal curve values, per cent	Combination—35 lb. sand, 65 lb. pebbles, per cent passing
	Sand	Pebbles	Sand	Pebbles	Combined	Per cent		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1½ in.	100	100	40.0	60.0	100.0	100	100	100
1 in.	100	68	40.0	40.8	80.8	81	75	79
¾ in.	100	50	40.0	30.0	70.0	70	63	67
½ in.	100	25	40.0	15.5	55.5	55	51	51
⅜ in.	100	10	40.0	6.0	46.0	46	44	41
No. 4	99	0	39.6	0.0	39.6	40	35	35
No. 8	91	0	36.4	0.0	36.4	36	30	32
No. 16	77	0	30.8	0.0	30.8	31	25	27
No. 30	56	0	22.4	0.0	22.4	22	21	20
No. 50	26	0	10.4	0.0	10.4	10	16	9
No. 100	4	0	1.6	0.0	1.6	2	10	1

Plot curve for combined aggregate. If this curve does not agree closely with the ideal curve, try another combination.

In column 8 are given values scaled from the ideal curve and in column 9 are given per cent passing values for a combination of 35 per cent sand and 65 per cent pebbles. These values are not plotted in the figure. After figuring and plotting several more curves, let us assume that the curve for 37 per cent sand is the closest approximation.

The ideal curve was developed for a combination of cement and aggregates. It is necessary at this point to decide on the percentage of cement to use. This is usually done by selecting the mix, expressed as 1 part cement to a certain number of parts of aggregate by weight. For the illustration, select a 1:6 mix. The percentage of cement is computed as follows:

$$\frac{1}{1+6}\,100 = 14.3$$

Follow the recommendation of Fuller and Thompson and subtract the 14.3 per cent from the 37 per cent to secure the percentage of sand to be used. In other words, at this stage the cement is substituted for a portion of the sand. The percentage of sand becomes 37 − 14.3 = 22.7. The proportion by weight becomes

$$14.3 : 22.7 : 63.0$$
$$1 : 1.59 : 4.40$$

Assuming unit weights of 94, 108.4, and 104.8 lb. per cu. ft. for cement, sand, and pebbles respectively, the mix by volume becomes

$$1 : 1.38 : 3.95$$

The amount of mixing water is determined in the field by judging the desired consistency.

ABRAMS' STUDIES

In 1915, or approximately 10 years following Fuller and Thompson's work, the manufacturers of portland cement through the Portland Cement Association established a laboratory at Lewis Institute, Chicago, with Duff A. Abrams in charge, for the purpose of studying concrete problems. For a number of years various individuals had been advancing different ideas about the factors affecting the strength of concrete. The first study undertaken by the new laboratory was one to determine the relationship between mixing water, gradation of aggregate, and richness of mix. Other items such as quality of cement and aggregates, method of curing, curing temperatures, and age were kept constant. The cement used was a mixture of four brands available on the Chicago market. The aggregates were from Elgin, Ill., and consisted of sand and pebbles. Results were published in 1918 as *Bulletin* 1 of Lewis Institue entitled "The Design of Concrete Mixtures."

Water-cement-ratio Law Concerning Concrete Strengths.—The most important result of this investigation was what is known as Abrams' water-cement-ratio law:

With given concrete materials and conditions of test, the quantity of mixing water used per bag of cement determines the strength of the concrete, so long as the mix is of a workable plasticity.[1]

The quantity of mixing water is expressed by a new term "water-cement ratio," which is the ratio of the volume of mixing water to the volume of cement. Consider a bag of cement weighing 94 lb. as 1 cu.

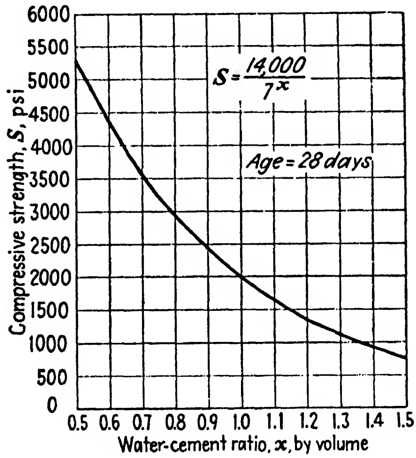


FIG. 5-3.—Relationship between compressive strength and water-cement ratio, as determined by Abrams.

This curve is based on test specimens made under laboratory conditions and with a mixture of four cements. Since these tests were made manufacturers have increased the quality of their cements, so that today this curve represents conservative results. It is often used to indicate 7-day strengths. The concrete was made and cured at a temperature of approximately 70°F.

ft., a water-cement ratio of 1 would require 1 cu. ft. or 7½ gal. of mixing water. Other values are shown in Table 6-3.

In figuring the amount of mixing water used in any batch, water absorbed by the aggregates is not considered. On the other hand, if there is any surface moisture in the aggregates, the amount of this moisture is included in the volume of mixing water. (See next chapter for example of computations involved in making the proper allowances.)

Water-cement-ratio Compressive-strength Curve.—Fig. 5-3 shows a portion of Abrams' original curve for the relationship between compres-

[1] ABRAMS, D. A., "Design of Concrete Mixtures," *Structural Materials Research Lab. Bull.* 1, Lewis Institute.

sive strength and water-cement ratio for the range of water-cement ratios that might be used today. The curve is drawn from the mathematical formula:

$$S = \frac{14,000}{7^x} \qquad (5\text{-}1)$$

where S is the compressive strength at 28 days in pounds per square inch, and the exponent x is the water-cement ratio as previously defined. In comparing present-day strengths with those shown in the graph it should be remembered that the quality of cements has been improved considerably since the tests were made. In fact, the curve shown might be considered as conservative for results to be expected now at 7 days.

The curve is really a combination of a number of curves. Mixes ranging from very rich to very lean were used, and for each mix the water content was varied to produce concretes ranging from very dry to very wet consistencies. For each mix the strength–water-cement-ratio curve resembled the one shown in Fig. 5-1. Only the portions to the right of the peaks were used in connection with the curve in Fig. 5-3. Concretes represented by points to the left of the peaks are too dry to be used in practice.

Another point worth noting is that the wetter consistencies of one mix may have as much strength as the drier (but workable) consistencies of a somewhat leaner mix. For instance, a 1:2½:4 mix with a slump of 5 to 6 in. requires the same amount of mixing water per bag of cement as a batch of 1:3:5 concrete with a slump of 1 to 2 in. According to the curve (Fig. 5-3) and the water-cement-ratio law, both mixes should have the same strength. It is only when batches of two different mixes are made to the same consistency that different water-cement ratios are required, in which case the strengths are different.

Fineness Modulus.—Abrams introduced another new term "fineness modulus," which is used in designing concrete mixes. The fineness modulus of an aggregate is calculated by dividing by 100 the sum of the total percentages in the sieve analysis retained on nine designated sieves. These sieves are the Nos. 100, 50, 30, 16, 8, 4, and the ⅜ in., ¾ in., and 1½ in. sieves of the US series.[1] In making a sieve analysis for the purpose of calculating fineness modulus, total percentages retained are used, as explained in the sieve-analysis test. It is important that there be a value for all nine sieves and no values for any other sieves. In

[1] Abrams used the Tyler standard-series sieves when he did his work. Three of these sieves now have different numbers in the US series. They are Nos. 48, 28, and 14.

computing fineness-modulus values for coarse aggregate, the total percentages retained on the smaller sized sieves are often incorrectly omitted.

The same value of fineness modulus may be obtained from a number of different gradations. In general, however, a small value indicates a fine aggregate and a large value a coarse aggregate. Sands commonly run from about 1.50 to 3.75 and pebbles from about 5.00 to 8.00 with 9.00 as the maximum when all the material is larger than the 1½-in. sieve. Combinations of fine and coarse aggregates have intermediate values.

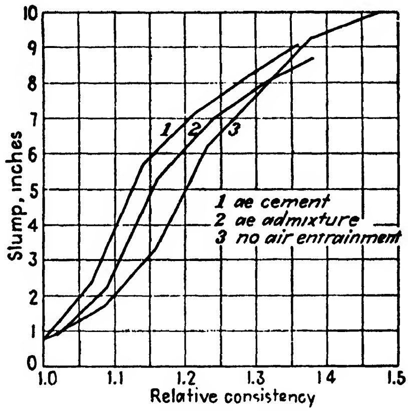


FIG. 5-4.—Relationship between slump and relative consistency as developed from Test 31 by several of author's classes. For relative consistencies other than 1.00, values of slump vary with materials and mixes. User should not necessarily expect to check these curves.

Normal and Relative Consistencies.—Concrete having a slump-test value between ½ and 1 in. was defined by Abrams as being of normal consistency. The term "relative consistency" indicates the relationship between the water content of any concrete and the water content of the same mix of the same materials at normal consistency. Concrete of normal consistency has, then, a relative consistency of 1.00.

Abrams has given no information concerning the slump values for any relative consistency other than 1.00 because there is no dependable relationship. With one set of materials and mix, a relative consistency of 1.10 will produce a certain slump, while a change of any or all the materials, or the mix, may produce a different slump.

Test 31 is a concrete project in which the mix is held constant and the amount of mixing water varied. By plotting slump against water-cement ratio, it is possible to secure the water-cement ratio for a slump of ¾ in. (median of the range ½ to 1 in.). With the water content at normal consistency, the relative-consistency values of the other batches can be calculated and plotted. Several such curves are plotted in Fig. 5-4.

Examp'e of Use of Abrams' Method of Proportioning.—A summary of the procedure to be followed in designing a mix according to the method proposed by Abrams will now be given, together with an illustration.

1. The first step is to decide on the compressive strength and the relative consistency. If a water-cement ratio is selected from Table 6-1, then the corresponding strength on Abrams' curve, Fig. 5-3, must be secured. To secure a relative-consistency value, select a slump value from Table 6-2, and then estimate the corresponding relative-consistency value. Figure 5-4 may be of some help but should not be relied upon completely. When the designed mix is actually made, the slump may be different, which will require the redesigning of the mix. Selections for the illustration are

$$\text{Strength} = 2{,}500 \text{ p.s.i.}$$
$$\text{Relative consistency} = 1.2$$

2. Make sieve analyses of the fine and coarse aggregates, as outlined in Test 17. Results for illustration are given in Table 5-3.

Fineness moduli are then computed for each aggregate. Illustration values are

$$\text{Sand} = 3.02$$
$$\text{Pebbles} = 7.43$$

TABLE 5-3.—SIEVE-ANALYSIS VALUES FOR ILLUSTRATIVE PROBLEM FOR ABRAMS' DESIGN METHOD

Sieves	Total percentages retained	
	Sand	Pebbles
1½ in.	0	3
¾ in.	0	50
⅜ in.	0	90
No. 4	2	100
No. 8	20	100
No. 16	40	100
No. 30	68	100
No. 50	80	100
No. 100	92	100
Fineness moduli	3.02	7.43

3. Determine maximum size of the coarse aggregate from the sieve-analysis data according to the rule: "The maximum size of aggregate is designated as the smallest sieve having a value between 0 and 15 per cent retained." Our value is 1.5 in.

4. Estimate a mix that is likely to give the correct strength at the desired consistency. It is not possible to solve directly for the answer. Let us try a 1:5

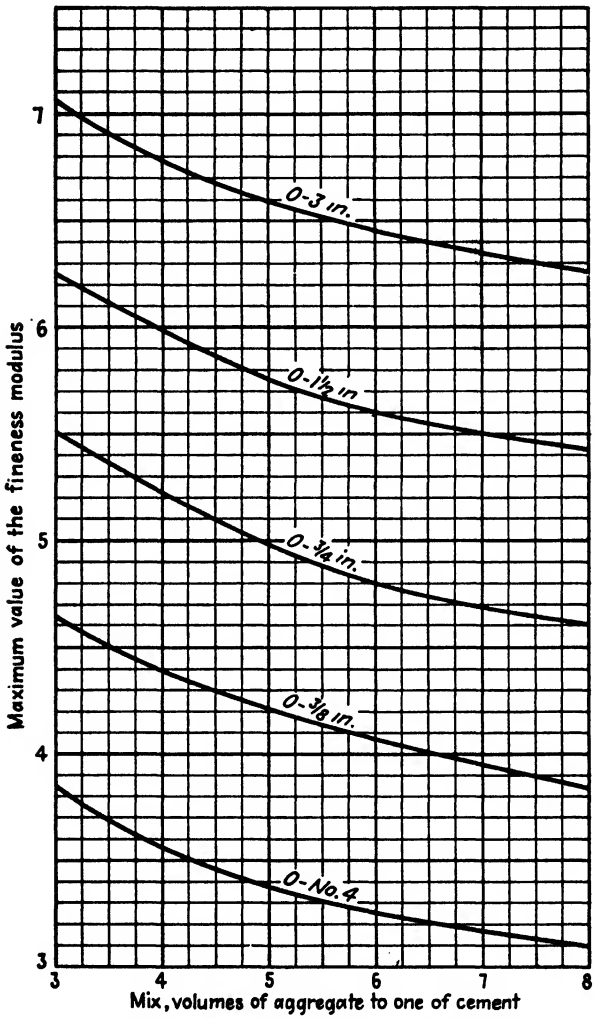


FIG. 5-5.—Chart giving maximum permissible values of fineness moduli recommended by Abrams. Curves are for rounded particles, such as sand and pebbles. Only a portion of Abrams' chart is reproduced here. For other materials and balance of chart see *Lewis Institute Bull.* 1.

mix. At this point we consider the aggregate as a combination of the fine and coarse aggregate. Later, the combination will be separated into fine and coarse.

5. Figure 5-5 is a diagram that gives the maximum values of the fineness moduli of combinations of fine and coarse aggregate, according to tests made at Lewis

Institute and the judgment of Abrams. For any given fine and coarse aggregates (fineness moduli known) the selection of the fineness modulus of the combination of the two fixes the proportions of each. The maximum permissible value of the fineness modulus of the combination depends upon the maximum size of the aggregate and the ratio of cement to combined aggregate.

Illustration.—The maximum size of our aggregate is 1½ in.; therefore, we find the curve labeled "0–1½ in." A mix, 5 parts of aggregate to 1 of cement, has been

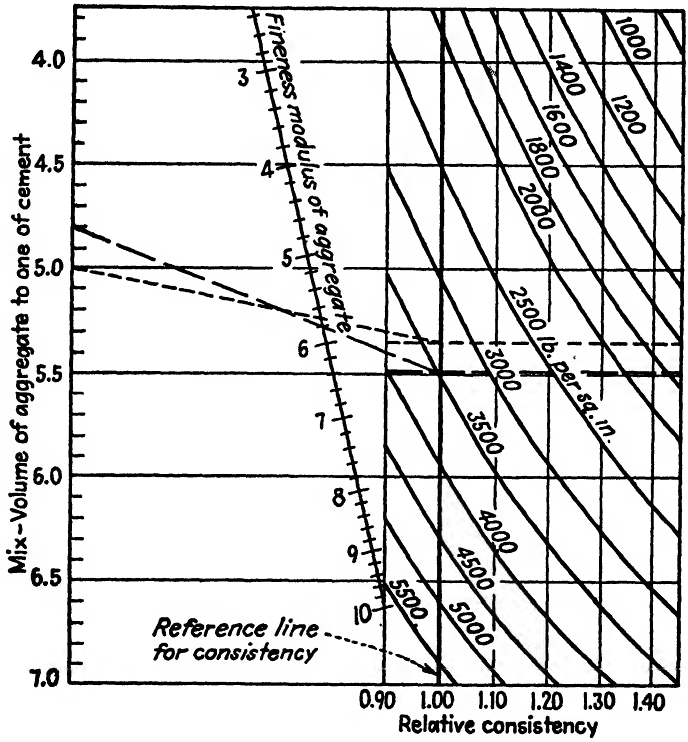


FIG. 5-6.—Abrams' nomographic chart for the design of concrete mixes. It is based on the strengths given in Fig. 5-3 and ties in with Fig. 5-5. Only a portion of the original chart is reproduced here.

estimated (step 4); therefore, we find the figure 5 at the bottom of the graph, follow up the vertical line to the curve—0–1½ in.—and then horizontally to the left to read the maximum, permissible value of the fineness modulus, which in our problem is 5.75.

6. Now we check in Fig. 5-6 to see if our estimate of a mix is correct. Place straightedge on the mix by volume (5) at the left and on the fineness modulus of aggregate (5.75) on the diagonal line, and note the value of the strength on the vertical line at a relative consistency of 1.0. Lay the straightedge now perpendicular to the vertical lines, and read the strength at the relative consistency of 1.2. The strength is 2,350 p.s.i., which is slightly low.

7. Since the strength is a little low, another estimate of mix should be made and the steps repeated. Let us try a 1:4.8 mix, for which the maximum permissible value of fineness modulus (from Fig. 5-5) is 5.80. Checking in Fig. 5-6, we find this estimate satisfactory.

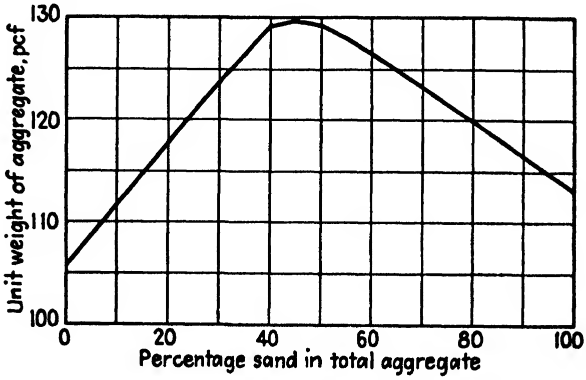


FIG. 5-7.—Typical curve showing the relationship between unit weight of aggregate and percentage of sand in total aggregate. Results from student work at the University of Illinois, using pebbles with a maximum size of $1\frac{1}{2}$ in. and a blended sand. Fineness moduli (F.M.) of pebbles-7.09 and F.M. of sand-2.48. Peak of curve will occur at different percentages of sand and other unit weights, depending upon the aggregates used.

8. The percentage of fine aggregate by weight is computed from the formula

$$P = \frac{A - B}{A - C} 100 \tag{5-2}$$

where P = percentage of fine aggregate
A = fineness modulus of coarse aggregate
B = fineness modulus of combined aggregate
C = fineness modulus of fine aggregate

The percentage of coarse aggregate is equal to 100 minus the percentage of fine aggregate.

$$P = \frac{7.43 - 5.80}{7.43 - 3.02} 100 = \frac{1.63}{4.41} 100 = 37 \text{ per cent}$$

The percentage of coarse aggregate is 100 − 37 = 63.

9. Make unit-weight tests on the fine aggregate and the coarse aggregate separately, as outlined in Test 12, and then on the combination of fine and coarse aggregate figured in step 8, as outlined in Test 13. The curve shown in Fig. 5-7 is typical of the relationship between unit weight and percentage of sand in total aggregate.

Values to use in illustration:

Sand = 108.4 lb. per cu. ft.
Pebbles = 104.8 lb. per cu. ft.

Combination 37 per cent sand, 63 per cent pebbles = 125.0 lb. per cu. ft. (These values are not taken from the curve in Fig. 5-7.)

10. We now have the necessary information to figure proportions and quantities of cement and aggregates for a batch of concrete. A 1-bag batch will be used.

a. Volume of combined aggregate per bag of cement	= 4.8 cu. ft.
b. Weight of combined aggregate per bag of cement, 4.8 × 125.0	= 600 lb.
c. Weight of sand per bag of cement, 0.37 × 600	= 222 lb.
d. Weight of pebbles per bag of cement, 0.63 × 600	= 378 lb.
e. Volume of sand per bag of cement, 222/108.4	= 2.05 cu. ft.
f. Volume of pebbles per bag of cement, 378/104.8	= 3.61 cu. ft.
g. Proportion by volume	= 1 : 2.05 : 3.61
h. Proportion by weight	= 1 : 2.36 : 4.02

Proportions are quite often given today by weight, or the weights of fine and coarse aggregate per bag of cement (values *c* and *d* above) are used.

11. The final step is to determine the quantity of mixing water. Abrams' water-cement ratio can be taken directly from the curve in Fig. 5-3, if it was not selected originally as one of the beginning items.

The water-cement ratio for a strength of 2,500 p.s.i. taken from Fig. 5-3 is

Abrams' value = 0.885
In gal. per bag of cement = 6.64

WORK OF EDWARDS AND YOUNG

During 1918, L. N. Edwards, then bridge engineer for the city of Toronto, Canada, published[1] the results of some tests he had made to develop information (1) relating to the average surface areas of sand and stone aggregates and (2) concerning the practicability of proportioning cement and aggregate on the basis of the surface area of the latter.

The first problem was to determine the approximate, average surface areas of the various sizes of aggregate. Small quantities of each size of aggregate were weighed out, the number of particles counted, the average volume of particles determined, and then the surface area of a sphere of an equivalent volume computed. In Table 5-4 are given the surface areas in square feet per 100 lb. of aggregate for a series of size ranges. Using these surface-area values and fractional percentages from the sieve analysis, the surface area of 100 lb. of aggregate is computed by multiplying each surface area by the percentage (expressed as a decimal) for each fraction and adding the results. The fractional percentages must add up to 100.

Edwards came to the conclusion that it was possible to proportion cement and aggregates on the basis of the surface area of the aggregate.

[1] EDWARDS, L. N., "Proportioning the Materials of Mortars and Concretes by Surface Area of the Aggregates," *Proc. A.S.T.M.*, Vol. 18, Part II, pp. 235–302.

Aggregate must, however, be uniform in quality and be graded. The method would not work for unusual gradations of aggregate or for non-uniform materials.

R. B. Young has made a practical application of the ideas of both Edwards and Abrams in connection with hydroelectric power development in the province of Ontario, Canada.[1] For the materials used satisfactory results were secured. Young accepts the water-cement-ratio idea of Abrams but prefers to determine the amount of aggregate necessary on the basis of surface area rather than fineness modulus.

Prior to the beginning of construction Young would establish experimentally the relationship between strength and water-cement ratio, and

TABLE 5-4.—TABLE GIVING SURFACE AREAS IN SQUARE FEET PER 100 POUNDS OF AGGREGATE FOR VARIOUS SIZE RANGES*

Fraction		Surface area, sq. ft. per 100 lb.	
Passing	Retained	Sand	Crushed stone
65	150	6,975	
35	65	3,490	
20	35	1,744	
10	20	875	
6	10	437	
¼ in.	6	255	
½ in.	¼ in.	130	163
¾ in.	½ in.	74.6	124
1½ in.	¾ in.	42.7	62
2½ in.	1½ in.	23.6	36

* From YOUNG, R. B., *Eng. News-Record*, Vol. 84, pp. 33–37 (Jan. 1, 1920).

between strength and cement content, expressed in pounds per 100 sq. ft. of surface area. The first step in these experimental studies would be to determine the mechanical analysis of the combined fine and coarse aggregates, which gave the most economical mixture, considering workability and economy of materials. "The most economical mixture," according to Young, "is one containing the lowest surface area per cubic foot of material, which can be successfully handled and placed."

With the combination of fine and coarse aggregate determined above, a series of tests would be made in which cement was proportioned according to surface area of aggregate, using from 4 to 6 quantities of cement per 100 sq. ft. of surface area. Water would be added as needed

[1] YOUNG, R. B., "Mixing Concrete by Surface Areas on Actual Work," *Eng. News-Record*, Vol. 84, pp. 33–37 (Jan. 1, 1920).

to give all mixtures the desired test consistency. A typical set of results is given in Fig. 5-8.

Allowing from 300 to 500 p.s.i. to take care of field conditions, cement contents and water-cement ratios would be established for four classes of concrete. Such a set of values is shown in Table 5-5.

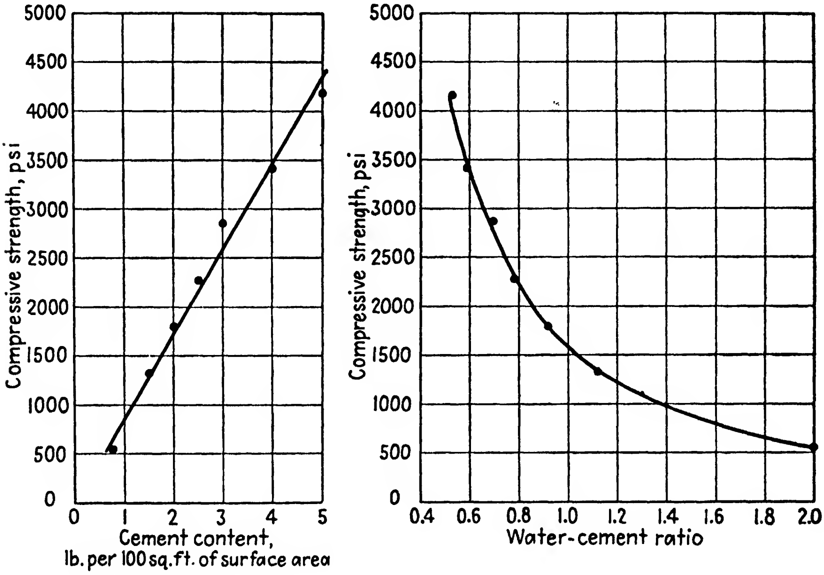


FIG. 5-8.—Typical curves showing the relationship between compressive strength and (1) cement content, in pound per 100 sq. ft. of surface area, and (2) Abrams' water-cement ratio, (volume of water to same volume of cement) for some consistency which Young called "test consistency."

In the field, sieve analyses of the aggregates would be made and the surface area calculated for enough aggregate to make a batch of concrete. Values of cement content and water-cement ratio for the class of concrete desired would be taken from Table 5-5 and necessary amounts figured to go with the amount of aggregate to be used. If the test consistency as determined in the laboratory was not suitable for the job, amounts of both water and cement would be increased or decreased as necessary, but always holding the ratio of water to cement the same as originally determined.

The surface-area method has not found much direct application in actual work since surface areas must be calculated from sieve-analysis data, on the assumption that the aggregate particles have the same surface area as spheres of equal volume, a calculation rather involved for field use. It is worth while, however, to remember that the fine particles, having large surface areas per unit of weight, require the larger amounts of cement paste to coat their surfaces.

TABLE 5-5.—TABLE SHOWING STRENGTHS, CEMENT CONTENTS, AND WATER-CEMENT RATIOS FOR FOUR CLASSES OF CONCRETE FOR USE IN DESIGNING A MIX BY THE SURFACE-AREA METHOD*

Class	Compressive strength, p.s.i.	Cement content, lb. per 100 sq. ft. of surface area	Water-cement ratio
A	2,500	3.18	0.68–0.74
B	2,000	2.58	0.78–0.86
C	1,500	2.08	0.91–1.04
D	1,000	1.48	1.14–1.37

* From YOUNG, R. B., *Eng. News-Record*, Vol. 84, pp. 33–37 (Jan. 1, 1920).

TALBOT-RICHART STUDIES

Professors Arthur N. Talbot and Frank E. Richart published in 1922 a method of analyzing the composition of freshly made concrete, together with suggestions for a method of proportioning the various materials used in concrete.[1]

The volume of any batch of concrete is equal to the sum of the volumes of the solid particles of cement and aggregates, plus the volume of voids. The volume of the voids is equal to the volume of mixing water plus a small volume of air voids. Because the volume of the air voids varies, it is necessary to make determinations of their amount. Otherwise, the composition of the concrete could be calculated from the weights of materials used and their specific gravities.

The nomenclature adopted by Talbot and Richart has been widely followed and should be learned.

a = volume of the solids of fine aggregate in a unit volume of freshly made concrete

b = volume of the solids of coarse aggregate in a unit volume of freshly made concrete

c = volume, solids of cement in unit volume of freshly made concrete

v = volume of the voids in a unit volume of freshly made concrete

w = volume of the water in a unit volume of freshly made concrete

[1] "The Strength of Concrete—Its Relation to the Cement, Aggregate, and Water," *Univ. Illinois Eng. Expt. Sta. Bull.* 137.

From the definitions above it follows that

$$a + b + c + v = 1 \tag{5-3}$$

Cement-space Ratio.—Concrete may be thought of as a combination of a cement paste and aggregate. In the above equation $v + c$ represents the volume of the cement paste in a unit volume of freshly made concrete. The expression $c/(v + c)$ may be used to represent the proportion of cement in the cement paste. Talbot and Richart named this the cement-space ratio.

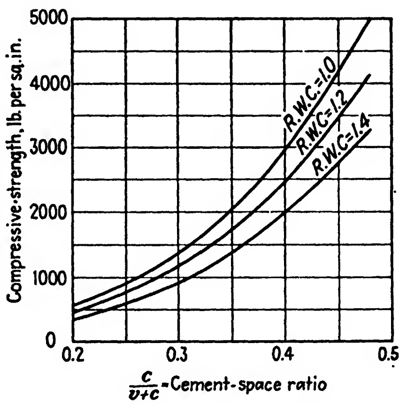


FIG. 5-9.—Relationship between compressive strength and cement-space ratio. Data taken from Talbot-Richart bulletin. Strengths are much too low for today's type 1 cement. Concrete of a consistency represented by the R.W.C. 1.0 curve is too dry to be used practically. See Fig. 6-3 for a more recent curve.

Relationship between Compressive Strength and Cement-space Ratio.—There is a relationship between compressive strength and cement-space ratio, the larger values of cement-space ratio giving the greater concrete strengths. The curves shown in Fig. 5-9 were prepared from data given in the Talbot-Richart bulletin. The strengths shown are low for cements of the 1920 era and, of course, are much too low for the type 1 cement of today.

The Talbot-Richart tests indicated that there was an appreciable difference in strength for the same cement-space ratio, when the consistency of the concrete varied. The concrete producing the values for the curve labeled "R.W.C. 1.0" was very dry (0-in. slump) and was very difficult to mold into the test cylinders. From a practical standpoint it was too dry to use. The range between the two curves labeled

"R.W.C. 1.2" and "R.W.C. 1.4" is the practical range. A single curve representing the average of this range is considered today to be of sufficient accuracy, with no distinction being made for consistency.

Basic and Relative Water Contents.—Concrete may also be considered as a combination of a mortar and a coarse aggregate, the mortar being composed of cement, fine aggregate, and voids. Whenever water is mixed in increasing amounts with the dry mortar materials, there is at first an increase in the volume of the mortar, which is greater than the volume of the water added; then there is a decrease in volume, followed by an increase again (see Fig. 5-10). The water content that produces the minimum volume of mortar is known as basic water content.

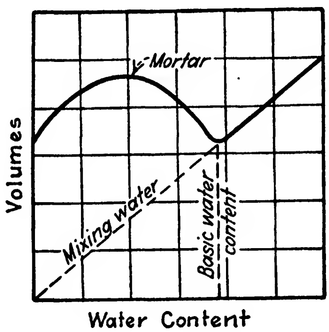


FIG. 5-10.—Typical curve showing the relationship between water content of mortars and the volume of the mortar. The voids curve has the same general shape since the voids only are varying as the volume changes.

Since the volume of the cement and fine aggregate particles remains the same as the water is increased, the change in the volume of the mortar represents the change in volume of the voids. Basic water content is normally defined as that water content which produces minimum voids in the mortar.

Since mortars and concretes may be made with different amounts of mixing water, it is necessary to have a term indicating the relative amount of water used in terms of some basic value that can be readily determined. This basic amount of water Talbot and Richart named basic water content and assigned a relative water content value of 1.00 to it.

When the term "relative water content" is applied to the concrete, it refers to the relative water content of the mortar used in the concrete. For illustration assume that (1) the volume of the mortar in 1 cu. ft. of concrete is 0.6 cu. ft.; (2) the volume of the water in 1 cu. ft. of concrete is 0.15 cu. ft.; and (3) basic water content of the mortar as determined by a mortar-voids test is 0.208 cu. ft. per cu. ft. of mortar. Since basic water content is expressed in terms of 1 cu. ft. of mortar, the water content of the mortar in the concrete must be in terms of 1 cu. ft. of mortar. If 0.6 cu. ft. of mortar has a water content of 0.15 cu. ft., then 1.0 cu. ft. would have 0.25 cu. ft. of water. Dividing 0.25 cu. ft. by 0.208 cu. ft. gives a relative water content of 1.20.

Relationship between Slump and Relative Water Content.—Talbot and Richart did not publish slump-test values for any of the concretes reported in their bulletin. Slump-test values are used quite generally to indicate consistency, and anyone designing a concrete mix will think first in terms of slump. While slump values for one set of materials and conditions would not be directly applicable to other materials and conditions, it is always helpful as a starter to know what has happened in other similar situations. Based on the Talbot-Richart technique for the mortar-voids test, a relative water content of 1.2 is about the minimum that can be used in any concrete.

Mortar-voids Test.—As previously mentioned, the concrete may be considered as a combination of mortar and a coarse aggregate, with the coarse aggregate acting as a filler for the mortar. In designing a mix, then, it becomes necessary to have data on the composition of the mortar that might be used in the concrete.

Talbot and Richart proposed a procedure that has become known as the mortar-voids test. Three to five combinations of cement and fine aggregate are used, the proportions being expressed by the ratio a_m/c_m, where

a_m = volume of the solids of fine aggregate per unit volume of freshly made mortar

c_m = volume of the solids of cement per unit volume of freshly made mortar

Ratios suggested by Talbot and Richart are 1, 2, 3.5, and 5. For each a_m/c_m value, the basic water content is determined by actual test. The cement and fine aggregate for each ratio are mixed with varying quantities of water until the amount producing basic water content is determined, as outlined in Test 28. After basic water content is determined, other water contents are used as may be necessary. Talbot and Richart suggest 1.2 and 1.4.

The composition of the mortar is figured for each a_m/c_m ratio at basic water content and at the desired relative consistencies. Curves plotted are similar to those shown in Fig. 5-11.

Before going ahead with the design of a mix, some consideration must be given to the coarse aggregate. Since coarse aggregate is considered a filler in the mortar, it is logical that the amount used should be as great as conditions will permit. It should be remembered that too much will make unsatisfactory concrete. As an aid in determining the amount

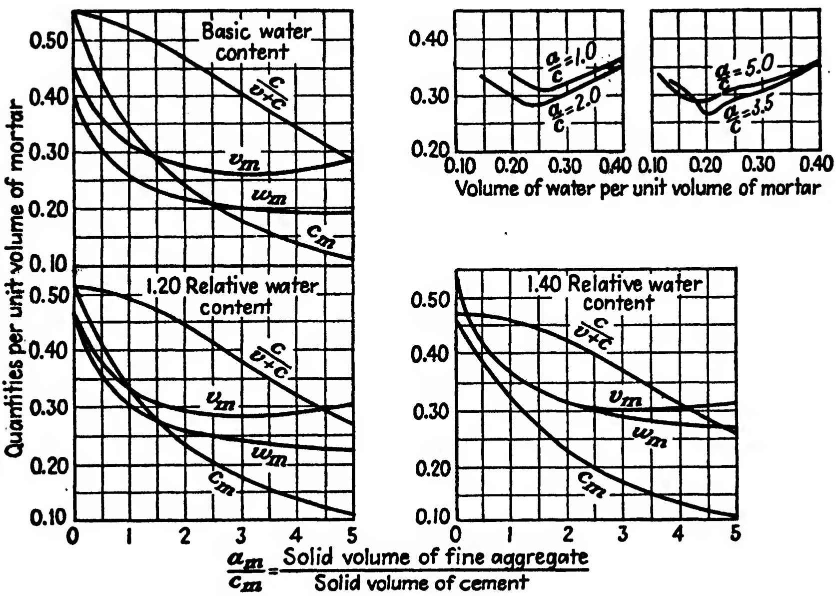


FIG. 5-11.—Characteristic curves for a coarse sand. From the Talbot-Richart bulletin. From a practical standpoint there is no need to plot the curves at basic water content, since concrete of that consistency is too dry to use in construction.

of coarse aggregate, Talbot and Richart proposed the use of a value known as b_0 and a ratio known as b/b_0.

b_0 Value.—The proportion of a unit volume of coarse aggregate which is occupied by the solid particles is known as the b_0 value. It is calculated from

$$b_0 = \frac{\text{unit weight of coarse aggregate, lb. per cu. ft.}}{G_b \times \text{unit weight of water, lb. per cu. ft.}}$$

where G_b is the specific gravity of the coarse aggregate, saturated surface-dry basis. b_0 may also be considered as 1 minus the proportion of voids in the coarse aggregate.

b/b_0 Ratio.—The ratio of the solid volume of coarse-aggregate particles per unit volume of freshly made concrete b to the ratio of the solid volume of the coarse aggregate particles per unit volume of coarse aggregate b_0 is known as the b/b_0 ratio. If the volume of the mortar used in making a given volume of concrete were exactly equal to the volume of the voids in the coarse aggregate, then the b/b_0 ratio would be exactly 1.00. Since it is not possible to do this, it is necessary to find out how close to 1.00 a person may come and still make satisfactory concrete with the materials available and under the job conditions that will prevail.

In determining the proper amount of coarse aggregate, batches of concrete can be made with certain factors remaining constant, such as consistency, cement factor, water-cement ratio, or aggregate-cement ratio, and varying the percentages of the aggregate that are coarse and fine. As the percentage of the aggregate that is coarse is increased, there will be some percentage above which the concrete cannot be handled satisfactorily. Values of b and b/b_0 can be computed for this percentage.

Talbot and Richart suggest values of b/b_0 of from 0.65 to 0.75. Maximum values of b will be about 0.40 and 0.45 for crushed stone and pebbles, respectively. Values of b_0 for the crushed stone are normally lower than those for pebbles, and thus it is not necessary to make a difference in the b/b_0 value for each type of coarse aggregate used.

Example of the Talbot-Richart Method.—1. Select the strength and the consistency of the concrete.

$$\text{Strength} = 2{,}500 \text{ p.s.i.}$$
$$\text{Consistency} = \text{R.W.C. } 1.2$$

2. Make a series of mortar-voids determinations as outlined in detail in Test 28, and plot the results as shown in Fig. 5-11.

3. Select from Fig. 5-9 (or from curves plotted from data secured from tests of the materials to be used) the cement-space ratio, $c/(v+c)$, which gives the desired strength at the desired consistency.

$$\frac{c}{v+c} = 0.400$$

4. From Fig. 5-11 determine the value of a_m/c_m, which for a relative water content of 1.2 has a $c/(v+c)$ value of 0.400.

$$\frac{a_m}{c_m} = 2.75$$

Note also the values of w_m and v_m corresponding to $c/(v+c)$ of 0.400.

$$w_m = 0.250$$
$$v_m = 0.290$$

5. Choose the value of b to be used in the concrete. Assume that the coarse aggregate available has a specific-gravity value of 2.65 and a unit weight of 104.8 lb. per cu. ft. The b_0 value for this coarse aggregate is 0.634. Assume also that a b/b_0 ratio of 0.710 is the maximum that can be used. Solving for b, a value of 0.451 is secured.

6. From the value of v_m found in step 4, compute the value of v from

$$\begin{aligned} v &= v_m(1 - b) \qquad (5\text{-}4) \\ &= 0.290(1 - 0.451) \\ &= 0.159 \end{aligned}$$

7. Solve now for values of a and c, using equation 5-3 and the a_m/c_m ratio from step 4.

$$\begin{aligned} a + c &= 1 - b - v \\ &= 1 - 0.451 - 0.159 \\ &= 0.390 \\ a/c = a_m/c_m &= 2.75 \\ a &= 0.286 \\ c &= 0.104 \end{aligned}$$

The water content of the concrete w is found from the water content of the mortar w_m

$$\begin{aligned} w &= w_m(1-b) \qquad (5\text{-}5) \\ &= 0.250(1 - 0.451) \\ &= 0.137 \end{aligned}$$

8. The proportion by solid volumes is

0.104 : 0.286 : 0.451

9. Determine the unit weights of the fine aggregate and the coarse aggregate as outlined in Test 12. Cement is always taken as 94 lb. per cu. ft. Assume values of 104.8 and 108.4 lb. per cu. ft. for the fine and coarse aggregates, respectively.

10. Compute the proportion of a cubic foot of cement which is occupied by the solid particles in the same manner as outlined for computing b_0. Do the same for the fine aggregate. We will call these values c_0 and a_0, respectively, since they correspond to the b_0 value for the coarse aggregate.

$$c_0 = \frac{94}{3.15 \times 62.355} = 0.479$$

$$a_0 = \frac{108.4}{2.67 \times 62.355} = 0.651$$

11. Compute the volumes of materials necessary to make a unit volume of concrete as follows:

$$\text{Volume of cement} = c/c_0 = \frac{0.104}{0.479} = 0.217$$

$$\text{Volume of fine aggregate} = a/a_0 = \frac{0.286}{0.651} = 0.439$$

$$\text{Volume of coarse aggregate} = b/b_0 = \frac{0.451}{0.634} = 0.710$$

If the unit volume of the concrete is 1 cu. yd., then the above values are in cubic yards. The cement value can be changed to bags by multiplying by 27, one bag of cement being considered as 1 cu. ft.

$$\text{Volume of cement} = 0.217 \times 27 = 5.86 \text{ bags}$$

12. The porportion by volume is

$$0.217 : 0.439 : 0.710$$
$$1 : 2.02 : 3.27$$

13. The weights of materials necessary to make a cubic yard of concrete are computed as follows:

$$\text{Cement} = 0.217 \times 27 \times 94 = 551 \text{ lb.}$$
$$\text{Fine aggregate} = 0.439 \times 27 \times 108.4 = 1{,}285 \text{ lb.}$$
$$\text{Coarse aggregate} = 0.710 \times 27 \times 104.8 = 2{,}009 \text{ lb.}$$

14. The proportion on a weight basis is

$$551 : 1{,}285 : 2{,}009$$
$$1 : 2.33 : 3.65$$

The aggregate-cement ratio is

$$\frac{1{,}285 + 2{,}009}{551} = 5.98$$

The percentage of the aggregate which is fine aggregate is

$$\frac{1{,}285}{1{,}285 + 2{,}009} 100 = 39.0 \text{ per cent}$$

15. The water content of a cubic yard of concrete in gallons is found as follows:

$$w \times 27 \times 7\tfrac{1}{2} = 0.137 \times 27 \times 7\tfrac{1}{2}$$
$$= 27.74 \text{ gal.}$$

The water-cement ratio in gallons per bag is

$$\frac{27.74}{5.86} = 4.73$$

The water-cement ratio as originally proposed by Abrams is

$$\frac{0.137}{0.217} = 0.630$$

With the information now available, concrete can be made under job conditions. It is quite possible that some adjustments in the proportions will need to be made. If the concrete is of too dry a consistency, the mix should be redesigned at a higher relative water content. If there appears to be too much coarse aggregate, the mix is redesigned using a smaller value of b/b_0. If strength tests show the strength is not the amount anticipated, the mix can be redesigned using a strength-cement-space ratio curve based on the test results. All the redesigning can be done without additional mortar-voids tests.

TRIAL METHOD

When it is impossible to carry out a series of laboratory tests as previously discussed, the trial method offers a means of approach. It is a method that can be handled by individuals not skilled in the more involved laboratory processes. On the other hand, a person having wide experience in laboratory and field work can design a mix as the work progresses without making any poor-quality concrete and at the same time keeping the cost within reasonable limits. The trial method is suggested in the Portland Cement Association booklet "Design and Control of Concrete Mixtures."

Trial batches are made up following the design of a mix by one of the laboratory methods to see how the concrete appears and acts while being mixed and handled. As a result of these trial batches changes may be made in the proportions. These trial batches should not be confused with the trial method of proportioning.

As in the other procedures the user must make some decisions first concerning what is wanted. In general the user selects a water-cement ratio from Table 6-1 and the slump value from Table 6-2. The trial batches are then used to determine the quantities of fine and coarse aggregate to use.

The water-cement ratio is fixed at a certain number of gallons per bag of cement. The amount of the aggregate per bag of cement controls the slump value to a large degree. The percentage of the aggregate that is fine has an effect too, but it is small in the range of percentages normally used. Two important ideas to remember are (1) the quantity of combined aggregate per bag of cement should be as large as the slump will permit; and (2) in the combined aggregate the percentage of the aggregate that is fine aggregate should be as small as conditions will permit. The slump value selected will control the amount of the combined aggregate. In connection with the percentage of sand, there is little advantage in carrying this value down to the absolute limit, there being little benefit as the limit is approached.

Another idea to remember in connection with the coarse aggregate is that the maximum size should be as large as job conditions will permit. See Table 6-4 for suggested values.

Small trial batches are suggested containing about 1/10 bag of cement and are mixed by hand in a pan or a wheelbarrow. Measurement of materials should be by weight, but if no scales are available, volumetric measurements can be made. Aggregates for these trial batches should be dried in air until no surface moisture can be seen, in order that the determination of the proper amount of mixing water is not made difficult by the presence of some free (mixing) water in the aggregates.

Measure out the exact amount of cement and water for a batch and also quantities of sand and pebbles, which are likely to be larger than necessary. First mix the cement and water thoroughly. Add a small quantity of fine and coarse aggregate and mix. If not stiff enough, add

TABLE 5-6.*—TRIAL MIXTURES TO BE USED AS GUIDES IN THE TRIAL METHOD OF PROPORTIONING

Proportions are given by volume and by weight. Determinations of unit weights are made on the aggregate in a saturated, surface-dry condition as outlined in Test 12.

Water-cement ratio, gal. per bag†	Slump, in.	Suggested trial mixes, maximum size of aggregate			
		1 in.		2 in.	
		By volume	By weight	By volume	By weight
5½	½–1	1:2:3	1:2¼:3½	1:2:3½	1:2¼:4
	3–4	1:1¾:2½	1:2:3	1:1¾:3	1:2:3½
	5–7	1:1½:2	1:1¾:2¼	1:1½:2½	1:1¾:3
6	½–1	1:2¼:3¼	1:2½:3¾	1:2¼:4	1:2½:4½
	3–4	1:2 :3	1:2¼:3½	1:2:3½	1:2¼:4
	5–7	1:1¾:2½	1:2:3	1:1¾:3	1:2:3½
6¾	½–1	1:2½:3½	1:3:4	1:2½:4	1:3:4½
	3–4	1:2¼:3¼	1:2½:3¾	1:2¼:3¾	1:2½:4¼
	5–7	1:2:3	1:2¼:3½	1:2:3½	1:2¼:4
7½	½–1	1:3:4	1:3½:4½	1:3:4¾	1:3½:5½
	3–4	1:2½:3¾	1:3:4¼	1:2½:4¼	1:3 :4¾
	5–7	1:2¼:3½	1:2½:4	1:2¼:3¾	1:2¼:4¼

* Values from Table IV, "Design and Control of Concrete Mixtures," 8th ed., Portland Cement Association.

† Water-cement ratios include surface moisture contained in the aggregate.

more aggregate until the concrete is of the desired stiffness. Measure the quantities of aggregates remaining to determine the quantities used. The question of the ratio of fine aggregate to coarse aggregate is left entirely to the judgment of the operator. If there seems to be an excess of one, another trial batch should be made with a change in the quantities of aggregates. Experience has shown that the volume of the coarse aggregate should be about 1.75 ± 0.25 times the volume of the fine aggregate for average conditions and for hand tamping.

For the benefit of those who may have no idea of the approximate proportions, the values in Table 5-6 will serve as a guide. Tables 5-7, 5-8, and 5-9 give some typical relations between cement content, water-cement ratio, consistency, and proportions of aggregate, which were developed using average materials for some of the more common mixes.

TABLE 5-7.*—TYPICAL RELATIONS BETWEEN QUANTITY OF CEMENT, WATER-CEMENT RATIO, AND CONSISTENCY

		Slumps, in.				
Mix		1:1½:3	1:2:3	1:2:4	1:2½:4	1:3:5
Cement content, bags per cu. yd....		6.4	5.8	5.2	4.75	4.0
Mixing water	6 gal.	7	1	0		
	7 gal.	8½	7	4	½	
	8 gal.	9	8½	7	4	0

* Compiled from a paper by MCMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, Vol. 22, pp. 122–156 (1926). Sand in these tests was graded 0-No. 4 sieve and the pebbles from No. 4 to 1½ in. F.M. = 3.14 and 7.00.

TABLE 5-8.*—TYPICAL RELATIONS BETWEEN PROPORTIONS OF FINE AGGREGATE, CONSISTENCY, AND CEMENT CONTENT

		Slumps, in.			
Mix		1:3:4	1:2½:4	1:2:4	1:1½:4
Cement content, bags per cu. yd..............		4.3	4.6	5.1	5.5
Mixing water	6 gal.			0	1½
	7 gal.		¼	4¼	6
	8 gal.	½	4	7	7½

* Compiled from a paper by MCMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, Vol. 22, pp. 122–156, (1926). Sand in these tests was graded 0-No. 4 sieve and the pebbles from No. 4 to 1½ in. F. M. = 3.14 and 7.00.

In Table 5-7, for instance, for a 1:2:3 mix, if 6 gal. of mixing water per bag of cement are used, the consistency will be such that there probably will be a 1-in. slump; while if 8 gal. are used, the slump may be around 8½ in. On the other hand, 6 gal. of mixing water will not produce workable concrete for the 1:2½:4 and the 1:3:5 mixes. The table is presented merely to show what can be expected under average conditions.

In Table 5-8 the proportion of coarse aggregate is kept constant and that of fine aggregate varied, and in Table 5-9 the proportion of fine aggregate is kept constant and that of coarse aggregate varied. In the first case, for any water-cement ratio, increasing the proportion of fine aggregate produces stiffer consistencies with less cement content. According to the water-cement-ratio strength law the same strength will be secured for any of these mixes using same water content. A 1:2:4 mix—often used on construction—may be handled much easier by increasing the proportion of sand without changing the amount of mixing water. The slump will be less, but the mix with the greater amount of sand will be much more workable.

TABLE 5-9.*—TYPICAL RELATIONS BETWEEN PROPORTION OF COARSE AGGREGATE, CONSISTENCY, AND CEMENT CONTENT

Slumps, in.

Mix		1:2:0	1:2:1	1:2:2	1:2:3	1:2:4	1:2:5
Cement content, bags per cu. yd.....		10.1	8.2	6.8	5.8	5.1	4.5
Mixing water	6 gal.	9	8	4¾	1	0	
	7 gal.	11	10	9	7½	4¼	½
	8 gal.				8½	7	4½

* Compiled from a paper by McMILLAN and WALKER, "Use of Water-cement Specification on the Portland Cement Association Building," *Proc. Am. Concrete Inst.*, Vol. 22, pp. 122–156 (1926). Sand in these tests was graded 0 to No. 4 sieve and the pebbles from No. 4 to 1½ in. F. M. = 3.14 and 7.00.

Table 5-9 indicates how the cement content and consistency change as the proportion of coarse aggregate is varied. For any water content, the addition of coarse aggregate stiffens the mix and, if anything, will make the concrete less workable.

Study Questions

1. What is meant by proportioning? By empirical proportioning?
2. Strength tests were made at what age in the earlier days of concrete work? At what age are they made now?
3. What is meant when the mix is given as 1:2:4? When given as 1:5? Are these by volume or by weight?
4. When did Fuller and Thompson do their research on proportioning? When and where did they make their report?
5. Upon what item did Fuller and Thompson lay great emphasis? In the light of present-day knowledge is this emphasis correct?
6. Give several ideas brought out by Fuller and Thompson which are in use today. How do cement contents of concrete today compare with cement contents when Fuller and Thompson did their work?

7. When did Abrams do his work on proportioning? When and where was it first reported?

8. State Abrams' water-cement-ratio law concerning concrete strengths. Be sure to include all the ideas involved.

9. Define water-cement ratio, fineness modulus, normal consistency, and relative consistency.

10. How did Abrams originally express water-cement ratios? How are they generally given today?

11. What ranges of values may be expected for the following: (*a*) water-cement ratio; (*b*) fineness modulus; (*c*) relative consistency?

12. What has happened to concrete strengths in the interval since Abrams did his original work on proportioning?

13. What was the basis of the work of Edwards and Young?

14. When did Talbot and Richart make their studies on proportioning? When and where were the results published?

15. What do the following letters represent: a, b, c, v, w, b_0? When the subscript m is added to the letters a, c, v, and w, what change is made in their representation? Is water always included in the voids?

16. What is meant by the term "basic water content"? by the term "relative water content"? the term "cement-space ratio"?

17. What is the b/b_0 ratio? What is its purpose?

18. Compare the Talbot-Richart concrete strengths with those reported by Abrams. Is there a significant difference? Which strengths are the lower ones?

19. What is meant by the trial method of proportioning? Who originated it? Regardless of which method may be used in designing a mix, is it generally necessary to do a certain amount of trial proportioning under actual job conditions?

20. Compare the results of the various investigators. Are there any radical conflicts of ideas?

CHAPTER 6

APPLIED PROPORTIONING

In the preceding chapter the various theories of proportioning have been given, and in this chapter will be presented material bearing on the choices of mixes and consistencies, recent strength data, data on aggregates, together with sample computations for figuring quantities of materials per batch and per cubic yard of concrete.

Choice of Strength.—The choice of strength for which the mixture is to be designed will depend to a large extent upon the exposure of the concrete to weathering rather than upon the loads coming on the concrete, since concrete is rarely loaded more than a fraction of its potential compressive strength. Observations have been made of structures in service in order to determine a relationship between some item of concrete design and performance. In Table 6-1 we have the water-cement ratios suggested by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete and by the American Concrete Institute standard on the Design of Concrete Mixes (A.C.I. 613-44) for various classes of structures for various degrees of exposure. Since there is a relationship between water-cement ratio and strength, the choice of a water-cement ratio fixes the strength.

Choice of Consistency.—Consistency is a general term relating to the relative fluidity of the concrete. It is an indication of the amount of mixing water in relation to the amount of dry materials. A dry consistency is one in which the amount of water is small and is barely sufficient to hold the particles of cement and aggregates together. A concrete of stiff consistency has a little more water than one of a dry consistency. A wet consistency is at the other extreme.

Another term often entering into discussions of consistency is "plasticity." The range of plastic consistencies includes those consistencies of concrete that will slowly change shape without crumbling when the forms are removed immediately after placing is completed. In the slump test, values range from about ½ to 4 in.

The terms "workable" and "unworkable" are used to indicate whether or not the concrete can be placed easily in some desired shape or location. A concrete that is described as workable for pavements may be unworkable for reinforced structures, and thus it is necessary to know where a

TABLE 6-1.—WATER-CEMENT RATIOS SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE*

Values are in gallons of mixing water per bag of cement

Type or location of structure	Severe or moderate climate, wide range of temperatures, rain and long freezing spells or frequent freezing and thawing					Mild climate, rain or semiarid rarely snow or frost				
	Thin sections		Moderate sections		Heavy and mass sections	Thin sections		Moderate sections		Heavy and mass sections
	Reinforced	Plain	Reinforced	Plain		Reinforced	Plain	Reinforced	Plain	
A. At the waterline in hydraulic or water-front structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:										
In sea water	5	5½	......	6	......	5	5½	......	6	
In fresh water	5½	6	......	6½	......	5½	6	......	6½	
B. Portions of hydraulic or water-front structures some distance from the waterline, but subject to frequent wetting:										
By sea water	5½	6	......	6	......	5½	6½	......	7	
By fresh water	6	6½	......	6½	......	6	7	......	7½	
C. Ordinary exposed structures, buildings, and portions of bridges not coming under above groups	6	6½	......	7	......	6	7	......	7½	
D Complete continuous submergence:										
In sea water	6	6½	......	7	......	6	6½	. . .	7	
In fresh water	6½	7	......	7½	......	6½	7	......	7½	
E. Concrete deposited through water	†	†	5½	5½	......	†	†	5½	5½	
F. Pavement slabs directly on ground:										
Wearing slabs	5½	6	†	†	......	6	6½	†	†	
Base slabs	6½	7	†	†	......	7	7½	†	†	

G. Special cases:

(a) For concrete exposed to strong sulfate ground waters, or other corrosive liquids or salts, the maximum water-cement ratio should not exceed 5 gal. per bag.

(b) For concrete not exposed to the weather, such as the interior of buildings and portions or structures entirely below ground, no exposure hazard is involved and the water-cement ratio should be selected on the basis of the strength and workability requirements.

* From the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete.

† These sections not practicable for the purpose indicated.

concrete is to be placed before the designation of workability means a great deal.

The slump test[1] is used as a measure of consistency. Whether the concrete is plastic and workable is determined largely by observation. The slump test is not a measure of either plasticity or workability, although when the slump values are at the extremes, it is quite probable that the concrete is neither plastic nor workable. A discussion of plasticity and workability will be found in Chap. 10.

Suggested slump values are given in Table 6-2 for various types of concrete structures.

Present-day Strength Curves.—The curve in Fig. 5-3 of the preceding chapter showing the relation between water-cement ratio and compressive strength was published in 1918. Since then the quality of the

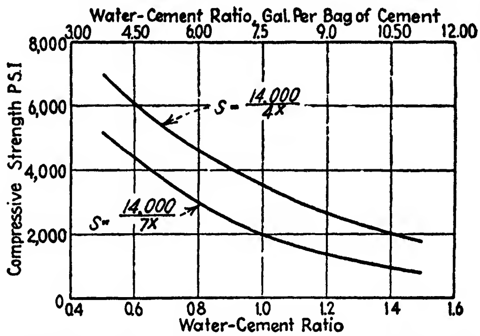


FIG. 6-1.—Showing new and old curves for the relationship between water-cement ratio and compressive strength. The new curve is from test data obtained by the author and the old curve is that of Abrams, published first in 1918.

cement has been improved, and today the strengths are much greater. The upper curve shown in Fig. 6-1 has been prepared from test data obtained by the author. The new curve has the formula $S = 14,000/4^x$. The curve is drawn through the lower range of values plotted and is, therefore, fairly conservative for present-day cements.

In making use of the new water-cement-ratio curve in connection with the Abrams methods of proportioning outlined in the preceding chapter, the following change in procedure must be observed: The strength in step 1 is selected on the basis of present-day cements, but the procedure is carried through for the corresponding strength according to the old curve. For instance, if the strength desired is 3,500 p.s.i., the procedure is followed for a strength of 2,000 p.s.i. on the old curve, both having the

[1] The reader is referred to Chap. 14 for a description of the slump test.

same water-cement ratio. In other words, a concrete designed according to the old curve to produce 2,000 p.s.i., will have a strength of 3,500 p.s.i.

Figure 6-2 shows a curve plotted from the strengths recommended for use in designing a concrete mix, values being taken from the Joint Committee report and the A.C.I. Standard on the design of concrete mixes. These values are above the Abrams curve and below the author's new curve. It is good practice to be conservative in estimating strengths of concrete when actual values are not available.

TABLE 6-2.—RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION*

Type of construction	Slump, in.†	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	4	1
Slabs, beams, and reinforced walls	6	3
Building columns	6	3
Pavements	3	2
Heavy mass construction	3	1

* From "Recommended Practice for the Design of Concrete Mixes," A.C.I. Standard 613-44. Same values appear in the "Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete."

† When high-frequency vibrators are used, the values should be reduced about one-third.

Abrams' curve can be used in estimating present-day strengths at 7 days.

Figure 6-3 shows the results of some student tests at the University of Illinois for the relationship between compressive strength and cement-space ratio at the age of 7 days. The tests were made during the years 1946 to 1947 and represent the work of a large number of individuals. While there is some scattering of points, the curve that might be used to represent 7-day strengths is drawn through the lower fringe of points. It is conservative, therefore, and can be used with safety.

Methods of Expressing Water-cement Rátio.—Abrams defined water-cement ratio as the ratio between the volume of water and the volume of cement, both in the same units. It was not easy for the average man on the job to visualize the ratios. Thus, the practice developed of using the ratio in terms of gallons of water per bag of cement.

Laboratory investigators usually weigh the water, and therefore, they are often inclined to express the ratios in their reports as pounds of water per pound of cement or, reversed, as pounds of cement per pound of water.

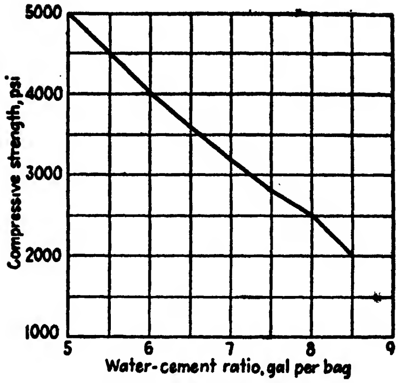


FIG. 6-2.—Relationship between compressive strength and water-cement ratio recommended in the Joint Committee report and the A.C.I. Standard on the design of concrete mixes.

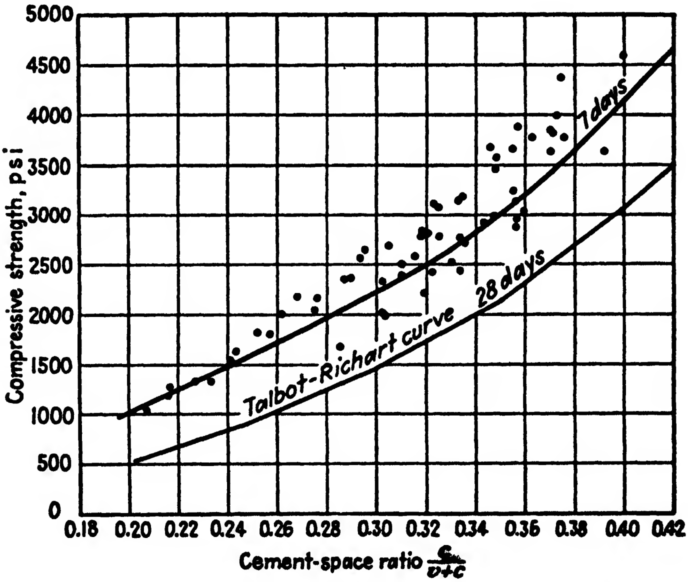


FIG. 6-3.—Results of student tests at University of Illinois showing the relationship between compressive strength and cement-space ratio, at age 7 days. Points plotted represent the average strength of at least 12 cylinders. Air-entraining cement was used in part of the tests and air-entraining admixture in the balance.

On many jobs now the cement is weighed, since weighing equipment is used for the aggregates. In order that the mixer may be used to its full capacity, the amount of the cement in a batch may not be equal to

TABLE 6-3.—RELATIONSHIP BETWEEN VARIOUS METHODS OF INDICATING THE RATIO OF WATER TO CEMENT*

Water-cement ratios				Cement-water ratios
Abrams†	Gal. per bag of cement	Gal. per 100 lb. of cement	By weight	By weight
0.5	3.75	3.989	0.332	3.014
0.6	4.50	4.787	0.398	2.512
0.7	5.25	5.585	0.464	2.153
0.8	6.00	6.383	0.531	1.884
0.9	6.75	7.181	0.597	1.675
1.0	7.50	7.979	0.663	1.507
1.1	8.25	8.777	0.730	1.370
1.2	9.00	9.574	0.796	1.256
1.3	9.75	10.372	0.862	1.160
1.4	10.50	11.170	0.929	1.077
1.5	11.25	11.968	0.995	1.005

* In this table the unit weight of water is taken as 62.355 lb. per cu. ft., the figure given in various A.S.T.M. specifications concerning methods of testing.

† Abrams expressed water-cement ratio as the volume of water to the volume of cement, both expressed in the same units.

TABLE 6-4.—MAXIMUM SIZE OF AGGREGATE RECOMMENDED FOR VARIOUS TYPES OF CONSTRUCTION*

Minimum dimension of section, in.	Maximum size of aggregate, in.,† for:			
	Reinforced walls, beams, and columns	Unreinforced walls	Heavily reinforced slabs	Lightly reinforced or unreinforced slabs
2½–5	½–¾	¾	¾–1	¾–1½
6–11	¾–1½	1½	1½	1½–3
12–29	1½–3	3	1½–3	3
30 or more	1½–3	6	1½–3	3–6

* From Design of Concrete Mixes, A.C.I. Standard 613–44.

† Maximum size of aggregate is based on square-opening sieves.

a whole number of bags. For convenience in such cases it might be better to have the water-cement ratio expressed in gallons per 100 lb. of cement. One of the columns in Table 6-3 contains such values.

Selection of the Maximum Size of Coarse Aggregate.—The maximum size of the coarse aggregate should be as large as practicable and available but should not exceed two-thirds of the minimum clear distance between reinforcement. Limits recommended in the A.C.I. Standard on the Design of Concrete Mixes (A.C.I. 613-44) are given in Table 6-4. In the case of sidewalks and pavements the maximum size is usually limited to about one-fourth the thickness of the slab.

Selection of the Aggregate.—Practice has established the gradation requirements normally required for fine and coarse aggregates. These are given in the Standard Specifications for Concrete Aggregates (A.S.T.M. Designation: C 33) quoted at the end of Chap. 4.

In deciding on the requirements that may be imposed for either fine or coarse aggregates, consideration must be given to availability and cost. There are times when the best quality material is not available in the territory and to set up specification requirements that would require shipping the material a great distance would mean very high costs. In general, concrete is made from aggregates available reasonably close by, and the engineer attempts to produce concrete of the desired quality from these materials.

The fine aggregate should be what is normally called a coarse sand, with 95 to 100 per cent passing the No. 4 sieve. At the other end of the size range, from 10 to 30 per cent should pass the No. 50 sieve and from 2 to 10 per cent pass the No. 100 sieve. It must be kept in mind that sands with smaller maximum sizes have given satisfactory results, as well as coarse sand with small percentages passing the Nos. 50 and 100 sieves.

Practically all fine aggregate used in the United States has been natural sand, but there is no reason why stone sand can not be used satisfactorily. It was used satisfactorily on Norris Dam. Because natural sand exists in abundance throughout the United States and engineers and contractors have had little experience with stone sand, the latter has not found much usage.

The gradation curve for a coarse aggregate should be either a straight line between the diameter for the No. 4 sieve and the maximum diameter selected, or slightly above the straight line. Gradations represented by a curve under the straight line contain too much of the larger sizes. Concretes made from coarse aggregates with such gradations are often difficult to handle. If divided coarse aggregate is used, the percentages for each fraction are selected in such a way that the total percentages passing for the various sieves fall on the gradation curve for the job and materials.

Most specifications permit the use of either naturally rounded or crushed rock as coarse aggregate. Many gravel deposits contain an excess of fine aggregate, and unless crushed stone is available for use as a coarse aggregate, some fine aggregate may have to be wasted. Decision as to which shall be used is often left to the contractor.

Selection of Relative Amounts of Fine and Coarse Aggregates.—It has been well established that the proportion of the aggregate that is coarse should be as great as conditions will permit. The method of arriving at this result varies and depends to a large extent upon the individual responsible.

TABLE 6-5.—RECOMMENDED APPROXIMATE PERCENTAGES OF SANDS*

Maximum size of coarse aggregate in.	Sand, per cent of total aggregate by volume of solids†	
	Rounded coarse aggregate	Angular coarse aggregate
½	51	56
¾	46	51
1	41	46
1½	37	42
2	34	39
3	31	36
6	26	31

* From Design of Concrete Mixes, A.C.I. Standard 613-44.

† When the fine and coarse aggregate both have the same specific gravities, the percentages are by weight of aggregate also.

Fuller and Thompson suggested the idea of an ideal gradation curve and the selection of proportions of each, which would make the actual curve agree with the ideal curve at approximately 40 per cent. Abrams developed the fineness-modulus function and provided a fineness-modulus chart (Fig. 5-5) for use in determining the percentages of fine and coarse aggregate. Talbot and Richart developed the b/b_0 ratio and the Illinois Division of Highways, the mortar factor for determining the amount of coarse aggregate to use. All work toward the same goal—to use as much coarse aggregate as conditions will permit.

Table 6-5 and Fig. 6-4 give the percentages of sand recommended in the Design of Concrete Mixes, A.C.I. Standard 613-44. The values are based on the experiences of the men who prepared the standard. They are intended to be suitable under practically all circumstances; in some cases it may be possible to use lower values.

The percentages given are the percentages based on the volumes of the solid particles—both sand and coarse aggregate. They are given this way in order to take care of differences that may exist in the specific gravities of the two aggregates. In case the specific gravities are the same for the two aggregates, the percentages are by weight also.

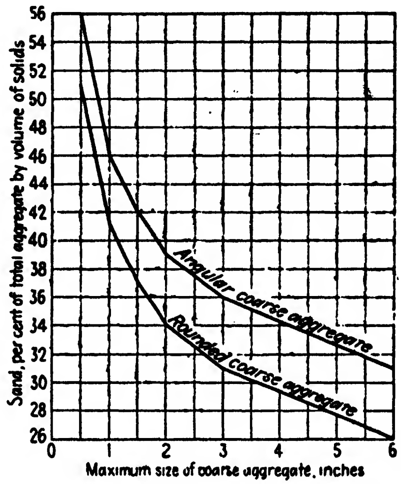


FIG. 6-4.—Graph showing the relationship between percentage of sand in the total aggregate, by volume of the solid particles, and maximum size of the coarse aggregate, for both rounded and angular particles. Data are taken from Table 6-5.

If the Talbot-Richart values of a and b are known, the percentage of sand may be computed from

$$\text{Per cent sand} = \frac{a}{a + b} 100$$

DESIGNING A MIX

In designing a concrete mix for any particular job using certain available materials, several choices must be made based to a large extent on experience. These are strength or water-cement ratio (from Table 6-1) and consistency as expressed by slump. If the choice of a certain strength requires a water-cement ratio greater than shown in Table 6-1, then the use of the water-cement ratio given in Table 6-1 is recommended.

If the mix is to be designed by either the Abrams or the Talbot-Richart method, some way must be devised to secure the corresponding Abrams relative-consistency value or the Talbot-Richart relative water content. Recommended slumps are given in Table 6-2.

Certain tests on the materials available will need to be made. These include specific gravity, sieve analysis, unit weight, absorption, and mortar voids for the Talbot-Richart method.

Abrams' Method.—No important modifications of the Abrams method as outlined in Chap. 5 have been developed. In view of the fact that present-day cements produce greater strengths than did the cements when Abrams did his work, certain details must be followed.

If the concrete is to be designed for a present-day 28-day strength, secure the water-cement ratio from either Fig. 6-1 or Fig. 6-2. Then determine from Fig. 5-3 the Abrams strength for this water-cement ratio and proceed with the design of the mix.

Figure 7-1 shows a family of curves giving the relationship between compressive strength and age for a series of water-cement ratios. This chart may be used for any strength at any age under 28 days to secure the corresponding 28-day strength. Spot in the point for the desired strength and age. If a curve passes through the point, follow it up to 28 days and secure the 28-day strength. If no curve passes through the point, supply a curve that fits the pattern of curves. After the present-day 28-day strength is secured, follow the procedure outlined in the preceding paragraph.

Some engineers consider that the Abrams curve is representative today of our 7-day strengths. In cases in which the strength desired is at 7 days, the design is carried forward using all of Abrams curves and the present-day 7-day strength.

If a water-cement ratio is taken from Table 6-1, the Abrams strength is taken from Fig. 5-3 and the design carried forward as outlined in Chap. 5.

Talbot-Richart Method.—The Talbot-Richart method has been put to use by the Illinois and Michigan highway organizations. The details differ in some respects. Important points are noted in the discussion that follows.

Illinois Method.—The Illinois Division of Highways in 1930 first put into use the Talbot-Richart, mortar-voids method of proportioning, with certain modifications.[1] Main points of difference are:

1. Compaction in the mortar-voids determinations is much greater than in the Talbot-Richart tests. It was found that various individuals could check each other better if each layer in the container was com-

[1] *Manual of Instructions for Proportioning Engineers*, Dept. Public Works and Buildings, Division of Highways.

pacted to the point of incipient appearance of water at the surface of the mortar.

2. Relative water contents used in the field as a result are much higher, ranging from 1.40 to 1.55.

3. A function known as "mortar factor" is substituted for the b/b_0 ratio. Mortar factor is defined as the volume of mortar in the concrete divided by the volume of coarse aggregate (solids + voids) in the same amount of concrete. Mortar factors used are 0.73 and 0.76 for pavement and structural concretes respectively.

Concrete is designed to give minimum strengths of 3,500 p.s.i. in compression and 650 p.s.i. in beams, both at an age of 14 days. To arrive at the cement-space ratios to use in designing mixes, a large number of small mortar cylinders were made with the mortar having relative-water-content values of 1.40, 1.45, 1.50, and 1.55, and tested in compression at 14 days. Strengths were plotted against cement-space ratio, $c/(v+c)$. Four curves were drawn, one for each relative water content.

Experience of the Illinois Division of Highways has shown that to obtain these minimum strengths it is necessary to employ the cement-space ratios in the design of the mortars, which correspond to a compressive strength of 4,500 p.s.i. The cement-space ratios for this strength, taken from the set of curves mentioned above for relative-water-content values of 1.40, 1.45, 1.50, and 1.55 are 0.37, 0.38, 0.39, and 0.40 respectively

Mortar-voids tests are made in the laboratory, using the cement and fine aggregate under consideration, for a_m/c_m ratios of 1 to 5. Basic water content is determined for each ratio, and then tests are made at relative-water-content values of 1.40, 1.45, 1.50, and 1.55. The usual values of $c/v+c$, c_m, v_m, and w_m are computed for these relative-water-content values. Characteristic curves are plotted similar to those shown in Fig. 5-11.

The following quantities per bag of cement are then calculated for each relative-water-content for use in the field: (1) weight of fine aggregate in pounds; (2) volume of mortar produced in cubic feet; and (3) the volume of mixing water in gallons. A curve is then drawn showing the relationship between the volume of mortar and the weight of fine aggregate (see Fig. 6-5 for a typical curve). The variation in the number of gallons of water per bag of cement is small. Therefore, an average value is used in the field for the range of relative-water-content from 1.40 to 1.55. For conditions and materials of Fig. 6-5, the average volume of mixing water is 5.20 gal. per bag of cement.

The amount of coarse aggregate is determined by means of the mortar factor and the percentage of voids in the coarse aggregate. Figure 6-6 has been prepared to give the volume of the solids of coarse aggregate to be used per cubic foot of mortar for a range of percentages of voids and mortar factors. The mortar factor for pavement concrete has been selected as 0.73.

The exact quantities of materials to be used in each batch are determined by the proportioning engineer in the field by what is known as the trial batch method. For example, a first trial might be made with 210 lb. of fine aggregate per bag of cement. From Fig. 6-5 the volume of

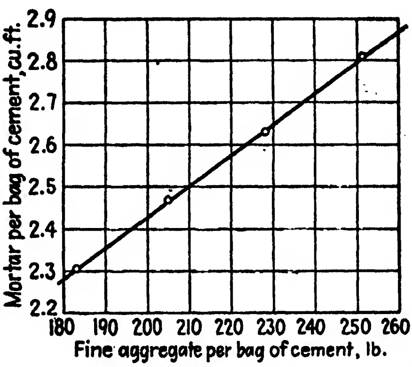


FIG. 6-5.—Typical graph showing the relationship between the volume of mortar and the weight of fine aggregate per bag of cement. Data for calculating the values plotted were secured from the laboratory mortar-voids tests. This curve is to be used by the proportioning engineer in the field to establish the mix. (*From Illinois Manual of Instructions for Proportioning Engineers.*)

the mortar per bag of cement is 2.50 cu. ft. If the percentage of voids in the coarse aggregate is 36, the volume of solids of coarse aggregate per cubic foot of mortar, taken from Fig. 6-6, for a mortar factor of 0.73 is 0.877 cu. ft. The volume of solids of coarse aggregate per bag of cement is

$$2.50 \times 0.877 = 2.1925 \text{ cu. ft.}$$

For a specific gravity of 2.68 for the coarse aggregate, the weight of coarse aggregate is

$$2.1925 \times 2.68 \times 62.355 = 366 \text{ lb.}$$

Quantities of materials per bag of cement are now known, and a trial batch can be made and observed. If the concrete is of too wet a consistency, another trial batch is made using a larger weight of fine aggregate per bag of cement; if the concrete is too dry, less fine aggregate is used. Should it appear that there is too much coarse aggregate in the concrete a higher, mortar-factor value should be selected for another trial batch. A reduction in mortar factor should not, in most cases, be made until some full-size batches have been made and placed.

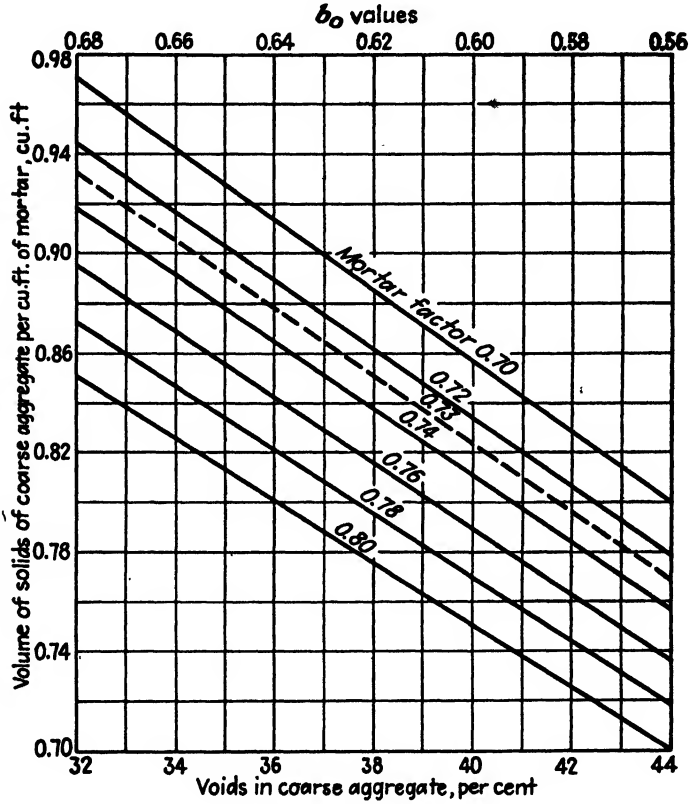


FIG. 6-6.—Chart for use in the field in determining the volume of solids of coarse aggregate per cubic foot of mortar, taken from Fig. 6-5. (*From Illinois Manual of Instructions for Proportioning Engineers.*)

It should be remembered that the above values for quantities of materials are the basic ones and must be adjusted for field use on the basis of absorption and surface moisture determinations, as explained elsewhere in this chapter.

Michigan Method.—The Michigan State Highway Department began in 1928 the use of the mortar-voids method of proportioning their concrete mixes. The mix is designed for a cement content of 5.5 bags per cubic yard of concrete. Before adoption of the use of entrained air in the concrete, the b/b_0 was 0.76 and the relative water content 1.215. With the switch to air-entrained concrete the b/b_0 value was increased to 0.78 and the relative water content reduced to 1.150. Air contents range from 3 to 6 per cent.

Using essentially the same technique for making the test as did Talbot and Richart, Michigan makes mortar-voids tests for a_m/c_m ratios of 2, 3, and 4. Basic water content is determined for each ratio, and then

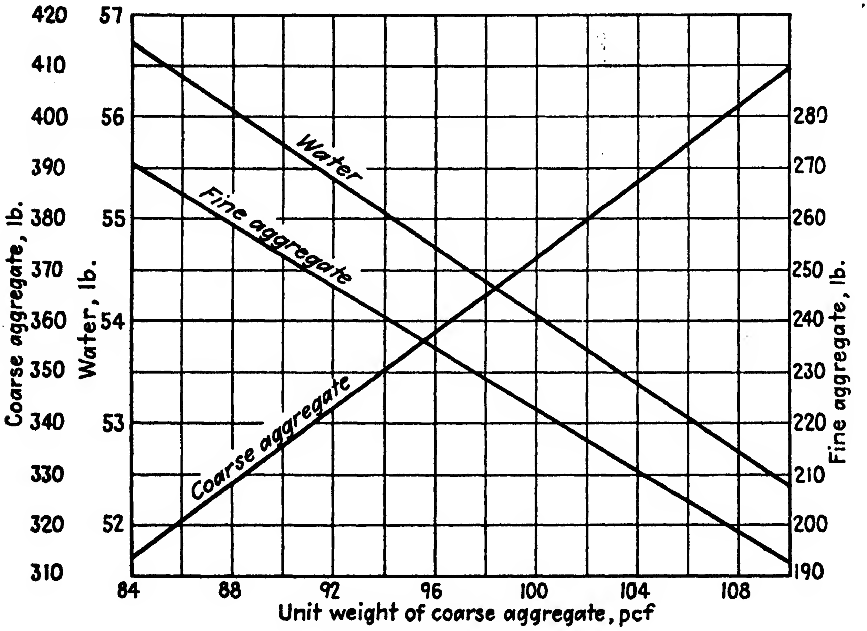


FIG. 6-7.—A typical chart prepared for use in the field by the porportioning engineers of the Michigan State Highway Department. The quantities given are per bag of cement. All weights of aggregate are on an oven-dry basis. The weights of water given include water absorbed by these particular aggregates.

batches are prepared at the desired relative-water-content value and tested. Characteristic curves are plotted only at the desired relative-water-content value, similar to those in Fig. 5-11.

Since Michigan is using a constant cement content of 5.5 bags per cubic yard of concrete, it means that the value of c remains constant for all concrete, except for small variations due to a variation in the specific gravity of the cement. For a specific-gravity value of 3.11 for the cement, the value of c is 0.0987.

On the basis of their experience Michigan has set values of 0.78 and

0.76 for the b/b_0 ratio for concrete with and without entrained air. In effect, this means that in every cubic yard of concrete there will be 0.78 or 0.76 cu. yd. of coarse aggregate. The value of b_0 is calculated for the coarse aggregate, as explained in Chap. 5. Knowing b_0 and the b/b_0 ratio, the value of b can be calculated.

This gives values now for c and b. The corresponding value of c_m can be calculated from the formula

$$c_m = \frac{c}{1-b}$$

As a result of the mortar-voids test, values of c_m, v_m, and w_m have been plotted against the a_m/c_m ratio. The a_m/c_m ratio can be taken from the c_m curve where that value is equal to the one computed above. Values of v_m and w_m can be taken from their curves at the proper a_m/c_m ratio. It is now possible to compute values of a and v.

From this point on, the procedure outlined in Chap. 5 can be followed beginning with step 8.

A chart similar to the one shown in Fig. 6-7 is prepared for the cement and aggregates to be used on a job. The proportioning engineer will make unit-weight tests from time to time on the coarse aggregate as it is received and adjust the batch weights based on values taken from the chart. Since the chart weights are based on oven-dry aggregates, allowance must be made for absorption in figuring the usual saturated surface-dry weights. Allowance must also be made for surface moisture in the aggregates, as explained elsewhere in this chapter.

CALCULATIONS

There is a great variety of calculations that may be made in connection with the design and control of concrete mixes, including the determination of the air content and field batch weights. We are presenting herewith a sample set of calculations for all these items, leaving it to the reader to pick out what he may want at any time.

The layout of calculations is intended to be directly applicable for the calculation of values in connection with Tests 29 to 35 on concrete.

Unit Weight of Concrete, Air-free Basis.—The unit weight of the concrete, in pounds per cubic foot on an air-free basis, can be calculated from the batch weights and the specific gravities of the individual materials. In the case of the aggregates the specific-gravity values to be used are the ones named "bulk specific gravity, saturated, surface-dry basis." The volume of the concrete is taken as the sum of the volumes of solids of cement, fine aggregate, coarse aggregate, and the volume of the mixing water.

The volume of the solids of cement is found by dividing the weight of cement used in the batch in pounds, by the specific gravity of the cement, times the weight of a cubic foot of water.

$$\text{Volume of solids of cement, cu. ft.} = \frac{\text{weight of cement, lb.}}{\text{sp. gr. cement} \times 62.355}$$

The volumes of the solids of fine and coarse aggregates are found in a similar manner. The volume of the mixing water is found in the same manner, using a specific-gravity value of 1. If the amount of mixing water is given in gallons, the volume is found by dividing the volume in gallons by 7½ gal. per cu. ft.

The unit weight of the concrete is calculated by dividing the total weight of all the materials in the batch by the sum of the volumes of all the solids and the volume of the mixing water.

Illustration.—Given the following information concerning a batch of concrete and the materials used in it:

Material	Specific gravity	Unit weight, lb. per cu. ft.	Batch weights, lb.
Cement	3.15	94	650
Sand	2.68	114	1,325
Pebbles	2.64	105	2,550
Water	1	62.355	370

Calculations of volumes of solids of cement and aggregates and the volume of mixing water:

$$\text{Volume of cement solids} = \frac{650}{3.15 \times 62.355} = 3.314 \text{ cu. ft.}$$

$$\text{Volume of sand solids} = \frac{1{,}325}{2.68 \times 62.355} = 7.929 \text{ cu. ft.}$$

$$\text{Volume of pebbles solids} = \frac{2{,}550}{2.64 \times 62.355} = 15.490 \text{ cu. ft.}$$

$$\text{Volume of mixing water} = \frac{370}{1 \times 62.355} = 5.934 \text{ cu. ft.}$$

$$\text{Volume of batch, air-free basis} = 32.667 \text{ cu. ft.}$$

The total weight of all materials in the batch is

650 lb.
1,325 lb.
2,550 lb.
370 lb.
4,895 lb.

The unit weight of the concrete, air-free basis, is

$$\frac{4{,}895 \text{ lb.}}{32.667 \text{ cu. ft.}} = 149.84 \text{ lb. per cu. ft.}$$

Actual Volume of Batch.—The calculation of the actual volume of the batch is based on the actual weights of materials used and the unit weight of the concrete as determined by an actual unit-weight test. When the air content of the concrete is determined by the pressure meter, the actual volume may be calculated from the air-free volume and the percentage of air.

Illustrations.—Continuing with the previous illustration values, assume now the actual unit weight of the concrete is determined as 144 lb. per cu. ft. and the air content as 3.9 per cent.

The actual volume of the batch based on the unit-weight value is

$$\frac{4{,}895 \text{ lb.}}{144.00 \text{ lb. per cu. ft.}} = 33.99 \text{ cu. ft.}$$

The actual volume based on the air content is

$$\frac{32.667 \text{ cu. ft.}}{100 - 3.9}\, 100 = 33.99 \text{ cu. ft.}$$

On construction the basic weights of materials remain the same, batch after batch. In student work in the laboratory these weights change from batch to batch, in order to introduce some variable into the series. If several groups are performing the same series of tests, the author has averaged the unit weights from all the groups. These average unit weights are plotted against the primary variable and a more or less smooth curve drawn through the average points. Values taken from this curve are then used as the actual unit weights in all further calculations.

Quantities of Materials per Cubic Yard of Concrete.—Quantities of materials used per cubic yard of concrete can be calculated from the batch weights and the volume of the batch by a direct proportion. Cement quantities are given in either pounds or bags, the aggregate quantities in pounds or cubic yards, and the water normally in gallons.

The actual volume of the batch should always be used in these calculations when the information is available. If no test value is available, a close approximation may be made by using the volume of the batch on an air-free basis. If air-entraining cement or an air-entraining admixture is to be used, a close approximation of the actual volume may be made by adding 4 per cent to the air-free volume.

The quantity of any material per cubic yard of concrete is found as follows:

$$\frac{\text{Quantity of material used in batch}}{\text{Volume of the batch, cu. yd.}}$$

If the unit of measure for the material in question is not the one desired, it is necessary to convert to the desired unit. If the volume of the concrete is in cubic feet, it will be necessary to divide by 27.

Illustration.—To continue with the illustration figures, the calculations are

$$\text{Cement} = \frac{650}{33.99/27} = 516 \text{ lb./cu. yd.}$$

To convert to bags, divide by 94

$$\text{Cement} = \frac{516}{94} = 5.49 \text{ bags/cu. yd.}$$

$$\text{Sand} = \frac{1{,}325}{33.99/27} = 1{,}055 \text{ lb./cu. yd.}$$

$$\text{Sand} = \frac{1{,}325/(27 \times 114)}{33.99/27} = 0.342 \text{ cu. yd./cu. yd.}$$

$$\text{Pebbles} = \frac{2{,}550}{33.99/27} = 2{,}025 \text{ lb./cu. yd.}$$

$$\text{Pebbles} = \frac{2{,}550/(27 \times 105)}{33.99/27} = 0.714 \text{ cu. yd./cu. yd.}$$

$$\text{Water} = \frac{370/8\frac{1}{3}}{33.99/27} = 35.3 \text{ gal./cu. yd.}$$

$$\text{Water} = \frac{370}{33.99/27} = 294 \text{ lb./cu. yd.}$$

The yield value is the number of cubic feet of concrete produced by 1 bag of cement. Since the number of bags needed to make 27 cu. ft. of concrete has just been calculated, the yield value may be computed as follows:

$$\text{Yield, cu. ft./bag} = \frac{27}{\text{cement content, bags/cu. yd.}}$$

Illustration.

$$\text{Yield} = \frac{27}{5.49} = 4.92 \text{ cu. ft./bag}$$

Talbot-Richart Values.—The Talbot-Richart terms are defined in Chap. 5. Items *a*, *b*, *c*, *v*, and *w* are quantities per unit of volume of freshly made concrete. The volume of the freshly made concrete is an actual volume rather than an air-free one.

The volume of the solids of cement, c, is found from

$$\frac{\text{Total volume of cement solids in batch, cu. ft.}}{\text{Actual volume of batch, cu. ft.}}$$

The values a and b are found by substituting in the above formula the values for fine and coarse aggregates.

The value for the voids, v, is found as follows:

$$v = 1 - (a + b + c)$$

It should be noted that voids in freshly made concrete always include both water and air, never just the air.

Computation of the value for water, w, follows the pattern for cement.

The b_0 value refers to the coarse aggregate only and is the proportion of a cubic foot of coarse aggregate that is occupied by the solid particles. It is found as follows:

$$\frac{\text{Unit weight, test value, for coarse aggregate solids, lb.}}{\text{Calculated weight of a cu. ft. of coarse aggregate solids lb.}}$$

Mortar Factor.—The mortar factor developed by the Illinois Division of Highways for use instead of the b/b_0 ratio is found by dividing the volume of mortar in the batch by the volume of the coarse aggregate. The volume of the mortar is found by subtracting the volume of the coarse aggregate solids from the volume of the batch. The volume of the coarse aggregate is the weight of coarse aggregate in pounds divided by the unit weight of coarse aggregate in pounds per cubic foot.

Illustration.—To continue with the previous illustration values.

$$c = \frac{3.314}{33.99} = 0.097$$

$$a = \frac{7.929}{33.99} = 0.233$$

$$b = \frac{15.490}{33.99} = 0.456$$

$$v = 1 - (0.097 + 0.233 + 0.456) = 0.214$$

$$w = \frac{5.934}{33.99} = 0.175$$

$$a/c \text{ ratio} = \frac{0.233}{0.097} = 2.40$$

$$\text{Cement-space ratio, } \frac{c}{v + c} = \frac{0.097}{0.214 + 0.097} = 0.312$$

$$b_0 = \frac{105}{2.64 \times 62.355} = 0.638$$

$$b/b_0 = \frac{0.456}{0.638} = 0.715$$

$$\text{Volume of mortar} = 33.99 - 15.49 = 18.50 \text{ cu. ft.}$$

$$\text{Volume of coarse aggregate} = \frac{2{,}550}{105} = 24.29 \text{ cu. ft.}$$

$$\text{Mortar factor} = \frac{18.50 \text{ cu. ft.}}{24.29 \text{ cu. ft.}} = 0.762$$

Relative Water Content.—The relative water content is the water content of the mortar in the concrete divided by the water content of the mortar at basic water content as determined in the mortar-voids test. For the illustration, assume that w_m at basic water content was 0.250 at $a/c = 2.40$.

Illustration.—The volume of the mortar for the batch has been computed previously as 18.50 cu. ft. The volume of the mortar per cubic foot of concrete is

$$\frac{18.50}{33.99} = 0.544 \text{ cu. ft.}$$

The volume of water per cubic foot of concrete has been previously computed as 0.175 cu. ft. The volume of water per cubic foot of mortar, w_m, is

$$\frac{0.175}{0.544} = 0.322 \text{ cu. ft.}$$

The relative water content of the concrete is

$$\frac{0.322}{0.250} = 1.29$$

A more direct way to secure w_m for the concrete is to use the equation 5-5

$$w = w_m(1 - b)$$

Using values of $w = 0.175$ and $b = 0.456$

$$w_m = \frac{0.175}{1 - 0.456} = \frac{0.175}{0.544} = 0.322$$

Air Content (Gravimetric).—One of the methods given by A.S.T.M. for securing the entrained-air content of concrete involves the same, basic test data and calculations as used here in the illustrations.[1] This method of securing the air content is commonly known as the gravimetric method. Two formulas are given by A.S.T.M. as follows:

$$A\% = \frac{T - W}{T}100$$

$$A\% = \frac{S - V}{S}100$$

where A = air content, in per cent of actual volume
T = unit weight of concrete, air-free basis, lb. per cu. ft.
W = actual unit weight of concrete, lb. per cu. ft.
S = actual volume of the batch of concrete, cu. ft.
V = total volume of cement and aggregate solids and volume of mixing water, cu. ft.

When the Talbot-Richart values of w and v are known, the air content may be computed most readily from

$$A\% = 100\,(v - w)$$

Illustration. To continuing with illustration values

$$A\% = \frac{149.84 - 144.00}{149.84}\,100 = 3.9$$

$$A\% = \frac{33.990 - (3.314 + 7.929 + 15.490 + 5.934)}{33.990}\,100 = 3.9$$

$$A\% = 100(0.214 - 0.175) = 3.9$$

Air Content—Indiana Method.—The following illustration of the calculation of the air content of concrete using the Indiana method makes use of the previously used data and follows the data record form presented with Test 26. Lines are numbered and when a calculation is involved, the manipulation is indicated in parenthesis. In general, the numbers used are the line numbers.

CALIBRATIONS OF CONTAINER

Without hook gauge

1. Weight of container full of water, lb.	51.18
2. Weight of empty container, lb.	20.00
3. Weight of water in container, lb. (1 − 2)	31.18
4. Volume of container, cu. ft. (3/62.355)	0.50

[1] Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete, A.S.T.M. Designation: C 138-44.

With hook gauge

5. Weight of container filled with water to the hook gauge, lb........ 48.18
2. Weight of empty container, lb.................................. 20.00
6. Weight of water in container to the hook gauge, lb. (5 − 2)....... 28.18
7. Volume of container to the hook gauge, cu. ft. (6/62.355).......... 0.452

UNIT WEIGHT (ACTUAL) OF CONCRETE

8. Weight of container full of concrete, lb.......................... 92.00
2. Weight of empty container, lb.................................. 20.00
9. Weight of concrete in container, lb. (8 − 2)...................... 72.00
10. Unit weight (actual) of concrete, lb. per cu. ft. (9/4)............. 144.00

UNIT WEIGHT (AIR-FREE) OF CONCRETE

11. Weight of container and concrete, lb............................. 50.00
2. Weight of empty container, lb.................................. 20.00
12. Weight of concrete in container, lb. (11 − 2)..................... 30.00
13. Weight of container, concrete, and water to hook gauge, lb........ 65.70
14. Weight of water to fill container to the hook gauge, lb. (13 − 11). 15.70
15. Volume of water to fill container to the hook gauge, cu. ft. (14/62.355) 0.2518
16. Volume of air-free concrete, cu. ft. (7 − 15)..................... 0.2002
17. Unit weight of concrete, air-free basis, lb. per cu. ft. (12/16)...... 149.84

AIR CONTENT

18. Air content, per cent [17 − (10/17) 100]......................... 3.9

Air Content—Modified Indiana (Ohio) Method.—The following illustration of the calculations of the air content using the modified Indiana (Ohio) method makes use of the previously used data and follows the data record form presented with Test 27. Lines are numbered and when a calculation is involved, the manipulation of the values is indicated in parenthesis. In general, the numbers used are the line numbers.

CALIBRATION OF CONTAINER

1. Weight of container full of water, lb............................. 51.18
2. Weight of empty container, lb.................................. 20.00
3. Weight of water in container, lb. (1 − 2)......................... 31.18
4. Volume of container, cu. ft. (3/62.355)............................ 0.50

UNIT WEIGHT (ACTUAL) OF CONCRETE

5. Weight of container full of concrete, lb.......................... 92.00
2. Weight of empty container, lb.................................. 20.00
6. Weight of concrete in container, lb. (5 − 2)...................... 72.00
7. Unit weight (actual) of concrete, lb. per cu. ft. (6/4)............... 144.00

AIR CONTENT

8. Calculated weight of ⅛ cu. ft. of concrete (⅛ × 7)................ 18.00
2. Weight of empty container, lb.................................. 20.00

9. Weight of container and ⅛ cu. ft. of concrete, lb. (8 + 2) 38.00
10. Volume of water added from graduated glass cylinder, ml. 138
11. Air content, per cent 3.9

The formula for the air content of the concrete may be written

$$A\,\% = \frac{\text{vol. of water added, ml.,} \times 0.00003531 \text{ ml./cu. ft.}}{0.125 \text{ cu. ft.}}\ 100$$

Field Batch Weights.—Concrete aggregates as used on construction are normally wet. In spite of the fact that reference is often made to solid rock and use is made in this book of the term "solid particles of aggregate," rock is not 100 per cent solid. There are pore spaces into which a small amount of water may be absorbed. It is much better when the aggregates as they are used contain all the water they will absorb.

If the aggregates to be used in concrete were oven-dried first, there might be a loss of mixing water into the pores of the aggregate sufficient to impair the workability of the concrete and to cause shrinkage of the cement paste resulting in considerable crazing of the concrete. Since there is no point in drying concrete aggregates and the possibility of some difficulty, they are always in a moist or wet condition when used.

TABLE 6-6.—APPROXIMATE QUANTITIES OF WATER ABSORBED BY AGGREGATES*

	Percentage by weight
Sand	1.0
Pebbles and crushed limestone	1.0
Trap rock and granite	0.5
Porous sandstone	7.0
Very light and porous aggregates	25.0 max.

* From "Design and Control of Concrete Mixtures," Portland Cement Association.

There is normally present outside the aggregate particles a small amount of water known as surface moisture. This must be counted as mixing water. The amount of this surface moisture must be determined as often as may be necessary to pick up any changes that may occur.

Determination of the absorption value is made at the same time as specific gravity. See Tests 10 and 11. Approximate quantities are given in Table 6-6.

Determination of surface moisture is made as outlined in Tests 15 and 16. Approximate quantities are given in Table 6-7.

Illustration.—The batch weights previously used in the calculation illustrations will be used here. They are

Sand = 1,325 lb.
Pebbles = 2,550 lb.
Water = 370 lb.

These weights of sand and pebbles are on what is known as the "saturated, surface-dry" basis.

Assuming now that tests show the surface-moisture contents of the sand and pebbles as 4 and 1 per cents, respectively, the weights of surface moisture are

Sand = 0.04 × 1,325 = 53.00 lb.
Pebbles = 0.01 × 2,550 = 25.50 lb.
Total = 78.50 lb.

Field batch weights then become

Sand = 1,325 + 53 = 1,378 lb.
Pebbles = 2,550 + 25.5 = 2,575.5 lb.
Water = 370 − 78.5 = 291.5 lb.

It is interesting to note that the surface moisture in the aggregates totals nearly 9.5 gal. or 21 per cent of the mixing water.

TABLE 6-7.—APPROXIMATE QUANTITIES OF SURFACE MOISTURE CARRIED BY AVERAGE AGGREGATES*

Aggregates	Gal. per cubic foot of aggregate	Percentage based on saturated, surface-dry weight of aggregate
Very wet sand	¾–1	5–9
Moderately wet sand	½	4
Moist sand	¼	2
Moist pebbles or crushed stone	¼	1–2

* From "Design and Control of Concrete Mixtures," Portland Cement Association.

It sometimes happens that when crushed stone is used as the coarse aggregate, it is dry and will absorb some of the mixing water. Allowance must be made for this in figuring the amount of water to be added in the batch. Assume for the purpose of this illustration that the coarse aggregate has an absorption value of 1.3 per cent. Water absorbed will be 0.013 × 2,550 = 33.15 lb.

The batch weights then become:

Cement = no change
Sand = no change
Pebbles = 2,550 lb. − 33.15 lb. = 2,517 lb. (nearest whole pound)
Water = 370.00 − 53.00 + 33.15 = 350.15 lb.
= 42.0 gal.

The reason the 33.15 lb. is subtracted from the weight of pebbles (2,550 lb.) is that this basic weight of pebbles includes saturation water. It should be remembered that our basic weights for aggregates are on a saturated, surface-dry basis.

Vinsol Resin Admixture.—Assume now that Vinsol-resin crystals are available and that they are to be dissolved in a solution of 3 g. of sodium hydroxide per 100 ml. of water, at the rate of 1 g. of the crystals per 10 ml. of the sodium hydroxide solution.

Assume now that the desired amount of Vinsol-resin crystals is 0.01 per cent of the weight of the cement. Our first calculation will be for the amount of solution per 100 lb. of cement, since quantities for other amounts of cement can be secured by simple multiplication.

The weight of Vinsol-resin crystals will be 0.0001 × 100 lb. = 0.01 lb. At 454 g. per lb. the weight of crystals will be 4.54 g.

If 1 g. of the crystals are dissolved per 10 ml. of the Vinsol-resin solution, the quantity of solution needed will be 10 × 4.54 = 45.4 ml.

On the basis of 29.6 ml. per fl. oz., 45.4 ml. = 1.5 oz. For the 650 lb. of cement for the batch the amount of Vinsol resin solution is 6.50 × 1.5 = 9.75 oz.

Darex AEA Admixture.—Darex AEA is sold by the producer in liquid form only, ready to use. Assume that the amount to be used is 1.25 fl. oz. per bag of cement. The amount for the 650 lb. of cement is

$$\frac{650}{94} 1.25 = 8.65 \text{ oz.}$$

Study Questions

1. What values are given in Table 6-1? Whose table is this? Which has the greater destructive effect—fresh water or salt water? Do the higher values of water-cement ratio indicate a better concrete?

2. Within the limitations permitted by actual job conditions should

a. Water-cement ratio be large or small?

b. Consistency be wet or dry?

c. Slump values be high or low?

d. Maximum size of the aggregate be large or small?

e. Percentage of the aggregate that is fine be large or small?

f. Cement content of the concrete be large or small?

g. Fineness modulus of the combined aggregate be large or small?

h. b/b_0 ratio be large or small?

i. Mortar factor be large or small?

3. Does a broken-stone coarse aggregate require a larger percentage of fine aggregate than does a rounded coarse aggregate?

4. In making use of the Talbot-Richart mortar-voids method, what changes did the Illinois Division of Highways make? What changes did the Michigan State Highway Department make?

5. What is the mortar factor as used by the Illinois Division of Highways? What values are used?

6. What range of relative water contents does Illinois use? What value does Michigan use? Why are the Illinois values higher than the Michigan values for the same kind of concrete?

7. Which of the two highway organizations uses a constant cement content? What is the value in bags per cubic yard? What is the corresponding *c* value?

8. What difference does Michigan make in the relative-water-content value and b/b_0 ratio when air is entrained in the concrete?

9. Students should be able to calculate all the values illustrated under the heading "Calculations." Practice will be furnished in some of the assigned problems and in doing the calculations in connection with concrete projects in the laboratory.

CHAPTER 7

FACTORS AFFECTING CONCRETE STRENGTHS

In the two previous chapters the discussion has concerned the interrelationships between strength and the cement, water, and aggregates. There are, however, a number of other factors affecting the rate of development of strength, such as:

1. Characteristics of the cement
2. Age
3. Mixing
    a. Amount
    b. Temperature
4. Curing conditions
    a. Moisture
    b. Temperature
5. Admixtures

In the proportioning chapters the discussion has been based on temperatures of 70°F., moist curing for the entire period up to testing and for a mixing time of approximately 1 min. By varying these items changes in strength may be secured, and it is desirable for the user of concrete to know what happens when other variations are made.

Characteristics of the Cement.—The cement itself plays an important role in the development of strength. Practically all portland cement is made to meet A.S.T.M. requirements, and for what is now their type 1 cement these requirements have been changed from time to time to secure greater strengths. As pointed out in Chap. 3, the trend has been to increase the percentage of tricalcium silicate and decrease that of the dicalcium silicate. This change, coupled with an increased fineness of grinding, has made it possible for present-day concretes made with the type 1 cements to develop strength much faster now than was the case at the beginning of the twentieth century. More careful selection of the raw materials and better control of the burning have also aided during this development period in the production of a better cement.

A comparison of the curves in Figs. 7-1 and 7-2 shows the difference in concrete strengths for average, type 1 and type 3 portland cements. It appears now that the new air-entraining portland cements do not produce quite so much strength as their companion types of nonair-entraining cement, when there is no other difference in the concrete than the cement. On the other hand, it should be remembered that there can be a slight reduction in the amount of mixing water when air-entraining cement is used, and this reduction in mixing water results in offsetting the loss in strength due to air entrainment.

Age.—Age is a very important item in the amount of strength developed. Figures 7-1 and 7-2 give the age-strength relationship for

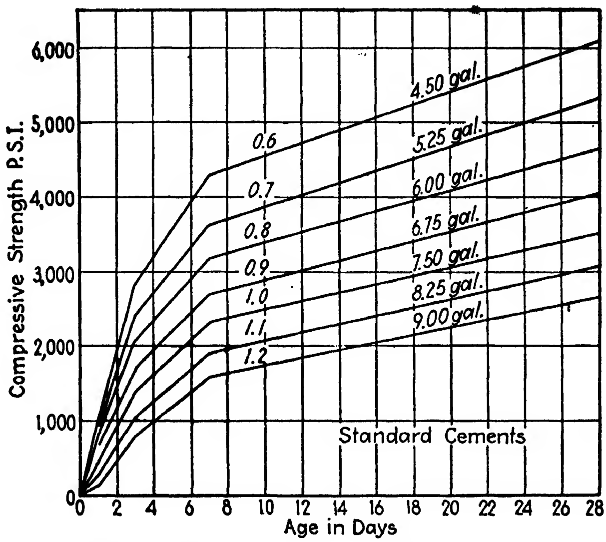


FIG. 7-1.—Showing the effect for type 1 cements of age upon compressive strength for the water-cement ratios in general use. The 28-day strengths are taken from the new curve shown in Fig. 6-1. Concrete to attain these strengths must be kept moist and at a temperature of 70°F.

type 1 and type 3 cements for the water-cement ratios in common use. The rate at which concrete develops strength is greatest at the early ages and gradually decreases. Cements high in dicalcium silicate, however, do not gain strength as rapidly in the early ages as the cements shown in these figures. They do maintain their rate of increase over a longer period.

Amount of Mixing.—The strength of concrete can be increased by increasing the time of mixing, as indicated by the curves shown in Fig. 7-3. The greatest gains are recorded in increasing the mixing time from 20 sec. to 2 min., and specification writers usually require mixing intervals of from 1 to 2 min. Mixing should, of course, continue until all the materials are mixed uniformly through the mass of concrete.

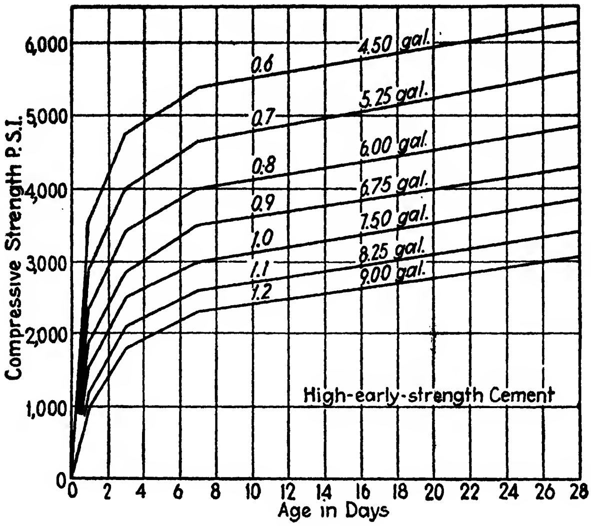


FIG. 7-2.—Showing the effect for a high-early-strength (type 3) cement of age upon compressive strength for the water-cement ratios in general use. Concrete to attain these strengths must be kept moist and at a temperature of 70°F.

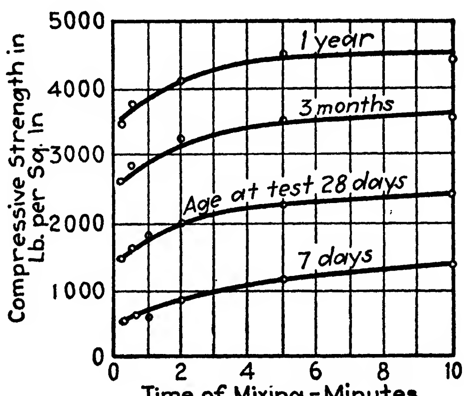


FIG. 7-3.—Typical relations between time of mixing and the compressive strength of concrete. (*From "Design and Control of Concrete Mixtures," published by the Portland Cement Association.*) Tests made more recently than those on which this diagram is based indicate that mixing times in excess of 1 min. do not produce appreciable increases in strength. (See Blanchette, "Effect of Mixing Time on Quality of Concrete Produced in Large Mixers," *Public Roads*, Vol. 15, pp. 217–230; Besson, "Over-a-Minute Mixing Adds No Strength," *Eng. News-Record*, Vol. 110, pp. 183–185; Thee, "Effect of Size of Batch and Length of Mixing Period on Rate of Production and Quality of Concrete Mixed in Standard 27E Pavers," *Public Roads*, Vol. 12, pp. 269–289.)

Temperature of Mixed Concrete.—During cold weather it is the practice to heat the concrete aggregates and sometimes the water before they are placed in the mixer, or an attempt is made to heat the concrete by means of a blowtorch while it is being mixed. Not a great deal of information has been published concerning temperatures above 70°F. William H. Bacheldor[1] concluded after testing concrete that came from the mixer at temperatures of 70, 100, and 130°F. that "to get a full development of the inherent strength of the concrete, the temperature of the concrete when placed should not exceed 70°F." Professor Jacob R. Shank[2] concluded after a series of laboratory tests that "the heating of concrete materials must be expected to reduce the strength somewhat." For a 20°F. increase in temperature over 70°F. Professor Shank reports a 10 per cent reduction in strength. Values are not given for increases in temperature greater than 20°F.

Moisture during Curing.—It is a well-established fact that the strength of concrete can be increased materially by keeping it moist especially during the early ages. More than enough water is mixed in the concrete for the hydration of the cement. The purpose of applying moisture at the surface of the concrete is merely to prevent the evaporation of the water in the concrete.

Figure 7-4 shows a typical relationship between moist curing and strength. All the cylinders were tested at 4 months. The cylinders were stored first in moist sand and then in air. As the length of time in damp storage increased, the strength of the concrete increased.

On construction it is usually impossible to keep the structure wet for any great interval of time, 7 to 10 days being the usual period. Because of the inconvenience in applying moisture for the periods indicated, there is a tendency to use other methods for the development of the necessary strength. As pointed out in the chapter discussing durability, maintenance of the proper moisture content aids in the development of a more durable concrete.

In making use of the various strength curves in connection with proportioning, it should be remembered that they are based on 28 days of moist curing, the first day or two of which the concrete remains in the molds.

Curing Temperatures.—Temperature of the concrete during the early age of the concrete has an important bearing on the strength of the

[1] "Overheating of Aggregates Found Detrimental to Concrete," *Eng. News-Record*, Vol. 105, p. 973 (1930).

[2] "Heating Concrete Aggregates Affects Compressive Strength," *Eng. Expt. Sta. News, The Ohio State University*, Vol. VI, No. 2, pp. 1–2 (1934).

concrete. Temperatures on the job vary a great deal and it is difficult, therefore, to estimate what the total effect has been at any particular age.

Results of a series of tests made at the University of Illinois are shown in Fig. 7-5. In these tests the concrete remained in the molds in the laboratory air during the first 24 hr., after which the test specimens were placed in storage at the temperatures indicated. The concrete that was frozen developed no additional strength. Concrete cured at 40°F. developed less strength than that cured at 70°F., while that cured at 100°F. developed more strength. The concrete that was heated with

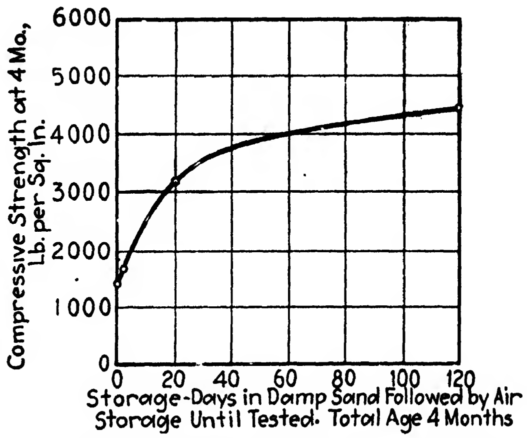


FIG. 7-4.—Showing effect of moist curing on the compressive strength of concrete at age of 4 months. Specimens were stored in damp sand for the period indicated in the horizontal scale, followed by air storage until tested at 4 months. (*From "Design and Control of Concrete Mixtures," published by the Portland Cement Association.*)

live steam lost strength after 14 days. For the 28-day strengths each degree change in temperature affected the strength about 35 lb. per sq. in. A. R. Lord reported[1] that in connection with the Wacker Drive improvement it was observed that for each degree change in temperature the strength of the concrete was affected 50 lb. per sq. in. The mixes on Wacker Drive were leaner than in the series reported in Table 7-1. It is to be expected that greater effects per degree change in temperature will be observed for the weaker concrete than for the stronger.

What would happen to the frozen concrete if it were subjected to normal curing temperatures after freezing? It often happens on construction that concrete is frozen a day or two after placing, and the

[1] LORD, A. R., "Notes on Wacker Drive," *Proc. Am. Concrete Inst.*, Vol. 23, pp. 28–69 (1927).

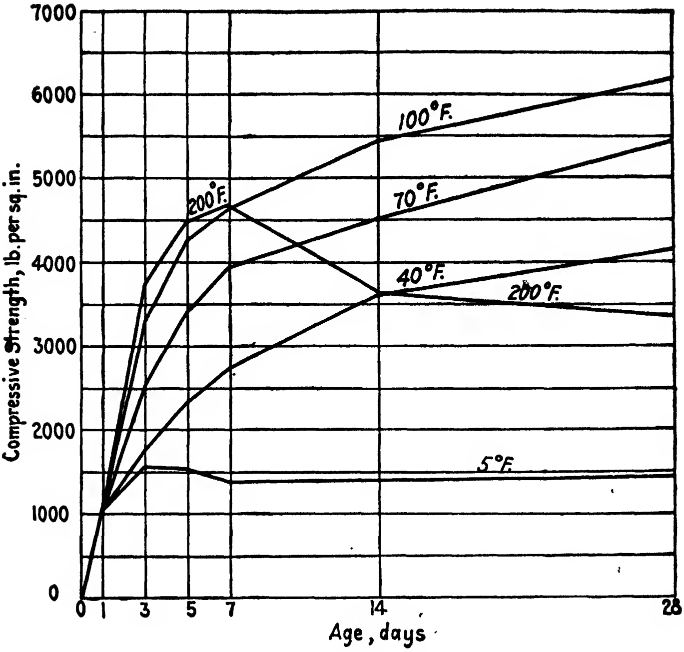


FIG. 7-5.—Effect of curing temperatures on the rate at which concrete develops strength.

Each value is the average of the results of three 6- by 12-in. cylinders. Concrete for approximately six cylinders was mixed in a tilting drum mixer for 2 min. Cylinders molded and capped in the standard manner. Cylinders remained in the molds for 24 hr., at the end of which time they were placed in the curing container Curing temperatures were secured as follows. 5°F. in an electric refrigerator; 40°F. in an ice chest; 70°F. in the regular moist room; 100°F. in a water bath; and 200°F. in steam. Frozen cylinders were thawed out before testing. Cylinders were tested in a 200,000-lb. hydraulic machine.
Mix in each case was 1:2:3 by volume with an 0.8 water-cement ratio. A type 1 portland cement was used.

TABLE 7-1.—COMPARISON OF THE RATES OF GAINING STRENGTH OF CONCRETE CURED AT VARIOUS TEMPERATURES

	Values, lb. per square inch				
Age, days	5°F.	40°F.	70°F.	100°F.	200°F.
1	.....	.....	1,005		
3	1,555	1,740	2,530	3,280	3,730
5	1,545	2,335	3,410	4,260	4,470
7	1,395	2,730	3,940	4,650	4,670
14	1,415	3,600	4,520	5,440	3,650
28	1,460	4,140	5,440	6,200	3,370
49	.....	.....	.....	.....	3,430

question is raised whether the concrete will ever develop strength. H. M. Fitch[1] reports that if the concrete is given a day at 70°F. it will begin to develop strength at the normal rate upon being thawed out. Results shown in Fig. 7-6 are similar to those secured by Fitch. A study of all his test results leads Fitch to conclude that if the freezing period is omitted in the plotting of the age-strength curves, the curve will be essentially the same as though the concrete had never been frozen. Curing before and after freezing was done in the usual, moist storage room at 70°F.

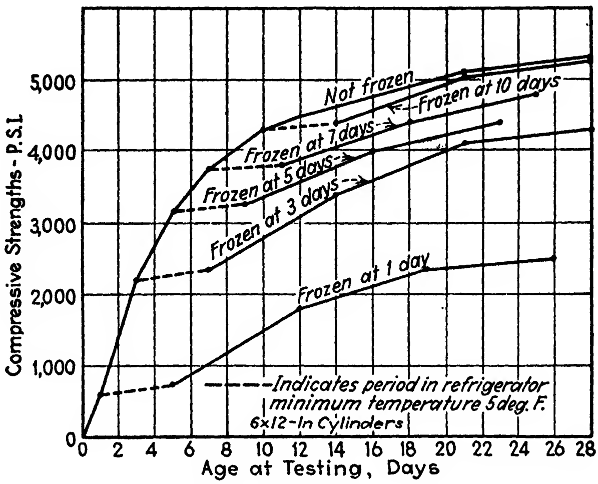


FIG. 7-6.—Showing effect of freezing period on the strength of concrete. Mix 1:2:3 by volume, water-cement ratio, 6¼ gal. per bag of cement. Cylinders subjected to freezing were placed in an electric refrigerator with a minimum temperature of 5°F. Storage before and after freezing was in usual moist room at 70°F. Fitch, as indicated in Fig. 7-7, found a more rapid recovery following freezing, but he used 4- by 8-in. cylinders. [*From C. C. Wiley, "Effect of Temperature on the Strength of Concrete," Eng. News-Record, Vol.* 102; *pp.* 179–181 (1929).]

Results secured by Fitch for all series of the same mix are shown in Fig. 7-7.

A. G. Timms and N. H. Withey[2] conducted tests with initial curing periods of ¼, ⅔, 1, and 3 days, using a standard cement and two high-early-strength cements, with three different water contents. Results for the standard portland cement are shown in Fig. 7-8. Results for the

[1] "Effect of Low Curing Temperatures on the Strength of Concrete," Master's thesis (1933) at the University of Illinois.

[2] "Temperature Effects on Compressive Strength of Concrete," *Proc. Am. Concrete Inst.*, Vol. 30, pp. 159–180 (1934).

high-early-strength cements are similar, but the strengths developed in the initial curing periods at 70°F. are higher. These investigators found that "subsequent warming of the concrete exposed to temperatures of 50 and 33°F. was not of much benefit in improving the later strengths when no provision was made to supply moisture to further the curing action."

What would happen to concrete frozen while still plastic if it were subjected to normal curing temperatures and moisture after freezing?

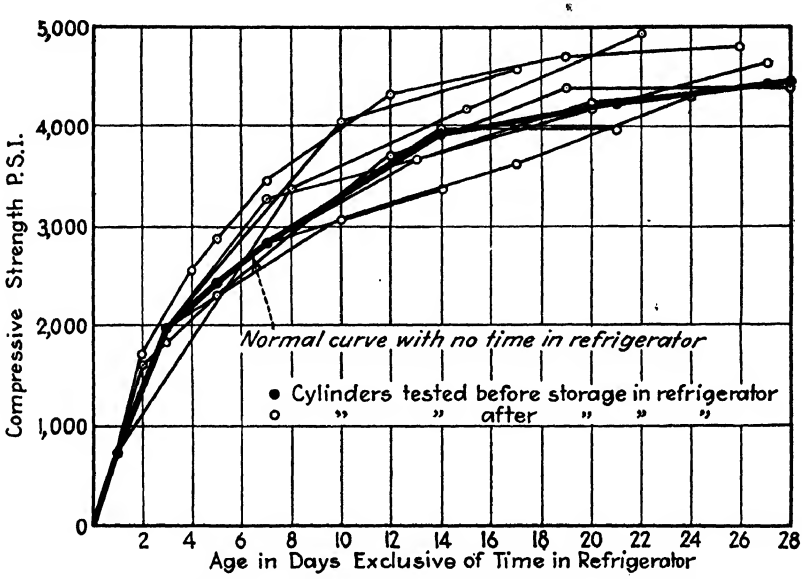


FIG. 7-7.—Relationship between age and compressive strength for concrete which has been stored at least 1 day at 70°F., then in a refrigerator (varying intervals with a minimum temperature of 4°F.), followed by moist storage at 70°F., but plotted with the interval in the refrigerator omitted.

Mix 1:2:3½ by volume. Cylinders were 4 by 8 in. Each point plotted represents the average strength of at least three cylinders. [*From H. M. Fitch, "Effect of Low Curing Temperatures on the Strength of Concrete," Thesis* (1933), *University of Illinois*.]

R. B. Young indicates that "compressive strength is usually reduced by 10 to 50 per cent."[1] E. A. Hagy reports that in 1930 some footings were placed in close to zero weather with no attempt to protect the concrete. After 3 weeks the concrete thawed out and seemed as plastic as when poured. "We had made cylinders at the time the footings were poured and had protected them. We made cylinders from this frozen

[1] *Proc. Am. Concrete Inst.*, Vol. 39, p. 127.

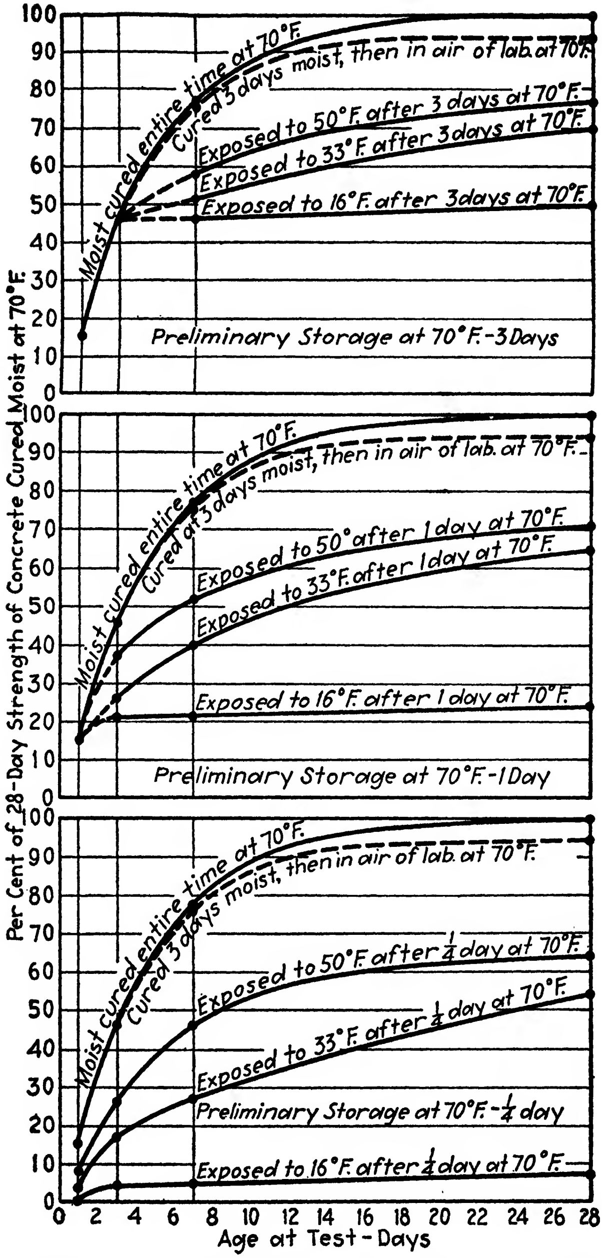


Fig. 7-8.—Showing effect of storage temperatures on the compressive strength of a concrete made with a standard portland cement, with a water-cement ratio of 6 gal. per bag of cement and with a cement content of 5.68 bags per cu. yd. (*From Timms and Withey, "Temperature Effects on Compressive Strength of Concrete," Proc. Am. Concrete Inst., Vol.* 30, *pp.* 159–180.)

concrete after it became plastic and cured them, and after a 6 months' period, there was not over a 5 per cent difference in the compressive strength of the two concretes."[1]

An important item to remember is that proper curing conditions must prevail in order for strength to develop and that the freshly thawed concrete must not be counted upon to carry any loads, even though the concrete in the frozen condition may appear to have considerable strength. Tests by the author indicate that concrete tested in the frozen condition may have as much as 2,400 p.s.i. more strength than when not frozen.

Even though there are reports on record of freshly made concrete being frozen immediately with no, or little, apparent harm being done, it has been the practice of engineers to maintain concrete in a nonfreezing condition for at least several days after placing. If a person lacks experience in cold-weather concreting, the safest course to follow is to wait for above-freezing air temperatures or to maintain the concrete above a freezing temperature for a period of time after placing.

Calcium Chloride.—Calcium chloride is placed in the mixing water to serve as an accelerator in the hardening of the concrete.

The effect of calcium chloride is summarized by Rapp and Wells as follows:[2]

> The addition of calcium chloride appears to increase somewhat the heat contributed at the end of 24 hr. by dicalcium silicate and tetracalcium ferroaluminate and to decrease the heat from tricalcium aluminate present in cements. The heat contributed by tricalcium silicate shows very little change when calcium chloride is added. Calcium chloride increases the rate at which the heat is evolved from all cements tested and in general gives an increase of about 4 cal. per g. of cement at 24 hr. It decreased the time of set of the 11 commercial cements and increased the flow of the concrete mix and the strength of the resulting concrete at all ages to 90 days, beyond which results have not yet been obtained.

Study Questions

1. Name the conditions that must prevail if concrete is to develop strength with age.
2. Name two items about the cement that must prevail in order that early strengths can be developed.
3. Does increased time of mixing of the concrete increase the strength of the concrete? Is it a significant amount beyond 1 min.? Beyond 2 min.?
4. What is considered normal temperature for concrete?

[1] *Proc. Am. Concrete Inst.*, Vol. 39, p. 129.

[2] "Progress Report on the Reaction of Calcium Chloride on Portland Cement," *Proc. Highway Research Board*, Vol. 13, pp. 291–299.

5. Does concrete gain strength while frozen? If freshly made concrete is frozen immediately, will the concrete in the frozen condition show any strength? If concrete that has developed a strength of 3,000 p.s.i. is then frozen, will the frozen concrete have a strength equal to, more or less than, the 3,000 p.s.i.?

6. Are there reports on record indicating that freshly made concrete that has been frozen immediately will develop into satisfactory concrete when thawed out and properly cured? Is it considered good practice to permit freshly made concrete to freeze while still plastic?

7. Is there any indication that curing temperatures substantially above normal may result in lowered strengths?

8. In order to develop the greatest amount of strength, should concrete be kept wet or dried out immediately upon placing?

9. What effect does calcium chloride in the mixing water have on the development of strength of the concrete?

10. For type 1 cement what is the approximate percentage increase in strength from 7 to 28 days?

CHAPTER 8

MAKING OF CONCRETE

The production of concrete involves the operations of handling and measuring materials, mixing, transporting, placing, finishing, and curing. Any or all of these items may contribute to the success or failure of the work. In a general discussion of this kind it is not possible to say that if certain things are done or not done, the strength will be increased or decreased a certain amount. There are a number of items that affect the strength of concrete, and in the field it is not possible to control all of these very carefully. If only one factor is varied, we may estimate what the strength may be as the variations take place. It is much better to make test specimens and determine for the conditions on that particular job just what variations in strengths are being secured. An attempt will be made in this and the next chapter to outline what is generally considered to be good practice.

Transportation and Storage of Materials

Materials for concrete must as a general rule be transported from the source of supply and stored until needed to make concrete. Occasionally a contractor will have a concrete-making plant at a gravel pit, which will eliminate the necessity for any transportation of the aggregates.

Most contractors build up a reserve of both cement and aggregates before placing of the concrete begins. This is desirable in that the contractor assures himself of continued production during the months when weather conditions are the most favorable and when he is ready to work. During the winter months it is not possible for the sand and gravel producers to operate, but they can begin before the time construction starts. Storage of cement any length of time after making is not desirable inasmuch as the strength of the concrete made with it will not be so great as if made immediately following production.[1] Storage has a greater effect on the early strengths than on the later ones as indicated in Fig. 8-1. Often a cement will be able to pass the A.S.T.M. minimum specifications even after a year's storage because the margin was large

[1] Abrams, Duff A., "Effect of Storage of Cement," *Structural Materials Research Lab., Bull.* 6, Lewis Institute.

when the cement was new. A safe rule to follow is not to put in storage more cement than can be used in from 3 to 4 months after it is made.

The amount of materials put in reserve will depend somewhat upon the contractor's past experiences and his estimate of what conditions are likely to be during the construction season. The reserve should be at least large enough to tide over any periods when it will not be possible to get materials.

When regular placing of concrete begins, daily shipments are started that will be sufficient to take care of each day's work. With everything running according to schedule, all of the materials can be used each day without placing any in storage—an item of additional expense. It is,

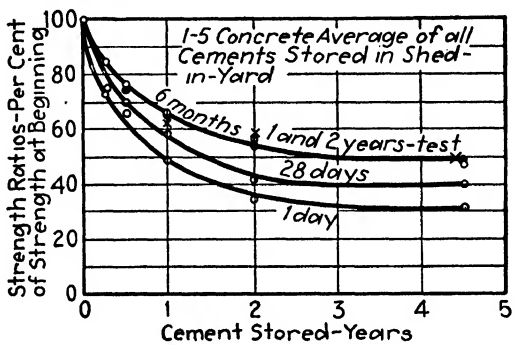


FIG. 8-1.—Effect of storage of cement on the compressive strengths of 1:5 concrete. (*From Abrams, "Effect of Storage of Cement," Bull.* 6, *Structural Materials Research Laboratory, Lewis Institute, 2d ed.*, 1924.)

of course, not possible to operate upon an exact schedule, largely because of weather conditions, and hence it is necessary to put materials in storage or draw upon the storage supply from time to time. Occasionally a contractor will try to operate without any reserve or without any facilities for handling reserve materials. The railroads make demurrage charges if the cars are not unloaded within a certain time, which is known as the free time and which is usually 2 days. The amount charged increases with the time the cars remain loaded. Some railroads sign agreements with the contractors by which the contractor may offset some of the demurrage charges by unloading cars before the free-time limit is up. Accounts are usually settled at the end of each month.

On some jobs prompt performance of the work is an important item, and the engineer will require in the specifications that the contractor maintain a reserve supply in order that work can always be done. This clause is necessary only when the producers are not meeting the demands during the construction season.

Cement.—Cement is usually shipped in boxcars, either in bulk or in bags. When the supply of boxcars is insufficient, gondola cars may be used, but this necessitates the use of a waterproof covering that may be a total loss to the manufacturer after it is used once. For jobs near a cement plant shipments are often made by truck. Shipments may also be made by boat.

Cement must be stored in a dry place. For the reserve supply it is advisable to use a building of some kind, generally of a temporary nature, which is normally built of wood and covered with tar paper. The floor level of the cement shed should be high enough in order that the men in handling the cement can walk into the railroad car or on the truck without stepping up or down. The floor level should also be high enough to prevent the cement from becoming wet through the floor.

FIG. 8-2.—A good type of metal portable cement shed.

Small quantities of cement are frequently stored on construction work under a canvas. It is claimed by the manufacturers of the new multiple-wall paper bag that no covering is necessary for short periods of outside storage.

Aggregates.—Aggregates are shipped in gondola cars or trucked if the haul is short enough. If a crane is used to unload directly from the car, the ordinary gondola car without bottom or side dump doors is preferred. As it is difficult to close up all the openings on the cars with the bottom or side dump doors, there is inclined to be a leakage of the sand. In case a contractor has an unloading trestle, special efforts are made to close up the openings in order that sand as well as coarse aggregate may be shipped in the dumping gondola.

It is ordinarily necessary to keep a man in the gondola car when unloading with a clamshell. In order to save the time of this man, some

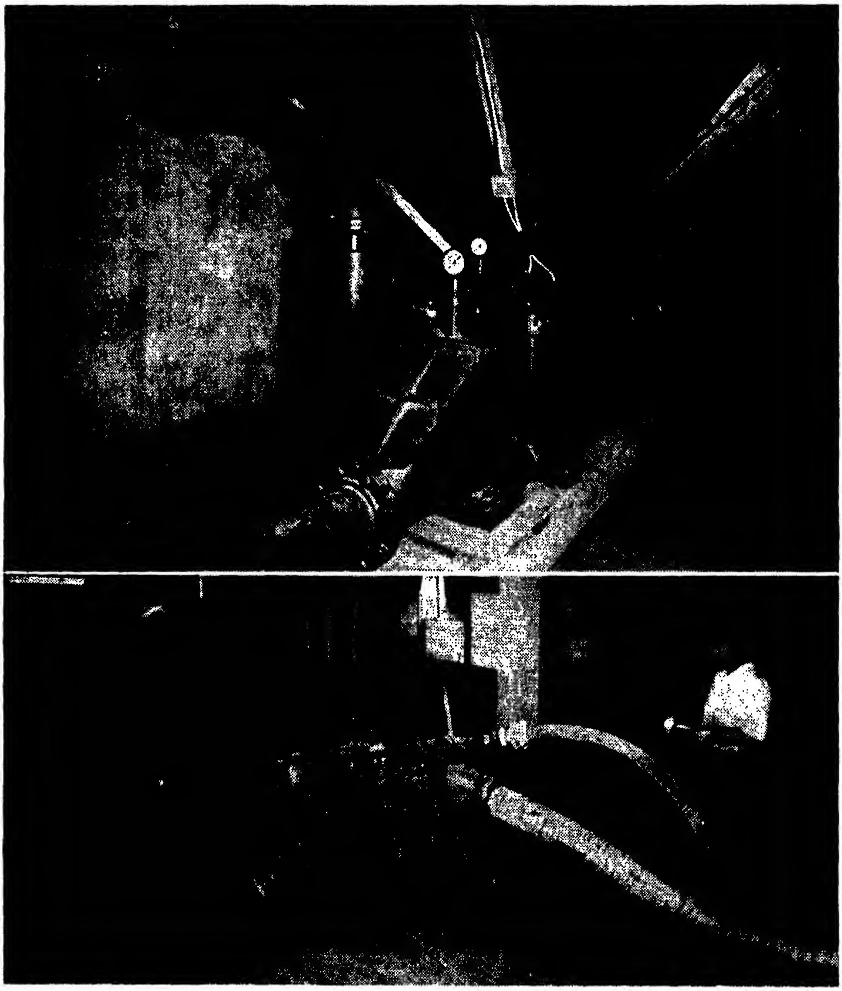


FIG. 8-3.—Unloading equipment for bulk cement. (*Fuller Company.*)

Cement is shipped in bulk in many instances, requiring special mechanical equipment to handle it on the way from railroad cars, trucks, barges, or ocean-going vessels to storage bins, and then from the storage bin to the batching equipment.

Above, Fuller-Kinyon stationary pump below hopper-bottom car. *Below*, Fuller-Kinyon remote-control unloader operating in barge. Man is holding remote-control device in his hands. Similar equipment is used to unload cars and to take cement out of storage bins.

The cement in these units is introduced into the compressed-air chamber by a screw conveyer, the cement itself sealing off the opening for the conveyer screw. The cement is then carried in suspension in compressed air as it moves toward the outlet end of the conveying line.

contractors receive their coarse aggregate in bottom dump cars, which are unloaded into a pit under and to one side of the track. The clamshell can then pick the material out of the pit without the aid of an attendant.

Storage Piles.—No special difficulties are experienced in the storage of fine aggregate in stock piles. There is ordinarily sufficient moisture in the sand to prevent segregation. It is difficult, however, to prevent segregation of the coarse aggregate. Definite provisions are usually made in the specifications covering the method of building up storage piles of coarse aggregates. Stock piles should be built up in layers not exceeding 4 ft. in thickness. The first layer should extend over as much area as the stock pile is ever to cover. The second layer should cover the first layer entirely before the third layer is started. *Stock piles should not be built by pyramiding.* If each bucketful from the crane is dropped in the same place each time there is a concentration of dust in the center of the pile and a segregation of the sizes. The larger particles roll down the side of the pile with the result that the smaller sizes are in the center of the pile and the larger ones at the edge.

Because of the difficulty of maintaining a constant gradation of the coarse aggregate, the practice of using multiple-size aggregates is growing. The handling of an extra size or two of aggregate makes this part of the work more difficult and usually more expensive. The benefits derived are, however, worth the additional cost.

Stock piles of different aggregates should be kept separate to avoid mixing. As the same crane will handle both materials, there is an advantage in having the stock piles close together. A separating wall is sometimes necessary.

Storage Bins.—Overhead storage bins are used in connection with the various measuring devices. The aggregates are placed in the storage bins directly from the cars or from the storage piles by means of the clamshell. From the storage bins the materials flow by gravity into the measuring equipment.

In some of the storage bins there is a tendency for dust and dirt to collect in the corners. When the bins are emptied, all of this dust and dirt is placed into a few batches of concrete, a practice that is undesirable. The ideal type of bin for coarse aggregate would be one with a perforated bottom to permit the fine material to escape.

MEASUREMENT OF MATERIALS

Uniformity and exactness in the amount of materials entering into each batch of concrete are generally recognized as being of the utmost importance. Variations in the amount of any one of the materials will cause variations in the amount of concrete produced, its consistency and strength, all of which may be undesirable. The engineer is interested primarily in securing uniform strength and the contractor in getting the proper amount of concrete. Variations in consistency increase the difficulty of securing uniformly smooth surfaces, a condition that is highly desirable in concrete pavements.

Size of Batch.—The size of a batch of concrete is indicated by the number of bags of cement in it and the proportions of the materials, as a 5-bag batch of 1:2:4 concrete, or by the number of cubic feet of mixed concrete. On much of the work that is given engineering supervision, the contractor operates the mixer at the full capacity permitted in the specifications. The amount of cement used is not a whole number

Fig. 8-4.—View of floating batching plant which serves transit mixers at docks throughout the New York City area. Batching plant consists of a 6-cu. yd. batcher and bin with four 75-cu. yd. aggregate compartments and two 250-bbl. cement compartments. (*Courtesy of Rock Products.*)

of bags. The size of the batch is normally then expressed in the number of cubic feet of mixed concrete.

Measurement of Cement.—Many contractors buy cement in bags, and thus the problem of measuring cement is easily taken care of. Cement is shipped in bulk also, which necessitates the installation of weighing equipment for it. Measurement of bulk cement by volume is unsatisfactory. A cubic foot of cement can be made to weigh from about 70 to 100 lb., depending upon the method and amount of compaction. The selection of 94 lb. as the weight of 1 cu. ft. of cement is purely arbitrary. Since most of our knowledge of concrete is based on cement weighing 94 lb. per cu. ft., it is well to continue on that basis.

Some mixers are not large enough to accommodate a 1-bag batch, which necessitates the splitting of a bag. On a job that does not warrant the use of a larger mixer, the use of weighing equipment for the cement is also unwarranted. Measurement by a shovel is undesirable but often times unavoidable on these small jobs.

In measuring cement with shovels it is well to empty a sackful into a box and determine the number of shovelfuls per bag. The number of shovelfuls per bag for each of the other materials should also be determined.

It is difficult to get all of the cement out of a cloth sack, and most workmen are inclined to leave a pound or two in each bag. This is an item that may need watching, especially in case the contractor or dealer is recovering this cement for resale. The paper sack does not have this objectionable feature.

Measurement of Water.—Measurement of water on the larger jobs is done by automatic meters or automatic measuring tanks of the vertical cylinder, center-siphon discharge type, capable of routine measurement within an accuracy of 1 per cent under all operating conditions. It is considered advisable to put the water into the mixer as quickly as possible, and the metering device has the advantage of delivering the water under pressure, whereas delivery from the tank is by gravity. Water is usually siphoned out of the tanks in order to secure maximum rate of flow throughout the full time of discharge. For stationary mixing plants equipment is available for weighing the mixing water.

Careful control of the quantities of water and cement are important inasmuch as they constitute the cement paste that is the binding material. Other things may affect the strength of the cement paste, but these other things would be the same regardless of the amounts of water and cement used.

Measurement of Aggregates.—Aggregates are now generally divided into two sizes, fine and coarse aggregate. Specifications provide that these materials shall be measured separately. In case the coarse aggregate is divided into two or three sizes, it is necessary to have a greater number of devices for measuring the coarse aggregate.

Measurement by shovelfuls or by the wheelbarrow is not accurate and should be allowed only on relatively unimportant work. On the small jobs where accurate measuring equipment is not warranted, more attention should be paid to the water and the cement than to the aggregates. On larger and more important work all of the materials should be carefully measured by weight.

In order to have a common basis for determining the quantity of material in a cubic foot, the A.S.T.M. has prepared a standard method of testing (Designation: C 29-42), commonly known as the "unit-weight test." In this determination a standard size and shape container (depending on the maximum size of the aggregate) is filled with the aggregate in three increments, and each increment is rodded 25 times with a bullet-nosed rod ⅝ in. in diameter and 24 in. in length. The weight of the material in the container is determined from which the weight per cubic foot is calculated.

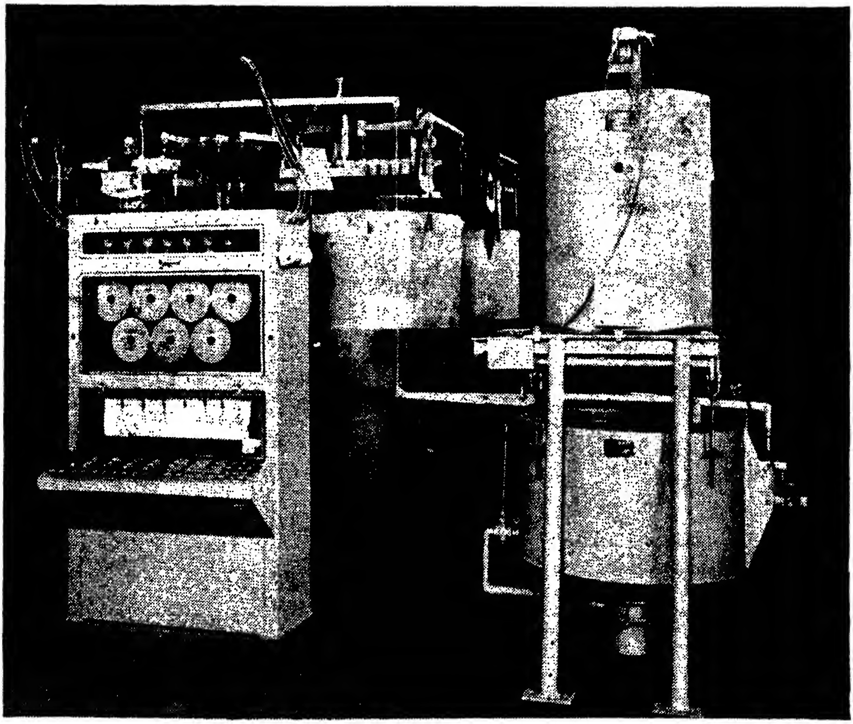


FIG. 8-5.—Automatic batching equipment. (*C. S. Johnson & Co.*)
The first automatic equipment was used on Hoover Dam and was made by C. S. Johnson & Co., Champaign, Ill., in 1934. Automatic equipment is recommended when two or more 2-cu.yd. mixers are to be served.

This test may be made on the aggregate in an oven-dry condition or in a saturated, surface-dry condition. In drying the aggregates to the latter condition the wet aggregates are spread out in a thin layer to dry in the air. They are stirred occasionally, and when the surface moisture appears to be evaporated, the test is performed. Since the aggregates on the job are in a moist condition, there is no point in oven-drying. It is just as easy, if not easier, to figure job-batch weights from the saturated, surface-dry condition as from the oven-dry condition. The test should never be made on aggregates containing surface moisture.

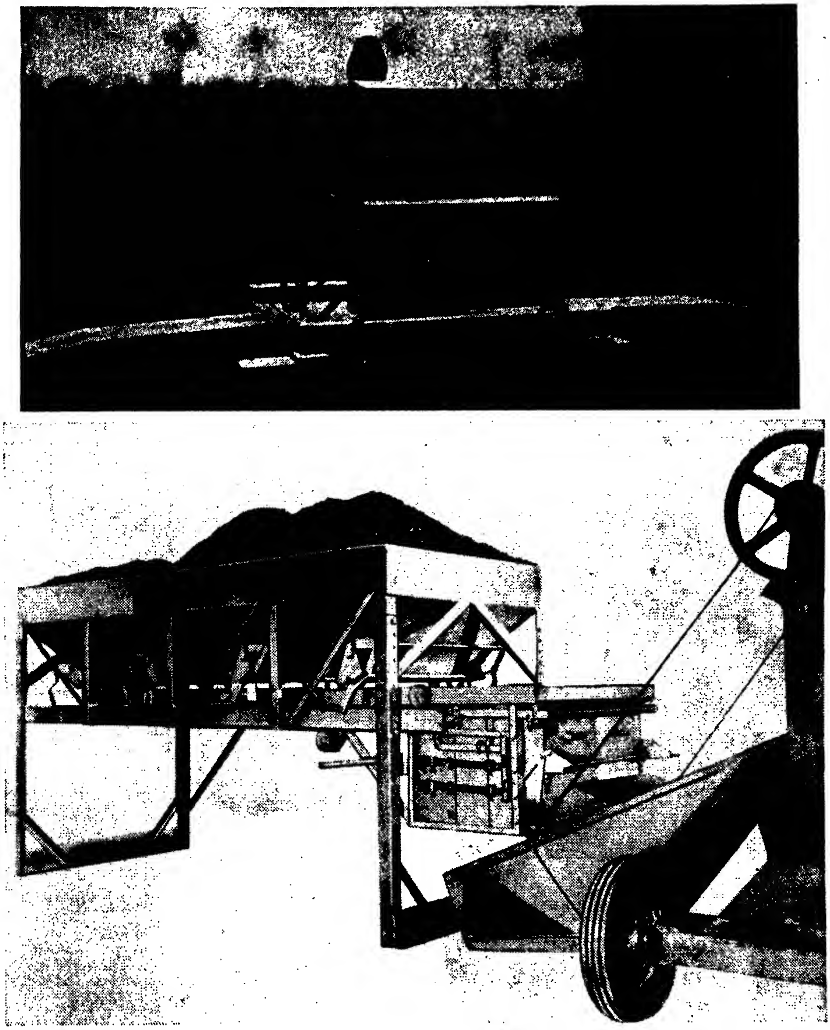


FIG. 8-6.—*Top,* portable weighing outfit for weighing materials in wheelbarrows. There is a lever arm for weighing three different amounts. The telltale indicator on top at left end of scale housing indicates whether the load is under or over the correct amount. Labor costs are high with this outfit.

Bottom, batching plant for mixers of sizes 6–S, 11–S, and 16–S. When the proper amounts of fine and coarse aggregates are weighed into the batcher hopper it is rolled to the end of the track where it is dumped into the skip of the mixer. Labor costs are low with this outfit. (*C. S. Johnson & Co.*)

Fine Aggregate.—Sand is most commonly used as fine aggregate. Because of the fact that it contains surface moisture in amounts from 2 to 10 per cent and that this surface moisture causes a bulking amounting to 15 to 50 per cent of the dry volume (see Fig. 8-7), it has become necessary to abandon the volumetric measurement. Weighing is the accepted method and is used on practically all jobs. For the small jobs, where the aggregates are deposited on the ground near the mixer, there are available small platform scales on which a wheelbarrow can be weighed. These are so made that both the fine and coarse aggregate can be weighed on the same scale very readily. Weighing of materials on all jobs regardless of size can be accomplished without any delay in the work.

Since the moisture content of aggregates varies from day to day, or even during the day, it is necessary to make determinations of the surface

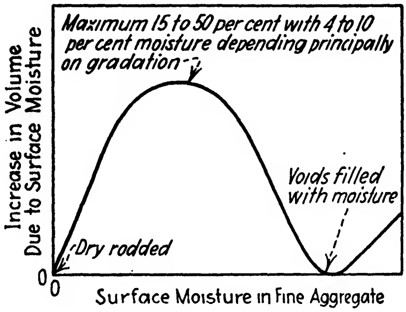


FIG. 8-7.—Showing the general effect on bulk volumes when the surface moisture in fine aggregate is varied. The volume of the fine aggregate when the voids are filled with water is only approximately equal to the dry, rodded volume.

moisture at frequent intervals. The frequency of such determinations will depend upon conditions on the job. After a little experience is gained, the inspector can easily tell when a test is necessary. There are several methods available for determining surface moisture: (*a*) surface drying, (*b*) A.S.T.M. flask (see Test 15) for sand, and (*c*) weighing in air and immersing in water, and knowing specific gravity, the surface moisture may be computed (see Test 16). As the fluctuations in surface moisture occur, the batch weights must be changed. If material in the stock pile is of a different moisture content than the newly received shipment, it may be necessary to take exclusively from the shipment until it is used up in order to have sufficient uniformity from batch to batch. When sand contains a very high percentage of moisture, such as it does when it comes from the washing plant, it may be necessary to hold it a few days until the moisture content is reduced to a more stable basis, since these wetter sands drain appreciably while being handled.

Uniform amounts of a given sand can be secured when measured under water volumetrically. This idea was put to practical use at one time for the measurement of sand for concrete. The device used was known as an inundator. The inundated volume of the sand was about the same as the rodded volume. When weighing of aggregates became general, the use of the inundator was discontinued.

Coarse Aggregate.—Much of the discussion under fine aggregate is also applicable to coarse aggregate. Even though coarse aggregates do not bulk because of the surface moisture in them, the practice of weighing

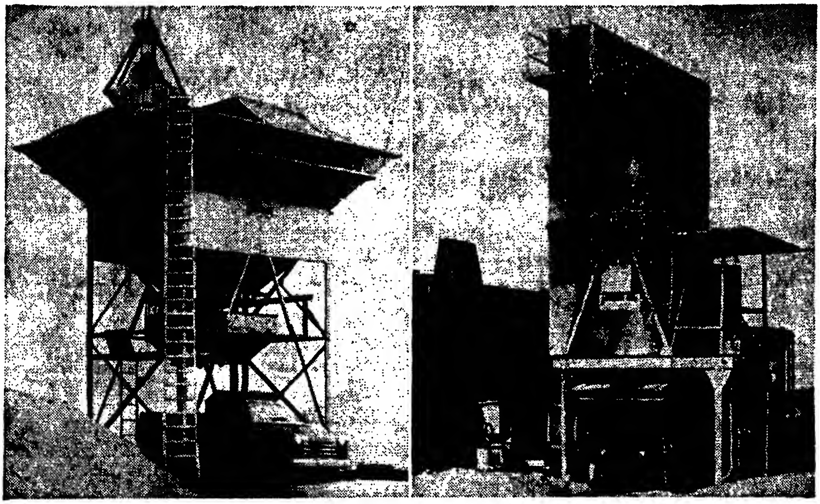


FIG. 8-8.—Roadbuilders' batching plant. (*C. S. Johnson & Co.*)

Aggregates are weighed as they flow by gravity from overhead storage bins and then are dumped into truck to be taken to mixer, as shown at the left.

Bulk cement is weighed as it flows by gravity from the enclosed storage bin shown at the right. The same truck hauls both cement and aggregates, moving from the aggregate to the cement batching units. The cement is moved horizontally from the bottom-dump car to the base of the storage bin by a screw conveyer and then is elevated by a bucket conveyer.

Batching units for cement and aggregates are normally separated a short distance from each other.

them has become quite general. Adjustments in batch weights must be made for surface moisture, the same as for fine aggregate.

MIXING

Mixing is the operation of incorporating the cement paste in the mineral aggregate. As actually performed, the cement paste is itself produced at the same time. All of the materials—cement, water, and aggregates—are placed in the mixer at the same time, and mixing is continued until the cement and water are thoroughly formed into a paste, which in turn must be distributed through the aggregate.

FIG. 8-9.—Charging the skip on a paving mixer. The mixer is a Koehring 34E Twinbatch Paver. The truck shown emptying into the skip will move ahead off the skip, the skip will be raised, and the cement and aggregates will slide into the first compartment of the mixer. Some truck bodies are large enough to carry several batches of materials. (*Koehring Company.*)

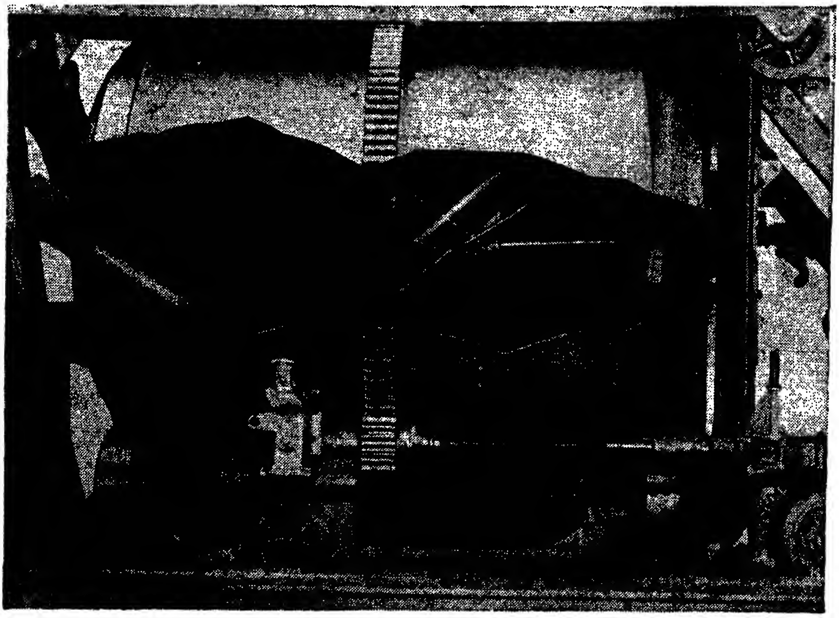


FIG. 8-10.—View of Koehring 34E Twinbatch Paver mixing drum with a portion cut away. There is a divider plate under the gear ring on the center of the drum which does not show in the picture. The divider plate creates the two mixing chambers. The batch is mixed first in the drum on the right and then transferred to the drum on the left using the transfer chute in the middle. When the mixing operation is completed, the concrete is discharged by the discharge chute on the left. Charging, transfer, and discharging operations are all synchronized so that there is no intermixing of batches and so that each batch has its proper amount of mixing. (*Koehring Company.*)

At first all concrete was mixed by hand, but today this method is impractical on all except the very small and unimportant jobs. Machine mixing is faster, cheaper, and produces better concrete.

Mixers.—The batch mixer is universally used at the present time. A batch mixer is one in which all the materials for one batch are placed in the drum, mixed, and discharged before any more materials are added. Some of the first mixers operated continuously, which accounts for the

FIG. 8-11.—View of Multifoote 34-E Duo Mix Mixer (dual-drum type). Note that the mixer is operating outside the forms. Concrete is delivered inside the forms using the bucket operating on the boom extending from the rear of the mixer. Cement and aggregates are delivered to the mixer skip at the front end of the mixer. (*Foote Company, Inc.*)

designation batch mixer. The old continuous mixer did not produce concrete of uniform quality and was therefore abandoned.

The mixing chamber of all mixers is known as a drum. Paddles are usually placed in the drum to aid in the mixing operation. The paddles also work the concrete toward the discharge end and thus aid in emptying the drum, which is accomplished by inserting a chute into the drum. Some mixers have drums that may be tilted to discharge the concrete. The tilting-drum type is much easier to clean in the smaller sizes.

Mixers are charged in one of three ways: with a skip, from a special storage hopper, or by direct shoveling into the drum. Only small mixers on unimportant work should be loaded by the last method. Stationary mixers usually use the second method, while the nonstationary ones use the first method. The skip receives the materials from the ground level and then elevates them in order that they will flow by gravity into the drum. For stationary mixers it is cheaper to elevate the materials a little higher with a clamshell in order that a small special hopper may be

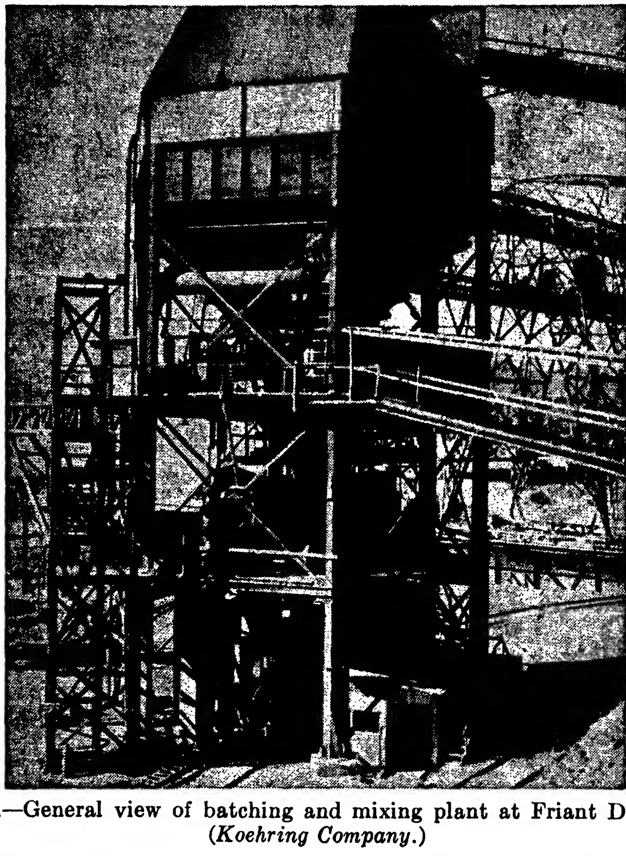


FIG. 8-12.—General view of batching and mixing plant at Friant Dam, Calif. (*Koehring Company.*)

placed between the measuring apparatus and the mixer. In some cases the material is run directly from the measuring hoppers into the mixer, as shown in Fig. 8-12.

Mixers are run by gasoline, electric, or steam power. Electric power, where available, is usually used for stationary mixers and gasoline for the movable ones. Steam is available for either type but is rapidly decreasing in use.

Dual-drum Mixers.—On several occasions in the early 1930's two paving mixers were operated in tandem. The concrete was mixed a portion of the time in the first mixer and then transferred to the second mixer for the balance of the mixing. From this use of two mixers in tandem developed the dual-drum mixer. The operations of discharging the second drum of its concrete, the transfer of the batch from the first

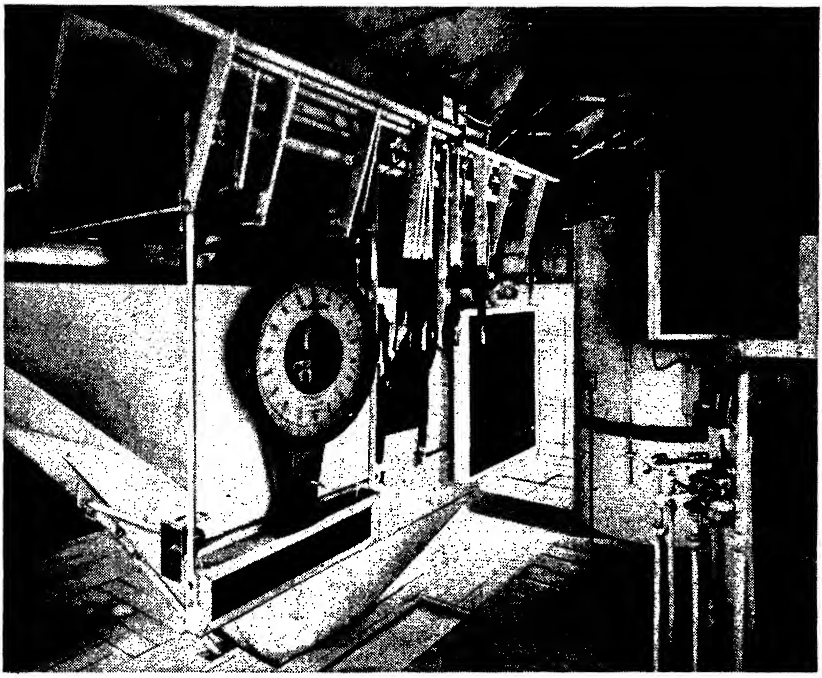


FIG. 8-13.—Batching equipment for a ready-mix plant. Aggregates are weighed using dial scale at the left and the cement using the beam scale to the right of the dial scale. Water is measured using the weigh-type water batcher shown at the right. The water batcher consists of a storage tank above and the weighing tank below. (*C. S. Johnson & Co.*)

to the second drum, and loading of the first drum are synchronized, and hence intermixing of the batches is negligible.

The advantage of the dual-drum mixer is that mixing capacity is doubled without increasing appreciably, except for the number of trucks supplying the mixer, any other items such as batching equipment, finishing equipment, and supervision.

Sizes of Mixers.—Mixers are made in a number of sizes ranging from about 1 cu. ft. to 4 cu. yd. Mixers under 3½ cu. ft. in size are used mostly by persons doing concrete for themselves who like to have a mixer of their own when they want it. The larger mixers of 2-, 3-, and 4-cu. yd. capacity are used mostly on jobs requiring large amounts of concrete.

Each size of mixer is given a number, and this number indicates the manufacturer's rated capacity of the mixer in cubic feet of mixed concrete. The manufacturer guarantees that the mixer will handle a 10

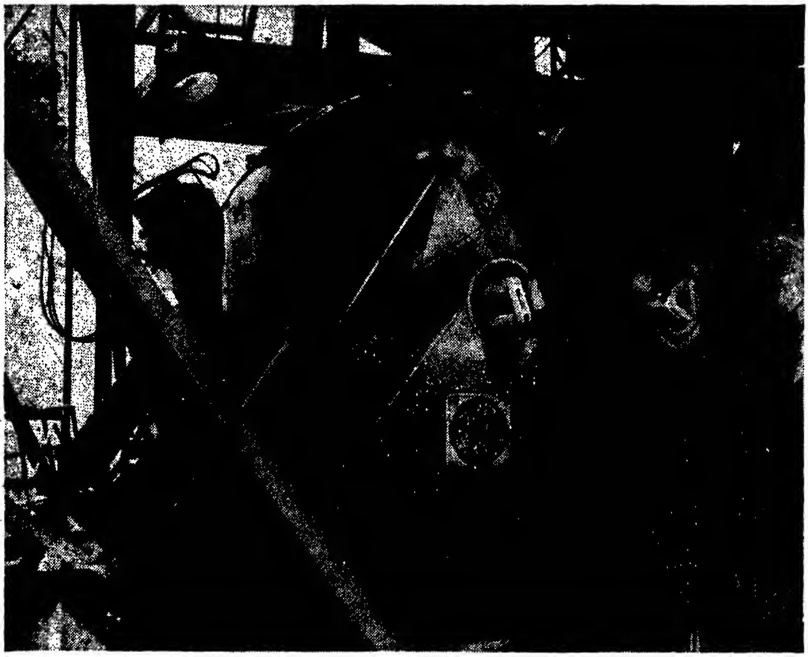


FIG. 8-14.—View of one of the No. 112-S tilting mixers used in the construction of Friant Dam in California. Mixer is in the discharge position. (*Koehring Company.*)

per cent overload satisfactorily, and most specifications permit this much overload but no more.

Sizes of construction mixers recognized by the Associated General Contractors of America in their concrete Mixer Standards, are 3½, 7, 10, 14, 28, 56, 84, and 112. Paving-mixer sizes are 13 and 27 in the single drum and 34 in the dual-drum type.

Time of Mixing.—The average mixer of approximately 1-cu. yd. capacity or less is designed in such a way that the concrete is satisfactorily mixed in from 1 to 1½ min., and practice today requires at least a full minute of mixing after all the materials are in the drum and before any of the concrete is discharged. It is generally considered that not enough additional strength is gained by increasing the time of mixing above 2 min. Recommended practice of the A.C.I. is 1 min. for mixers up to 1-cu. yd. capacity, and ¼ min. additional for each cubic yard of capacity.

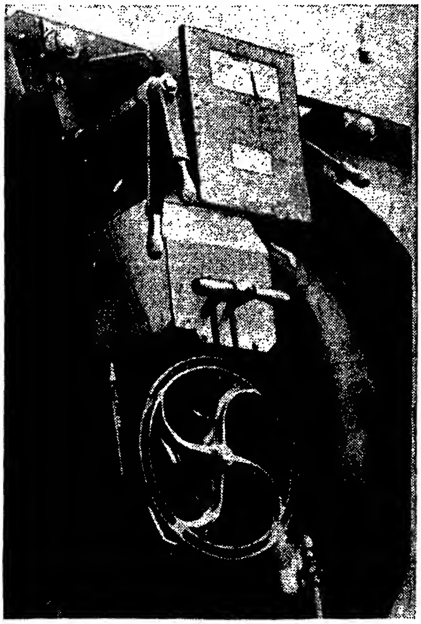


FIG. 8-15.—Batchmeter attached to concrete paving mixer to control primarily the length of mixing time. Mechanism is in the box in the upper center of the picture. To the left of the batchmeter is a green light, which is on while concrete is being discharged into the boom bucket. To the right of the batchmeter is a red light, which indicates to the mixer operator when he may start engaging skip hoist levers to raise the skip. The two vertical levers to the left of the batchmeter control the operation of the boom and the bucket. The two horizontal levers can be used to change from automatic mixing cycle to manual mixing cycle. (*Koehring Company.*)

Most mixers are designed for the drum to operate at a speed of 18 to 20 r.p.m. Increasing or decreasing the rate excessively above or below the rate specified by the manufacturer is likely to affect the thoroughness of mixing. Mixers should operate at the speed designated by the manufacturer as best.

In order to guarantee the proper amount of mixing, some engineers require a timing device to be placed on the mixer, which will start measuring time as the materials go into the drum and which will lock the discharge apparatus until the full amount of mixing is completed. A bell is usually rung to indicate when the time is up. Timing devices take the guesswork out of the mixing operation and should be on every mixer doing work on important jobs.

Ready-mixed Concrete.—With the development of equipment and methods for central mixing of concrete and for its subsequent distribution to various jobs or parts of the same job, has grown a business—that of selling what is designated as "ready-mixed concrete." Materials dealers, instead of selling the individual materials to make the concrete, have equipped themselves to mix the concrete and deliver it on the job ready to place in the forms. The dealers are able to sell the concrete for about the cost of the materials delivered individually on the job, thus making a saving to the contractor. The use of weighing equipment makes it possible to change mixes and sizes of batches easily.

Ready-mixed concrete may be centrally mixed and hauled to the job in trucks; may be mixed in a truck mixer that is charged with the batch at a central batching plant; or it may be partially mixed at the central plant and the mixing finished in the truck mixer. Concrete in the latter category is often called "shrink mixed."

The A.S.T.M. specifications for ready-mixed concrete are given in Chap. 12. In 1948 all but four of the state-highway organizations had provisions permitting the use of ready-mixed concrete in highway construction. Maximum, allowable hauling time varied from 30 to 90 min.

Truck Mixers.—The practice of mixing at a central location and hauling concrete to the job introduced the problem of segregation. The water and the finer materials come to the top, and the coarser particles settle to the bottom. Rehandling on the job eliminates some of the segregation but not completely.

Truck mixers were developed in order that freshly mixed concrete could be delivered at the job. The chassis for a truck mixer is much the same as for an ordinary truck. The drum is fixed in such a way that it can revolve and be raised at the front end when discharging. The drum is much longer along the axis than in the ordinary mixer. A mixing water tank is provided in order that the water can be added and the mixing done as required by the specifications. Water must also be carried along for the washing of the drum.

Tests by S. C. Hollister[1] on concrete from a truck mixer indicated that the speed of the mixer had no effect on the thoroughness of mixing nor the

[1] HOLLISTER, S. C., "Tests of Concrete from a Transit Mixer," *Proc. Am. Concrete Inst.*, Vol. 28, pp. 405–417 (1932).

strength, that the length of the mixing period had no effect between 40 rev. of the drum and 90 min. The strength curves for 28-day cylinders approximate the curve $S = 14{,}000/4^x$, which is given in Chap. 6 on proportioning. The minimum amount of mixing for this particular mixer was 40 rev. when the charge was placed in the mixer in such a way as to intermix the fine and coarse aggregate and 60 revolutions when there was no intermixing.

Tests by W. A. Slater[1] on concrete from a conveyer truck with no paddles inside the drum gave strengths increasing slightly as the time

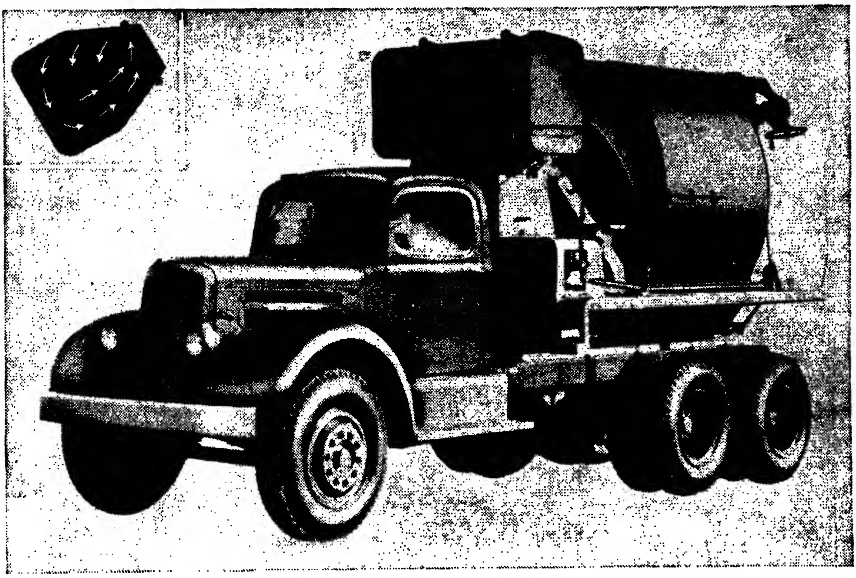


FIG. 8-16.—A 4½-cu. yd. Moto-Mixer Truck Mixer. When used as an agitator for hauling ready-mixed concrete its capacity is 6⅛ cu. yd. Truck mixers are also made with capacities of 2 and 3 cu. yd. *Insert* shows movement of concrete in the mixing drum. (*Chain Belt Company.*)

the concrete was agitated increased from 0 to 130 min. Both investigators found that as the length of mixing or agitating increased, there was some pulverizing of the aggregate.

Truck mixers are made to operate at what is known as an "agitating speed" of from 2 to 6 r.p.m. Mixing speeds are established by the manufacturer for his mixers. Mixing in the truck mixer is generally required to be at least 50 revolutions of the drum or blades at the mixing speed

[1] SLATER, W. A., "Tests of Concrete Conveyed from a Central Mixing Plant," *Proc. A.S.T.M.*, Vol. 31, Part II, pp. 510–525 (1931).

and not over 150 revolutions at any speed in excess of the agitating speed.[1]

Truck Agitators.—In order to overcome the segregation difficulties in connection with the hauling of ready-mixed concrete in ordinary truck bodies, special agitator trucks were developed. They are much like the truck mixer but operate at the agitating speed of 2 to 6 r.p.m.

Tests by Cook[2] at Louisville, Ky., indicated for his materials, equipment, and conditions, that:

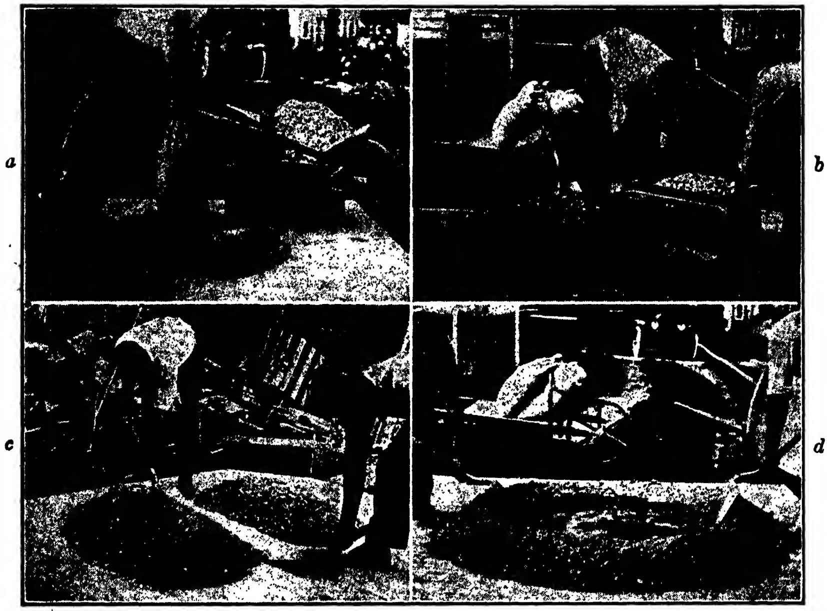


FIG. 8-17.—Steps in the mixing of concrete by hand.

1. Times of haul within normal specification limits results in no reduction in strength.

2. Excessive durations of haul, continued until the concrete is very stiff, result in strength losses generally less than 10 per cent.

3. Concrete having a slump of 4 to 5 in. immediately after mixing is decreased in slump by a 90-min. haul in an agitator about 1½ in.,

[1] "Recommended Practice for Measuring, Mixing and Placing Concrete," Am. Concrete Inst. Standard, 614-42.

[2] COOK, G. C., "Effect of Time of Haul on Strength and Consistency of Ready Mixed Concrete," *Proc. Am. Concrete Inst.*, Vol. 39, pp. 413–425.

when the concrete temperature is about 60°F. and 2½ in. when the concrete temperature is 80°F.

4. The amount of grinding is negligible for normal lengths of haul.

Hand Mixing.—At one time people generally felt that hand mixing was superior to machine mixing, but the mixers have so much in their favor now that in most cases hand mixing of concrete is not permitted. Hand mixing occasionally is necessary and the accompanying pictures (Fig. 8-17) are included to show how the operations are carried out. After the materials are carefully measured, the cement and sand should be mixed first dry. Then the coarse aggregate should be spread over the cement-sand mixture, and the whole remixed again. A crater is then formed in the center into which the mixing water should be poured. As soon as the water has been all taken up, the mixing may proceed.

Study Questions

1. How is cement transported from the manufacturing plant to the job? How are the aggregates transported?

2. Why does a contractor need to store a reserve supply of cement and aggregates?

3. What provisions need to be made concerning storage of cement?

4. What is meant by pyramiding? Is it good or bad practice?

5. How is each of these materials measured for a batch of concrete: Cement? Fine aggregate? Coarse aggregate? Water?

6. What is the objection to the volumetric measurement of the materials other than the water?

7. What is meant by the term bulking? What causes it? Which material is affected the most?

8. What kind of a mixer is used in mixing concrete? How are the materials put into the drum of the mixer? Which method is considered not good practice?

9. What is the range of sizes of concrete mixers? How is the size indicated?

10. What is meant by the manufacturer's rated capacity? by manufacturer's guaranteed capacity? At what percentage of the manufacturer's rated capacity is the mixer normally used?

11. What are the advantages of the dual-drum mixer? How does it work?

12. What is the usual rule for minimum mixing time? How is it controlled on mixers? What would be the mixing time under the rule above for a No. 13 mixer? a No. 34 mixer? a No. 112 mixer?

13. What is meant by ready-mixed concrete? by the term "shrink-mixed" concrete?

14. What is a truck mixer? What are the reasons for its use?

15. What is an agitator? What are the reasons for its use?

16. Explain how to mix properly concrete by the hand-mix method.

CHAPTER 9

PLACING, FINISHING, AND CURING OF CONCRETE

Distribution and Placing

Distribution and placing of the concrete involve its movement from the mixer to the final place in the finished structure. Methods and time involved may affect the strength and quality of the concrete. Conditions on various jobs are different, and the proper method must be determined for each one.

Time Limit.—Most engineers require that concrete must be placed in the forms within from 30 to 90 min. after it is mixed. In setting an arbitrary limit, such as 45 min., several factors that bear on the question are neglected. It is considered desirable to have the concrete in its final place before the cement has taken its initial set. Temperature affects the rate of setting. Time of setting is determined at 70°F. Temperatures above 70°F. hasten the setting, while temperatures below 70°F. retard the setting. In hot weather the time limit should be shorter than that for colder weather.

The other factor neglected is the time of setting of the cement itself. At 70°F. all cements are required not to have taken their initial set within 1 hr., as measured with the Gillmore needles, or 45 min. with the Vicat apparatus. Some cements have times of initial set as much as 3 hr.

Laboratory tests[1] of remixed concrete indicate that remixing up to 6 hr. had no harmful effects on the strength of the concrete, provided the mixtures remained plastic and workable and provided no mixing water was added. When mixing water was added, the strength corresponded with that for a water-cement ratio equal to the original water-cement ratio plus the increment added. The specification for ready-mixed concrete (A.S.T.M. C 94) permits a period of 90 min. to elapse between the introduction of the mixing water and the placing of the concrete for concrete transported in a truck mixer or an agitator.

Engineers have generally been of the opinion that concrete or mortar should not be retempered, that is, remixed with or without additional

[1] Gonnermann, H. F., and P. M. Woodworth, "Tests of Retempered Concrete," *Proc. Am. Concrete Inst.*, Vol. 25, pp. 344–387 (1929).

mixing water, and have as a rule included such a provision in specifications. No mention of retempering is made in the specifications for ready-mixed concrete quoted in Chap. 12.

Methods of Distribution and Placing.—The methods of distributing and placing on any job will depend upon the existing conditions. Only general situations can be discussed here.

Paving Mixer on Subgrade.—The simplest operation of distribution and placing occurs when a paving mixer is moving along the subgrade.

FIG. 9-1.—Concrete being discharged from a truck body, known as Dumpcrete, on a pavement-widening job in Tulsa, Okla. This truck body was designed primarily to haul air-entrained ready-mixed concrete without agitation. The high dumping position permits concrete to be chuted into wall or slab forms, or into concrete buckets or buggies. It is not necessary for the truck to operate on the subgrade between forms on paving work. Bodies are made to handle 2, 3, or 4 cu. yd. of concrete. *Insert*, body in the horizontal, hauling position. (*Maxon Construction Co., Inc.*)

The concrete is emptied first into a bucket operating on a boom on the mixer. From the bucket it is dumped into place in the pavement. Workmen with shovels spread it around approximately to the proper grade. On country road work mechanical finishing machines are sometimes used. Methods of finishing are discussed further on in this chapter.

The cost of distribution in this case is low but is counterbalanced by a high cost of getting the materials into the mixer.

Central Mixing Plants.—On many highway jobs and on some building construction, the concrete is mixed at a central mixing plant located at the railroad siding or the gravel pit. Movement of the mixed concrete is usually done with automobile trucks. Occasionally, industrial railroad equipment is used. The trucks have a capacity of from ½ to 2 cu. yd., and the truck of about 1-cu. yd. capacity is common. Some contractors prefer light trucks carrying small loads, while others prefer the larger types with greater carrying capacity.

Trucks for hauling ready-mixed concrete should be designed to dump upon the release of a catch by the driver. Frequently some of the concrete will remain in the truck, and unless the body is held in the dumping position, it will return to the normal loaded position. It is only with difficulty that the body can be gotten to the dumping position again.

Whenever ready-mixed concrete is used on building construction, a receiving hopper must be provided into which the concrete may be dumped from the trucks. This hopper should be so designed and placed as to permit a minimum of manual handling of the concrete.

On construction jobs that cover a larger area, it is possible to use narrow- or standard-gauge railroad equipment. The concrete can be mixed at a convenient point nearby and transported in containers on the railroad cars.

Methods of distribution at the building site will vary considerably and will depend somewhat upon the personal preferences of the men in charge. The various methods may be listed as follows:

1. Chuting
2. Elevator and buggies or wheelbarrows
3. Overhead cableway
4. Belt conveyer
5. Pumping through pipes

Chuting.—In this method the concrete is elevated in order that it will flow by gravity down chutes into place in the forms. It has generally been considered necessary to use rather wet consistencies when the chuting method was employed, but on more recent jobs drier consistencies have been successfully used. Concrete with as low as a 2-in. slump may be chuted if the gradation of the aggregate is correct. As an aid in the chuting small vibrators have been attached to the chutes, or in other cases, the chutes have been made to revolve.

Most of the chuting work has been done where the proportions were arbitrarily specified and based on dry volumes, and it has been the general practice to use wet consistencies, which have caused segregation and weak concrete. When chuting is permitted, the specifications should outline a method of supervision that will secure uniform concrete of the strength desired.

Concrete Buggies or Wheelbarrows.—Another method of distribution is to raise the concrete sufficiently (usually in an elevator) in order to discharge it into a hopper, from which it may be taken by gravity into concrete buggies or wheelbarrows to be moved (horizontally only) to the forms. This method of distribution is applicable to the smaller bridge jobs and to buildings and sidewalks. It permits the use of stiffer mixes than in the chuting method.

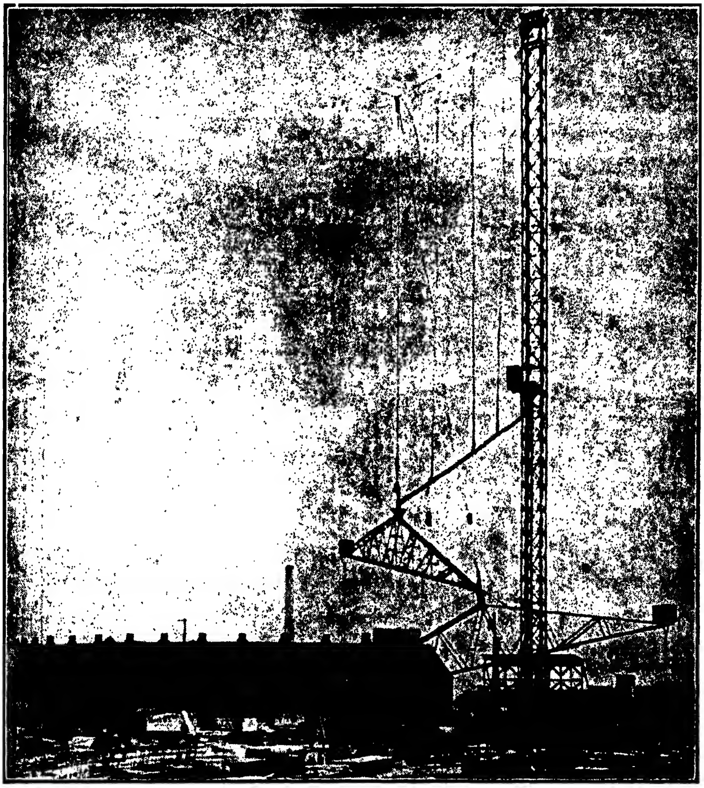


FIG. 9-2.—View showing a 240-ft. tower and chutes for distribution of concrete.

Overhead Cableway.—Concrete construction jobs covering large areas or of great length are especially adapted to the use of an overhead cableway for the distribution of the concrete. Long bridges and dams, sewage-treatment and water-storage basins come in the above classifications.

In most cases the cables are operated from steel towers, which can be moved perpendicularly to the axis of the bridge or dam or along the area it is serving. The towers operate on wide-gauge railroad track.

FIG. 9-3.—Power-driven unit used in distributing concrete. This unit, known as the Bell *Prime Mover*, is intended for horizontal distribution but will climb grades up to 20 per cent. Its capacity is 10 cu. ft. of mixed concrete. (*Bell Aircraft Coroporation.*)

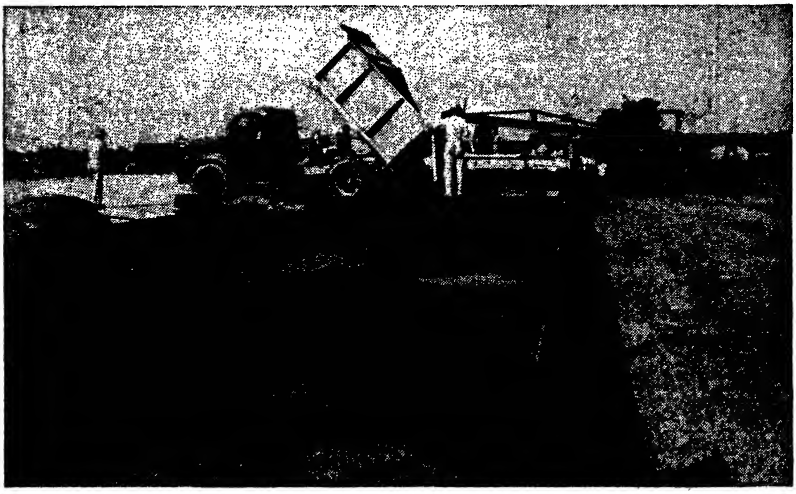


FIG. 9-4.—A truck dumping central-mixed concrete into place from a rolling steel-frame bridge riding on the forms. The volume of concrete needed on this airport job was such that five dual-drum 34-E mixers were used. Three were set up for central mixing and two operated along the runway, one of which can be seen beyond the truck. (*Courtesy of Engineering News-Record.*)

On Norris Dam two cableways were used. A large bucket for transporting the concrete is operated back and forth on this cable. When the concrete being distributed by an overhead cableway is going into comparatively thin sections, it is necessary to have a receiving hopper between the bucket and the forms; otherwise the force of the falling concrete might wreck the forms. The overhead cableway has proved satisfactory on a number of jobs because it has been available to move materials and equipment quickly and easily.

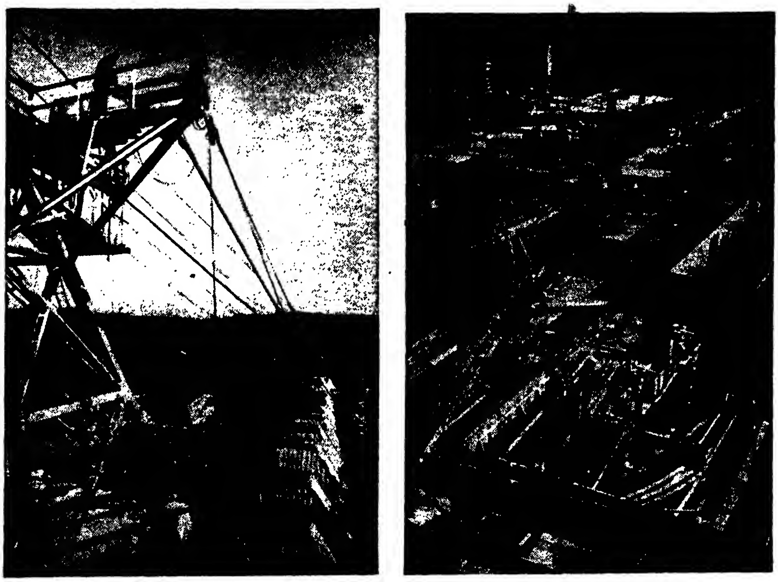


FIG. 9-5.—Showing two methods of distributing concrete. *Left*, general view of Norris Dam, Tennessee Valley Authority project, on which two overhead cableways were used in placing concrete and penstocks and in the handling of forms and equipment. *Right*, a series of belt conveyors used on a building job.

Belt Conveyor.—Another development in methods of distribution is the belt conveyer, which moves the concrete both horizontally and vertically. Concrete of any consistency necessary in reinforced-concrete work can be moved on the belt, which may be run at an angle of 45 deg. or less with the horizontal.

Pumping Through Pipes.—Concrete is being successfully pumped through pipe lines, single or double-acting displacement pumps being used. The pump is located at a convenient spot for delivery of the mixed concrete. A 6-, 7-, or 8-in. pipe line is laid to the part of the job where the concrete is desired. Turns must be made with long radius bends, and the pipe and turns must have a continuously smooth, inside surface. Sections of pipe are designed to be easily and quickly assembled or disassembled. After the last concrete has been put through the pump, a plug known as a "go-devil" is inserted in the line, and water pressure is used to force through the plug. Air pressure is sometimes used but is considered too dangerous for regular use.

Concrete has been pumped as far as 220 ft. vertically (with a booster pump at 140 ft.) and about 1,000 ft. horizontally. Additional horizontal

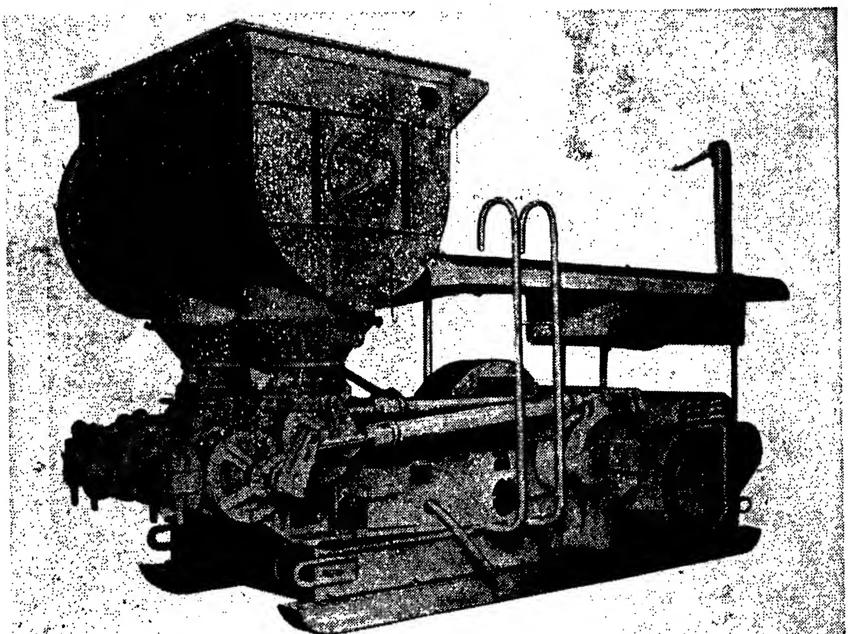


FIG. 9-6.—View of double-acting pumping unit, known as the 200 Double Pumpcrete. It is for use with 8-in. pipe and has a capacity of 50 to 65 cu. yd. per hr. (*Chain Belt Company.*)

distance may be secured by installing an additional pumping unit at the limit of pumping of the first unit. Pumping has been used on various types of job, including dams and locks, buildings, bridges, elevated structures, reservoirs, filtration and sewage-treatment plants, subways (including some in which the concrete was placed under air pressures greater than atmospheric), tunnels, and underwater concrete operations.

Practice has indicated the advisability of using a remixing device just ahead of the pump, since many of the operations following the original mixing cause segregation of the concrete ingredients. Remixing also often makes the concrete flow more readily into the pump cylinder, thus increasing the pumping rate.

Placing Concrete under Water.—It is frequently necessary to place concrete under water. This can be done without a great deal of extra effort and without injury to the concrete. Portland cement will set and gain strength under water, and hence the only unusual problem is to get the concrete in place without washing the cement away from the aggre-

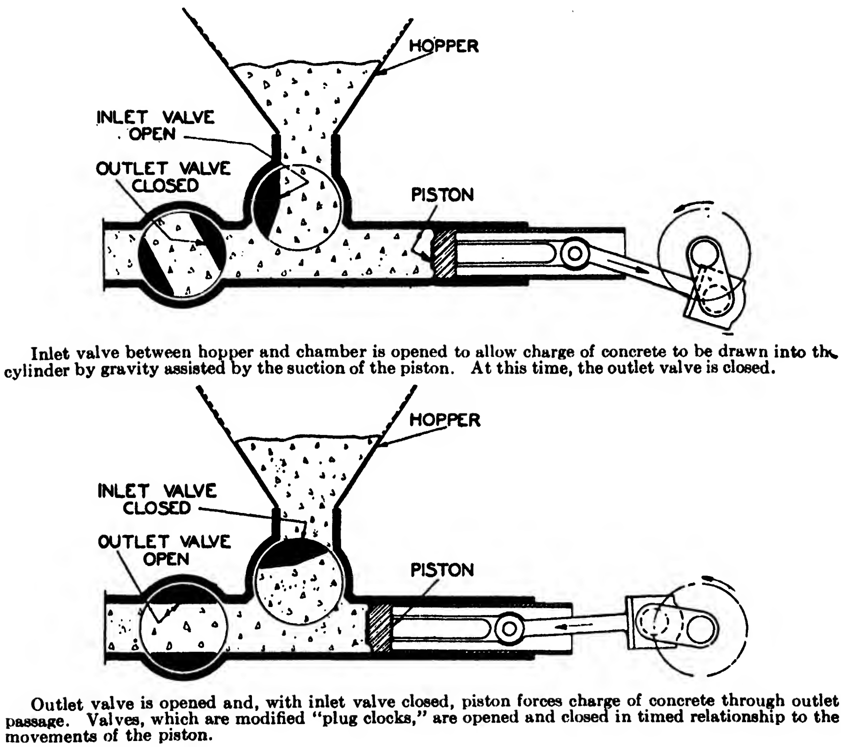


FIG. 9-7.—Sketch showing how the Pumpcrete unit functions. (*Chain Belt Company.*)

gates. Concrete should not be allowed to drop unprotected through water. The best method of depositing concrete under water is with the "tremie" pipe. The tremie pipe may be from 6 to 14 in. in diameter and must be long enough to reach from the surface of the water down to the concrete. The pipe is first filled with concrete and lowered into the water until it reaches the bottom. Then as more concrete is added at the top, some is permitted to flow out at the bottom. Once the flow of concrete is started, the bottom of the pipe is kept below the surface of the soft concrete. With this method there is practically no washing out of the cement. The pour should be continuous until the concrete is above the surface of the water. Otherwise, there may be a porous seam where two different pourings join.

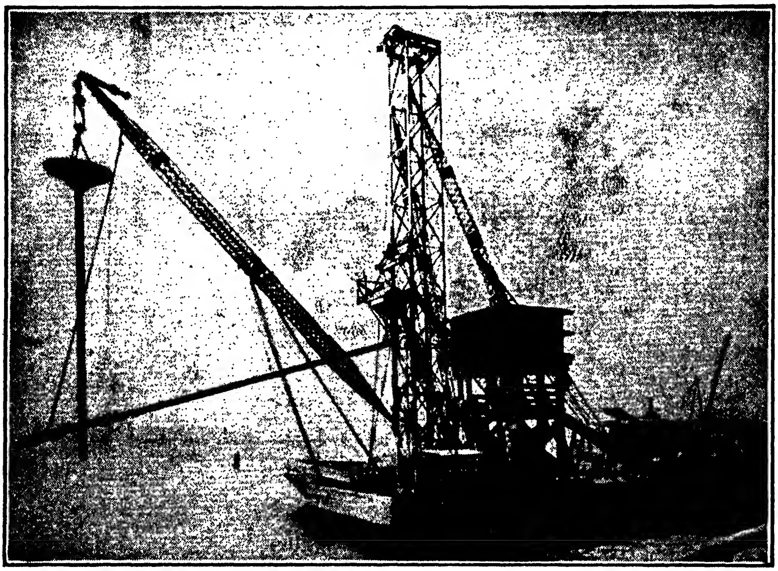


FIG. 9-8.—Mixing and placing plant for underwater concentration purposes. A 1-yd. mixer is mounted on the barge with an overhead bin, the mixer discharging directly into the bucket of the steel tower. A boom is mounted on the tower supporting a feed chute from the tower and also supporting a tremie chute with feed hopper. The end of the chute from the tower discharges directly into the tremie chute when it is lowered into the water, and the feed chute is made adjustable so it can be moved forward and backward as the position of the tremie chute changes. Tackle is arranged on the boom for raising and lowering the tremie chute.

Another method of placing concrete is to use buckets to take it from the surface to its position under water. Some washing out of the cement takes place as the concrete is dumped from the bucket.

The most important objection to the placing of concrete under water is that it is impossible to see what is being done. The concrete placed under water would in most instances be the foundation for some structure.

Vibration.—An important development has been the use of the vibrator in the placing of concrete. Vibrators are of two types—internal and external. In the internal type the vibrating unit operates in the freshly placed concrete, while in the external type it is placed on the forms, the reinforcing steel, or on the surface of the concrete. Power for the operation of the vibrators is usually electricity or compressed air.

Use of vibration in placing concrete is as much of an improvement over hand-placing methods as machine mixing was over hand mixing. On the other hand, there are many details to be observed in the use of the vibrator in order for it to produce the required results. If the concrete is not correctly prepared for vibration, vibration will not compact it properly. The vibrators, too, must be properly designed, with enough power to set up vibrations in the mass of concrete. There are also indications that the number of vibrations produced in the concrete must be at least 3,600 per min.

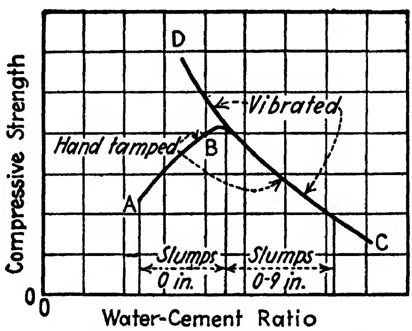


FIG. 9-9.—Typical comparison of water-cement-ratio strength curves for concrete compacted by hand tamping and vibration. In the illustration the mix of dry materials is kept constant. It is only when the concrete is too dry for hand tamping that the vibrator can increase the strength and then only for a comparatively small range of consistencies.

Vibration will reduce the cost of placing as compared with hand tamping. The labor item is reduced considerably, which is partially offset by the cost of the vibrator and the cost of operation.

Vibration will normally produce a concrete of greater density, which is a benefit in that it will be more resistant to the movement of water through it.

Water-cement-ratio strength curves for vibrated and hand-tamped concretes are the same. If a concrete has the proper consistency for hand-tamping methods of compaction, vibration will not add anything to the strength. On the other hand, concretes dry enough to show a zero slump may have their strength increased by vibration. Curve *ABC* in Fig. 9-9 is typical of what is secured when the mixing water is varied over a wide range for any given mix of dry materials. Concretes represented by the portion *AB* are dry when compacted by hand tamping, while for the wetter portion of this range the same concretes when vibrated will produce a strength curve represented by *DB*. It is only in the range of the drier concretes that vibration can increase the strength for any given water-cement ratio.

On jobs where the water-cement ratio is specified, vibration will permit of a reduction in the cement content of the concrete, which in turn will reduce the cost as well as the volumetric changes in the concrete. One investigator,[1] for instance, found that in placing concrete in walls vibration would permit a reduction in slump from 6½ to 1 in. for a placement period of 60 sec. The reduction in slump when the water-cement ratio is held constant is accomplished through the addition of more aggregate. The cement content was reduced from 6 to 5 bags per

FIG. 9-10.—High-speed electric vibrators mounted on rear of spreader are used to vibrate the lower 17 in. of a 21-in. runway slab. (*Courtesy of Engineering News-Record.*)

cu. yd. Field tests by Powers[2] indicated that concrete of any given strength could be produced by vibration "with 1½ to 2 sacks per cu. yd. less cement than is required for mixes suitable for hand placing." Powers also points out that the water content of concrete may be reduced 8 or 9 gal. per cu. yd. by vibration as compared to hand placing. Concrete for Hoover Dam, which was vibrated, had a cement content of approximately 1 bbl. per cu. yd. Another advantage of a reduced cement content is of particular value in mass concrete, in that the heat developed in setting is smaller with the smaller cement contents.

[1] DAVIS, R. E., and H. E. DAVIS, "Compaction of Concrete Through the Use of Vibratory Tampers," *Proc. Am. Concrete Inst.*, Vol. 29, pp. 365–373 (1933).

[2] POWERS, T. C., "Vibrated Concrete," *Proc. Am. Concrete Inst.*, Vol. 29, pp. 373–381 (1933).

Vibration has another advantage over hand-tamping methods in that concrete can be placed easier and with better results in intricate forms and around complicated reinforcing steel.

Vibrolithic Concrete.—Vibrolithic concrete was a patented variety of vibrated concrete used in pavement construction. A layer of 1:2:4 concrete 6 to 7 in. in thickness is first laid and struck off as in the regular type. Then a layer of crushed granite or trap rock is spread over the surface. Wooden mats made of narrow slats are laid on the concrete and a vibrating machine run over the mats. The aggregate is settled, and a layer of mortar is brought to the surface. The mortar is struck off and belted in the usual way.

FINISHING

Concrete surfaces may be finished by any one of the following methods shovel, wooden float, canvas belt, steel trowel, spading tool, or grinding stone. The finish given will largely depend upon the use to be made of the surface.

The finish produced by going over the surface of the concrete with the back of a shovel is known as a shovel finish. Shovel finishes are sometimes given to pavement bases for bituminous wearing surfaces or to surfaces that are later to be covered with a portland-cement mortar coating. Shovel finishes are not very smooth or attractive and are not recommended as good practice.

A float finish is secured by going over the surface with a wooden float. Wooden floats are of two types—hand floats and long-handled floats. Hand floats are used where a reasonably smooth surface is desired, such as on a sidewalk. The long-handled float is used on larger surfaces where a bridge would be necessary in order to use the hand float. The long-handled float does not produce as smooth a surface as the hand float.

Canvas belts may be used to give about the same kind of a finish as the wooden float. The advantage of the canvas belt over the float is that the labor costs are much less. The canvas belt may be used on sidewalks or pavements.

A steel trowel produces a much smoother surface than does any of the other tools mentioned. It works better on mortars than on concrete. The steel trowel may be used to finish floors, steps, sidewalks, or any horizontal surface. Sidewalks, however, should be finished with the float because the steel-trowel finish when wet is dangerously slippery

Vertical surfaces are usually finished by spading the concrete as it is placed in the forms. The purpose of spading is to bring mortar to the surface against the form and to compact the concrete.

Where an unusually smooth surface is desired, the concrete may be finished with a grinding stone. In such cases it is not uncommon to use special aggregates near the surface in order to produce certain color effects or designs. The grinding is continued until the cross section of the aggregate is shown. Floors and walls of buildings are frequently finished in this manner. Sometimes the surface is smoothed up with a carborundum stone after the forms are removed.

Any surfaces of concrete exposed to the elements should be dense to prevent water from seeping in. Continued wetting and drying or freezing and thawing will in time disintegrate the surface unless the concrete is made strong enough to withstand such actions. Special

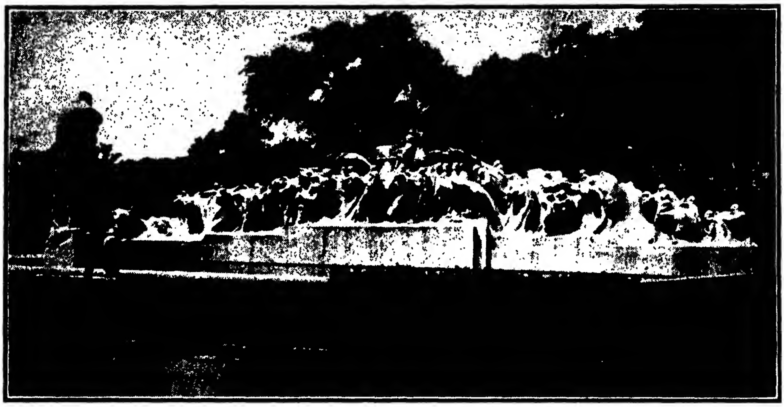


FIG. 9-11.—Lorado Taft's Fountain of Time at Chicago, Ill., was made with concrete.

effort should be made on exposed surfaces to secure dense, durable concrete in order to withstand this extra strain.

Ornamental Finishes.—Concrete is normally thought of as a material that lacks possibilities for ornamentation purposes, but this is not true. John Early, of Washington, D. C., did some very fine work with an exposed-aggregate concrete. Architects are using portland-cement stucco to secure desired color effects and designs on exterior walls. In other cases they are using the polished surfaces mentioned above. Designs are also being painted on the concrete. Brief descriptions will be given of each.

Work of John Early.—Early's work may be divided primarily into two classes: ornamentation of interior or exterior surfaces using a portland-cement mortar and the reproduction in concrete of the work of sculptors. In the ornamentation of the surfaces, parts of the work may be prepared in the workshop and set in place on the job, or it may all be constructed in place. Ordinary gray cement is used, and the color effects are obtained from the aggregates, which may be crushed marble, colored burned shale, or colored glass. Portions of the work prepared in the workshop are cast in a horizontal position. As soon as the mortar is hard enough, the cement paste is brushed from the surface exposing the aggregate. When the work is done in place on the job, a mortar backing is spread and while it is soft, the colored aggregates are applied. The Shrine of the Sacred Heart in Washington, D.C., is probably Early's most notable work in this field.

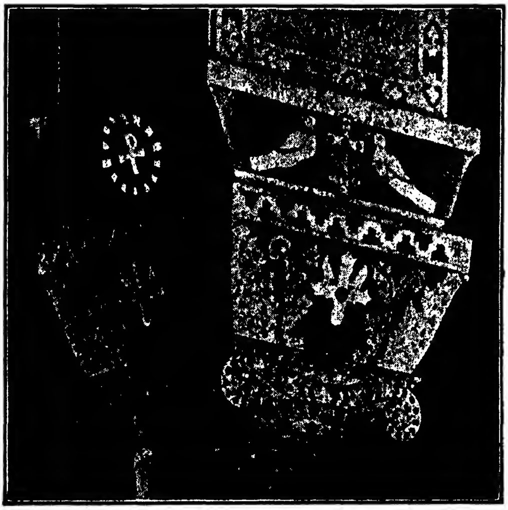


FIG. 9-12.—Detail of a column in the Sacred Heart Church, Washington, D.C.

In the other field, Early has done Lorado Taft's Fountain of Time group on the Midway in Chicago, the Black Hawk statue along the Rock River, and the Bear Pits in Forest Park, St. Louis. A more recent project has been the making and placing of the concrete ornamentation on the Bahai Temple at Wilmette, Ill.

Art Marbles.—Imitation marbles are being produced using colored cements and crushed marbles for the aggregate. In some cases no effort is made to imitate marble, but certain patterns or designs are worked out through the use of colored cements and marble aggregates. In either case the methods are alike.

Concrete made with cements and aggregates of the desired colors are molded into the required shapes. Normally, only the surface layer about ½ in. in thickness is made with the special materials. Cheaper materials are used for the backing-up concrete. After the concrete has hardened properly, the surface is ground away until the aggregate is exposed in cross section. Almost any color, combination of colors, or shape can be secured. The cost compares favorably with that of marble. This work is all done in the factory, and the finished pieces are put in place as needed on the job.

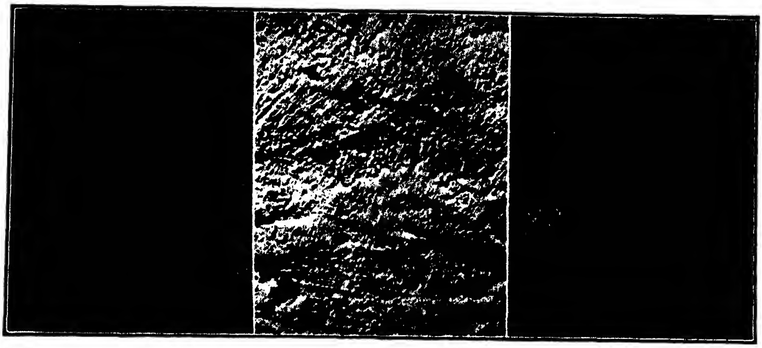
Terrazzo.—Terrazzo is a form of art marble but is made in place in the structure. It is used mostly for floors in homes and public buildings of all kinds. The concrete is placed first in the usual manner. Colored aggregates are then spread over the surface and rolled in. As soon as the concrete has hardened sufficiently, the surface is ground to expose the aggregates. Designs can be worked in or not as desired.

Cast Stone.—Exterior walls of buildings are being built with blocks of concrete that resemble cut natural stone. These are made of the same quality of concrete all the way through. Wetter mixes are used than in the case of the concrete building blocks mentioned previously. The concrete is permitted to remain in the molds at least 24 hr. The block manufacturer has a secret method of securing the surface that resembles the cut stone.

Stucco.—Portland-cement stuccoes are being used on the exteriors of homes and public buildings. Certain color effects and designs may be secured by the inclusion of a coloring compound or by the use of colored aggregates after the stucco is in place, but before it has hardened. Rough or smooth finishes may be produced by the man doing the work. Certain designs or patterns may be worked in by shaping the stucco. A dash coat of colored stucco is extensively used on the Pacific coast on monolithic walls to control color without changing the texture of the concrete.

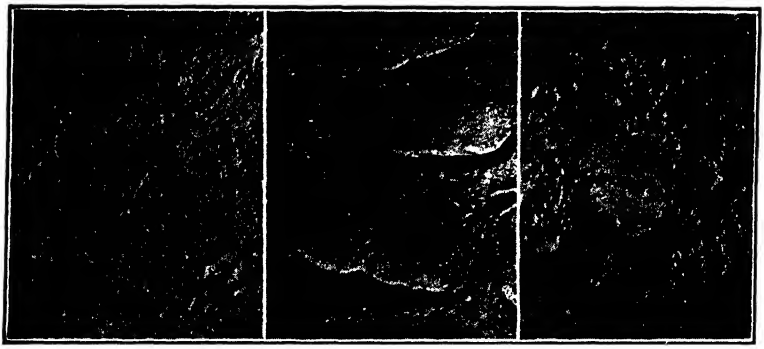
Painted Decorations.—A great variety of decorative effects may be secured by staining and painting concrete surfaces. The final effect secured will depend somewhat upon the texture and freedom from blemishes of the surface. Special care must, therefore, be exercised and only experienced workmen employed when the best results are desired.

After the concrete has had a sufficient amount of moist curing, it should be thoroughly dried out before proceeding with the decorating work. A coat of aqueous solution of zinc sulfate (4 lb. of crystallized zinc sulfate to 1 gal. of water) should be applied first in order to neutralize any lime that may be on the surface. By tinting the solution with a pigment color, the danger of leaving untreated areas may easily be avoided.



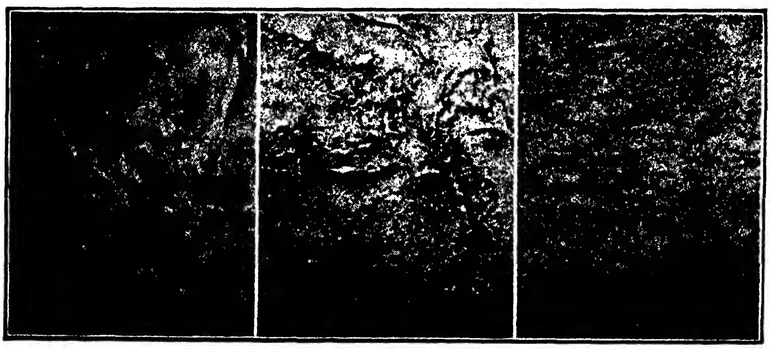
a b c

a. Colonial. Sanded surface finished with wood or cork float.
b. California texture. A carpet floated rough cast.
c. French trowel. Finished with a sweep stroke of the trowel.



d e f

d. Italian Cottage. A sponge finish on a soft plastic surface.
e. English. Spotted by side stroke of trowel.
f. Italian. A troweled rough cast.



g h i

g. French Brush. Uneven sand surface, hand rubbed.
h. Spanish. Feathered with wood float.
i. English Cottage. Feathered with edge of trowel.

FIG. 9-13—Some stucco finishes.

After an interval of at least 48 hr., a primer coat of boiled linseed oil should be applied to prevent the stain or paint from penetrating too deeply in the concrete. Pigment color should also be added to the priming coat for the same reason as given above. If the concrete is dense add turpentine to the oil in order to secure the desired penetration.

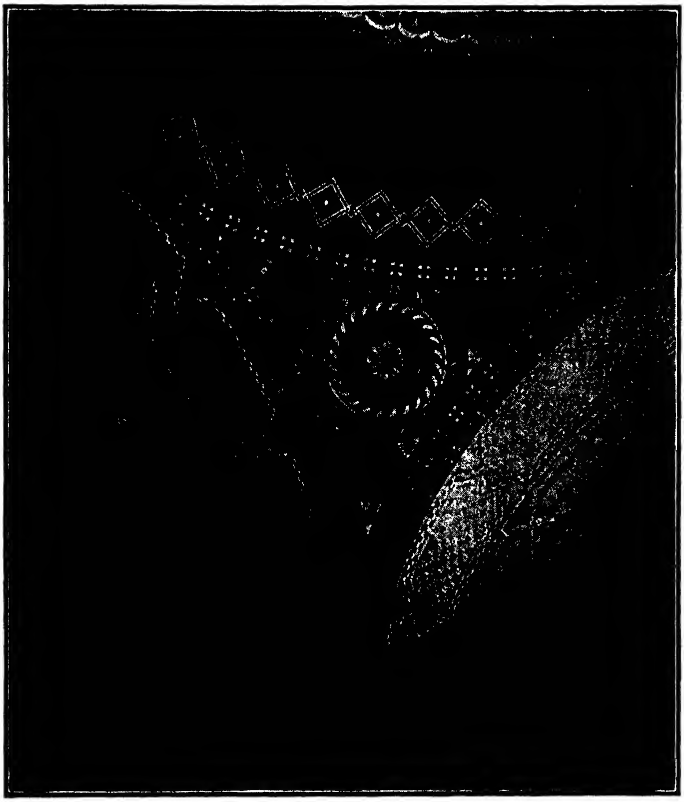


FIG. 9-14.—Painted decoration of ceiling in Los Angeles Public Library. Paint and stain were applied directly to the concrete.

As soon as the priming coat is dry, the surface is ready for the stain or paint. Stains consisting of a mixture of boiled linseed oil and Chinawood oils, thinned with turpentine or naphtha, and colored with pigments have proved satisfactory. A high-grade linseed-oil paint can be used as a stain if thinned sufficiently. Pleasing effects have been secured by staining the entire surface and then stenciling designs on with paint. Thin clear varnish or shellac will protect the painted surfaces.[1]

[1] For a more complete description see "Concrete in Architecture," a brochure prepared by the Portland Cement Association.

Finishing Concrete Pavements.—There are a variety of methods and combinations for finishing concrete pavements. First the concrete must be struck off to the desired shape and grade. A strike-off that operates on the side forms is the only method of securing a satisfactory surface. Long-handled floats or lutes have proved to be generally unsatisfactory.

Power-driven finishing machines are now used wherever it is possible. There are a number of types of these machines. The first operation is that of striking off the surface after workmen have spread the concrete

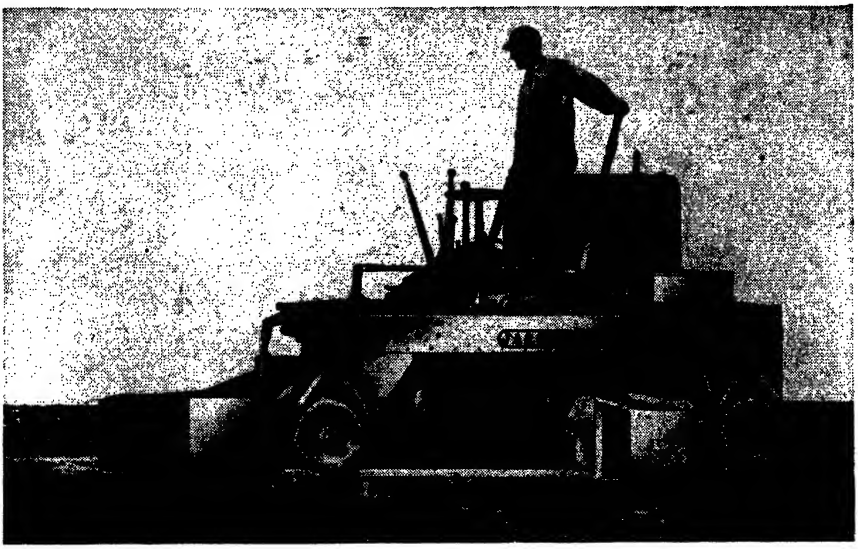


FIG. 9-15.—Jaeger diagonal screed finishing machine. (*Jaeger Machine Co.*)

over the subgrade. In the early days of concrete paving work a tamper was quite generally used but rarely today. Now some of the machines are equipped with a surface vibrator for the purpose of compacting the concrete. Following the use of the vibrator there is a second smoothing operation, employing a screed operated at right angles to the center line.

In some instances a longitudinal float is next operated over the surface, either by hand or mechanically. The purpose is to remove irregularities caused by the previous operations. The ridges left by the longitudinal float are removed by a hand-operated, long-handle float. By this time the concrete should be stiffening (or setting), and hence the hand float cannot produce new irregularities.

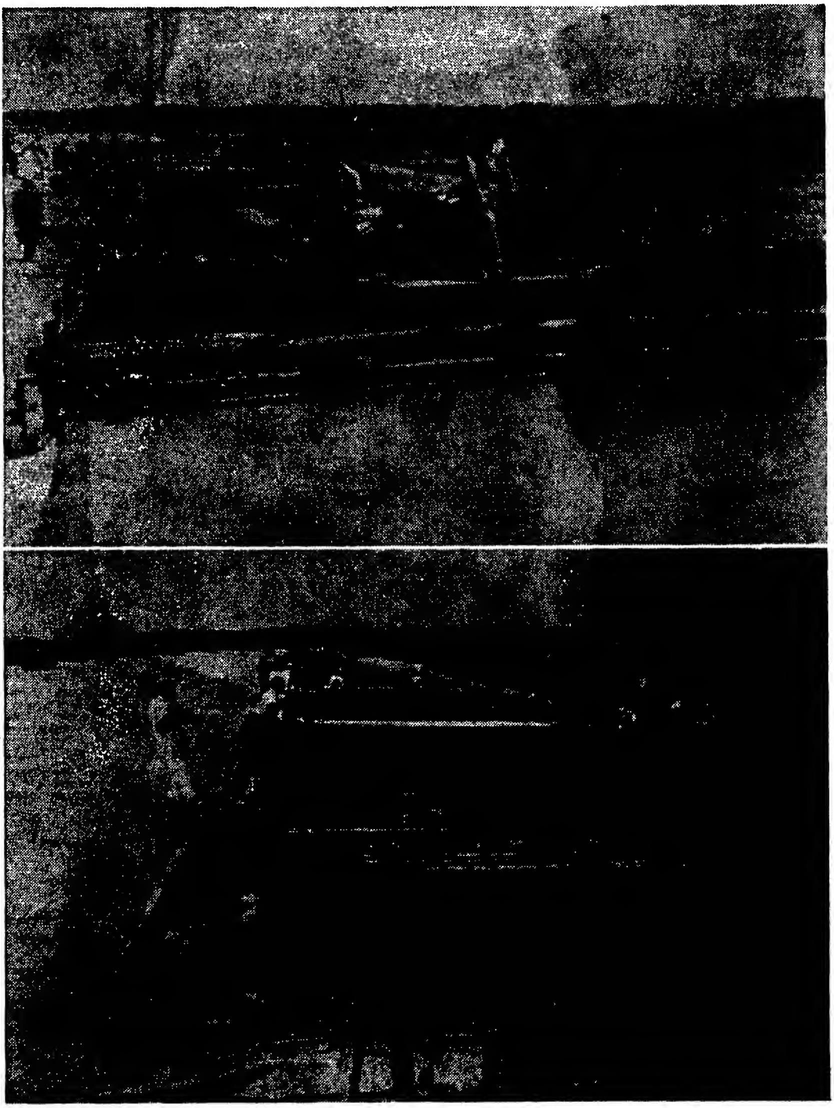


FIG. 9-16.—Finishing operations on a large airport runway job included: *Above*, two finishing machines, each equipped with external pipe vibrators; and *below*, longitudinal screed, hand finishing with wooden screeds and burlap drag, and hand troweling at joints. (*Courtesy of Engineering News-Record.*)

The final operation usually is the pulling of a canvas belt back and forth across the surface as it advances in the direction of concreting operations. The belting operation is done shortly after the water sheen has disappeared from the surface of the concrete. As ordinarily constructed, several thicknesses of canvas are sewed together to form a belt 8 to 10 in. in width and with a length a little greater than the width of the

FIG. 9-17.—Kelley Compactor Power Float in operation. The final finishing operation of this concrete floor is with a steel trowel. (*Kelley Electric Machine Co.*)

slab to be belted. Attaching the canvas to a board ½ in. in thickness and 8 in. in width gives the belt a little more rigidity that aids in the final smoothing operation. It is especially desirable where much of the finishing is done by hand operations.

A rattan broom is sometimes pulled transversely across the surface following the belting operation, to remove the thin watery mixture that may have worked to the surface and to produce a roughened surface that has antiskid properties.

Gunite.—Gunite is a mixture of cement, sand, and water applied by pneumatic pressure through a machine known as the "cement gun." The dry sand and cement, which are mixed before being placed in the gun, are carried in suspension in a hose by a stream of air to the nozzle where water is introduced through a smaller hose. The amount of water can be regulated by a valve in the hand of the operator.

FIG. 9-18.—Placing Gunite in the lining of an irrigation canal in the Rio Grande Valley in Texas. (*Cement Gun Company, Inc.*)

The usual mixes vary from a 1:2½ to a 1:5. Under ordinary conditions with the usual 1:3½ mix the amount of water used per bag of cement is about 3½ gal. From 15 to 50 per cent of the sand, depending upon its characteristics, is normally wasted because it bounces back and drops to the ground. The percentage of "rebound" is higher with the coarse sands than with the finer ones.

The most common uses for gunite are for lining reservoirs; encasing steel, particularly on viaducts over railroad tracks; repairing disintegrated concrete structures such as dams, bridge piers and abutments, dry docks; lining coal bunkers; building baffle walls in Imhoff tanks and filter chambers; and building thin curtain walls on structural-steel buildings.

PROTECTION

Concrete must be protected from heat, wind, rain, and cold during the setting period and the first stages of hardening. Heat and wind will dry out the surface and cause the concrete to check or crack. The

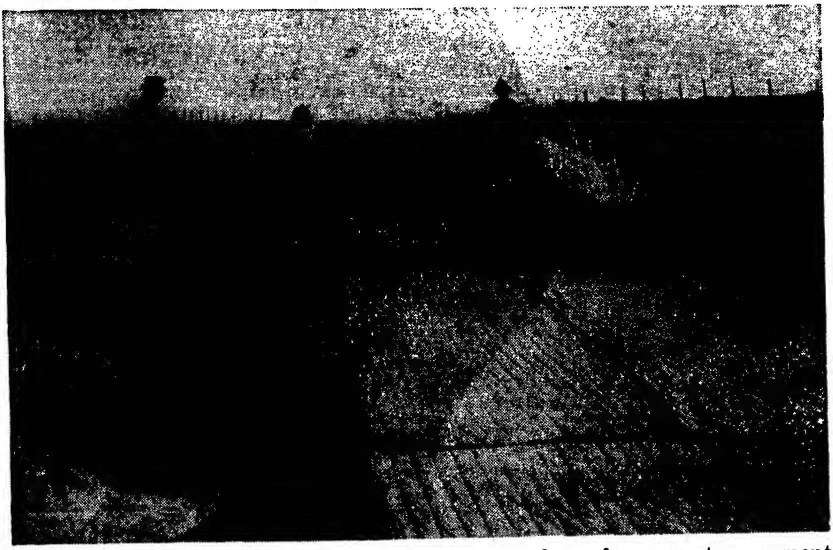


FIG. 9-19.—Application of cotton mats to the surface of a concrete pavement. These mats protect the concrete from the drying action of the sun and wind during the first 24 hr. After that they serve in the curing of the concrete Cotton mats have been used largely in the southern part of the United States. (*Portland Cement Association.*)

only damage that rain can do is to mar the surface. Cold can, of course, prevent the concrete from gaining strength rapidly enough and in case of freezing too quickly may stop all possibilities of any gain in strength.

Protection from Heat and Wind.—In protecting concrete from heat and wind, the chief purpose is to prevent evaporation of the mixing water. If the cement paste is permitted to dry out during the setting period, shrinkage cracks will develop in the concrete. Shrinkage cracks are undesirable because of the consequent weakening of the concrete.

Protection of horizontal surfaces from the wind and sun is most easily accomplished by carefully placing strips of wet burlap or canvas directly on the concrete and then keeping them wet by subsequent sprinkling. Paper coverings used in curing are placed as soon as the finishing operation is completed and serve to protect the concrete from drying. Curing compounds, which are sprayed on, are applied also as soon as the finishing operation is completed.

Canvas stretched on frames may be used but is hard to handle in strong winds. Frames are also easily broken, and therefore, most contractors prefer to use the strips laid directly on the concrete. Canvas or burlap carefully laid on the surface will not produce objectionable marks on any concrete that is finished with a belt or a wooden float. In cases where a steel-trowel finish is desired, the protection must be accomplished in such a way that the covering material does not touch the concrete. Vertical surfaces are protected by the forms and need no special attention.

Protection from Rain.—Rain falling on concrete will not cause a reduction in the strength. The cement in the upper surface, however, may be washed out down to the coarse aggregate. More cement paste can be brought to the surface by additional floating and belting, provided the concrete is soft enough. If the concrete is too hard to be reworked, nothing much can be done except to give it a flush coat of cement and fine sand. The appearance is not as good as the regularly finished surface, but after traffic has worn the pavement a while, no difference can be detected

Protection from the rain is most easily accomplished with canvas. Burlap is not good because of its nonwaterproofing qualities. The water can get through the burlap in sufficient quantities to wash the surface quite badly. Most canvas is not 100 per cent waterproof but does keep out a satisfactory amount of water and is much better than the burlap.

Cold-weather Concreting.—Making, placing, and curing concrete in cold weather is an operation that is more difficult and expensive than in warm weather. Special procedures must be followed, and attention must be given to the maintenance of satisfactory temperatures in order that sufficient strength may be developed for the use of the concrete.[1] It is impossible to state the limits of the critical period when concrete may be seriously damaged by a few cycles of freezing and thawing, but experience and meager laboratory tests indicate that 500 p.s.i. is a minimum strength to be attained before freezing.

[1] An extensive report with bibliography on this subject has been issued under the heading of "Proposed Recommended Practice for Winter Concreting Methods," *Proc. Am. Concrete Inst.*, Vol. 44, pp. 309–327 (December, 1947).

Following are a few paragraphs from the recommended practice report of the American Concrete Institute:[1]

Whenever it is anticipated that the air temperature at the point of placement is likely to fall below 40°F. during the 24-hr. period after placing concrete or below 30°F. during the succeeding 6 days, it is recommended that protective measures be taken as outlined in the following paragraphs.

Heating of Materials.—For air temperatures not lower than 30°F. the mixing water should be heated to bring the temperature of the concrete at the mixer to between 50 and 80°F. or, alternatively, for small jobs only (less than 20 cu. yd. of concrete), the concrete may be heated by means of a torch inside the mixer.

FIG. 9·20.—Showing protection of concrete on building construction during cold weather.

For air temperatures of from 30 to 0°F. both the water and the fine aggregate should be heated to bring the temperature of the concrete at the mixer to between 50 and 90°F. Only coarse aggregate that is free from frozen lumps should be used.

For air temperatures below 0°F. the water, the fine aggregate, and the coarse aggregate should all be heated to eliminate frost and to bring the temperature of the concrete at the mixer to between 50 and 90°F.

Mixing water should be heated under such control and in sufficient quantity so that appreciable temperature fluctuations from batch to batch are avoided. To avoid flash set where either aggregates or water are heated to a temperature in excess of 100°F., the loading of the mixer should be in such sequence that the cement does not come in contact with such hot materials.

[1] *Ibid.*

Aggregates should be heated in a manner such that frozen lumps, ice, and snow are eliminated and overheating or excessive drying is avoided. At no point should the aggregate temperature exceed 212°F., and the average temperature of an individual batch of aggregate should not exceed 150 F. The use of steam coils is recommended for heating aggregate, but for small isolated jobs aggregates may be thawed by heating them carefully over culvert pipes in which fires are maintained.

When aggregates in stock piles, cars, or trucks are thawed or heated by means of steam coils, the exposed surface should be covered with tarpaulins as much as practicable to maintain a uniform distribution of heat and prevent the formation of frozen crusts.

Curing Temperature.—Newly placed concrete made with normal cement should be kept at a temperature of not less than 50°F. for 7 days or not less than 70°F. for 3 days. It is good practice to maintain a temperature of at least 40°F. for the next 4 days. At the end of the curing period artificial heating should be discontinued and housings removed in such a manner that the fall in temperature at any point in the concrete will not exceed 40°F. in 24 hr.

Concrete made with high-early-strength cement should be kept at not less than 70°F. for 2 days or not less than 50°F. for 3 days.

The surface temperature of the hardened concrete should not be permitted to exceed 100°F. at any time during the curing period. The methods of protection and curing should be such that the loss of moisture from the concrete is not excessive during the curing period.

Certain structures, including buildings, may be entirely enclosed in housings made of wood, canvas, Sheetrock, Celotex, Sisalkraft, tarred paper, plywood, or other suitable material, and heated with salamanders or live steam. Forms aid in retaining heat and keeping out cold. Bridge abutments and piers may be packed in straw as well as enclosed in housing. In heating the air surrounding freshly placed concrete it is recommended that the temperature of the surface of the concrete at the coldest point not be below 40°F. while the temperature at the hottest point should not be more than 100°F.

Protecting pavement concrete is much more of a problem because of the large amount of exposed surface in comparison to its volume. It is so expensive and the results so uncertain that not many attempts are made to pour concrete pavements in cold weather. The subgrade must not be frozen when the concrete is placed, which means that it must be kept from freezing or be thawed out. Straw is probably the most effective covering for protecting concrete against freezing. It may be placed as soon as the concrete is shaped with no appreciable amount of marking of the surface.

CURING

Concrete begins to gain strength as soon as the setting action is complete. Most of the strength acquired by concrete is developed in the first 28 days. Certain strengths are figured in the design of the structure, and it is expected that these strengths will be developed within the first 28 days. Any strength developed after 28 days is extra and adds to the factor of safety in the design. The tendency now is to speed up construction by developing the desired strengths in less than 28 days.

One of the methods used to develop strength and resistance to weathering is known as curing. Just how much strength will be added will depend upon conditions and may vary from 25 to 100 per cent of the strength secured without curing. This increased strength is secured at a comparatively low cost.

Proper curing adds, also, to the wear-resisting qualities of the concrete. Concrete used in pavements is subjected to considerable wear and, therefore, curing of concrete pavements is doubly important. Because of the general relationship, which indicates good wearing qualities with high strengths, there is a tendency to omit proper curing of concrete pavements when the strength-test results are higher than felt necessary. High compressive strength in the mass of the concrete under the wearing surface is not necessarily a measure of the wearing qualities of the surface layer. Proper curing of concrete pavements is essential regardless of the strength being developed.

Proper curing will also add to the waterproofing quality of the concrete. The development of additional compressive strength mentioned above produces a concrete that is better able to resist the passage of water through it. This passage of water is normally through the cement paste and not through the aggregate. Anything that will improve the quality of the cement paste, therefore, will improve the waterproofing quality of the concrete.

Concrete in order to gain the greatest amount of strength needs both water and heat. Water is mixed with the cement and aggregates to make a workable mass and to aid in placing. The amount of water required for complete hydration of the cement is equal to about 50 per cent of the weight of the cement, but since complete hydration is not attempted on construction, a quantity (10 per cent) has been considered as the amount actually used in hydration under average conditions. Amounts of mixing water usually run between 40 and 80 per cent of the weight of the cement.

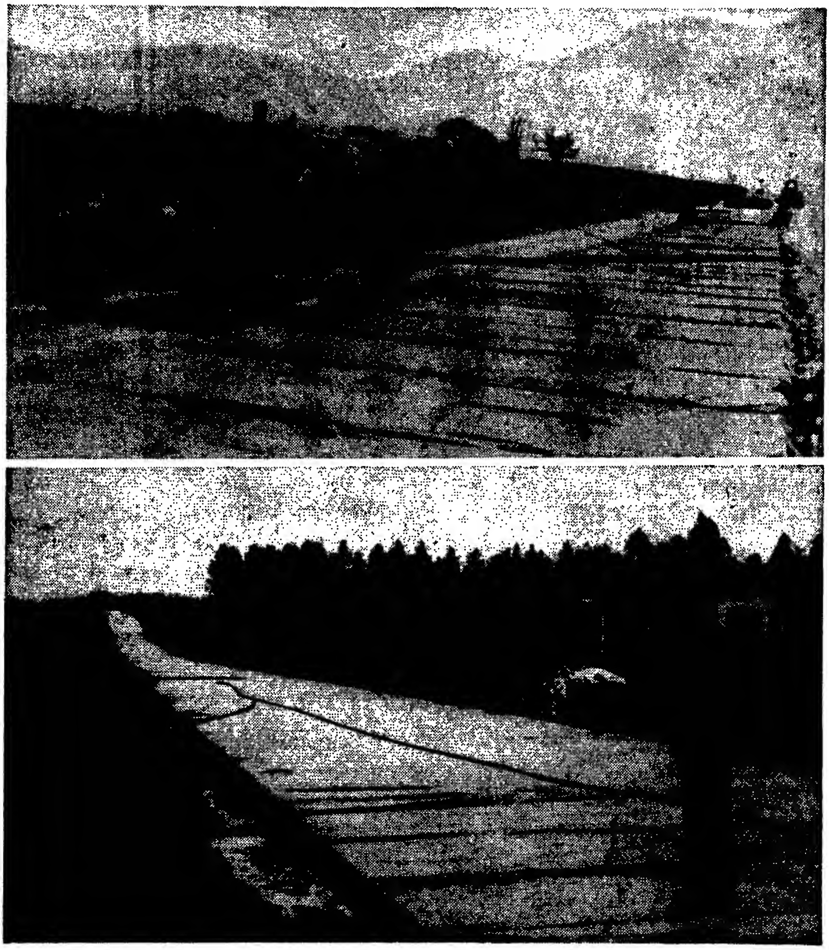
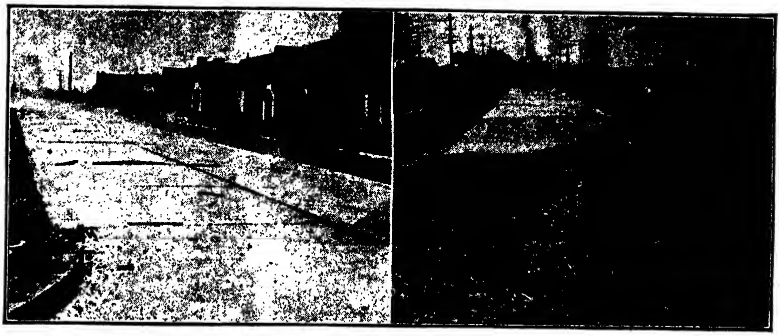


FIG. 9-21.—Application of water to covering placed on top of concrete to retain the water for curing purposes. In these cases the covering is cotton mats. *Top*, contractor has attached a spray bar to tank truck which operates on the shoulder. *Bottom*, pipe line is laid along the pavement with hose connections inserted at regular intervals for use of man wetting the covering. (*Portland Cement Association.*)

Curing methods are based to a large extent on the idea of retaining in the concrete all or much of the mixing water. Various methods are used to keep the concrete surfaces wet, thus preventing evaporation, or by actually sealing the surface.

The greatest benefit from curing is secured when the concrete is prevented from drying out for a period of at least 3 days. Valuable results are secured up to about 10 to 14 days. Engineers generally do not consider it worth while to keep the concrete wet more than 14 days, even though the desired strength is not then developed. As the concrete develops strength, the rate of evaporation is reduced, which in turn helps to retain the moisture in the concrete.



Left, continuous spraying. *Right*, covering with straw and wetting intermittently.

Left, ponding. *Right*, covering with dirt and wetting intermittently.
FIG. 9-22.—Methods of curing.

Methods of Curing.—Wherever forms are used, they should be left in place as long as possible. In case it is necessary to remove them, the surfaces of the concrete may be kept wet by sprinkling with water. The amount of sprinkling necessary will depend upon the rate of evaporation. The tendency has been to omit curing of building concrete. Because the buildings are designed with a factor of safety of 3 or 4, there is small chance for a failure of the structure due to improper strength resulting from the omission of the curing. In many cases, however, the factor of safety has been reduced below that figured in the design.

The most difficult problems of curing are found in connection with pavement concrete, where there are large exposed surfaces open to the sun and wind. This exposed surface also receives the wear of traffic and therefore needs extra quality. Any of the following methods of water curing are generally permitted. Engineers differ on the desirability of the others.

FIG. 9-23.—Use of paper in curing pavement concrete. *Above*, paper blanket being unrolled on the new concrete. Note the supplemental stringer sheets along the edges. These are pulled out after removal of forms, carried down over the edges of the slab, and covered with a blanket of earth. *Below*, paper blanket being rerolled for reuse. (*The Sisalkraft Co.*)

Covering with Earth or Straw.—As soon as the concrete is sufficiently hard, a layer of approximately 2 in. of earth or 6 in. of straw is spread over the surface and kept wet for a period of from 3 to 10 days. The frequency of wetting will depend upon the rate of evaporation, which in turn depends on the material and the temperature and humidity of the air. One to three or four wettings per day of the coverings are necessary.

FIG. 9-24.—Use of paper in curing of concrete slabs.

Paper blankets can be used in protecting and curing concrete floors. The blankets are applied and the edges held down temporarily with planks until glue can be applied for a permanent seal. View during the construction of Technological Institute Building, Northwestern University. *Insert* shows appearance of concrete surface under the paper. (*The Sisalkraft Co.*)

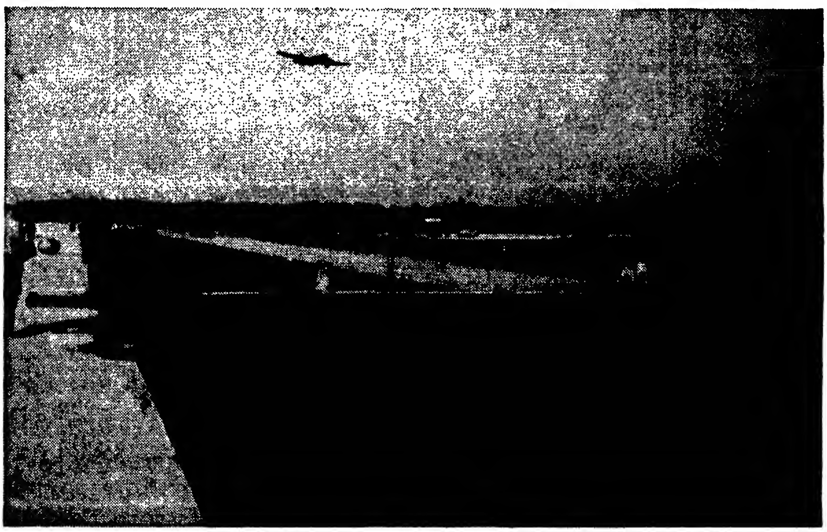


FIG. 9-25.—Application of a curing compound to the surface of a concrete airport runway slab, using a mechanical sprayer. The spraying unit is at the left end of travel on the frame. Width of the slab here is 25 ft. and the thickness 21 in. (*Courtesy of Engineering News-Record.*)

Whether earth or straw are used will depend upon the cost and availability of straw. The labor charge is high in connection with the use of earth. Wet-earth curing on city streets may be undesirable if there are many pedestrians desiring to cross the pavement. The surface of the concrete cannot be readily cleaned of all the earth covering, which will cause large amounts to get into the drainage system or may become a nuisance to the residents along the street by being blown about.

Paper Coverings.—A new addition to the methods of curing horizontal surfaces is paper prepared to resist the movement of water through it. The paper is placed on the concrete surface as soon as the concrete has been finished and is allowed to remain in place for the usual curing period

Fig. 9-26.—Mechanical spreader for applying calcium chloride.

The paper used for curing is specially prepared for this purpose. It is tough and may be reused as many as 15 times. Paper blankets for curing are sold in rolls on timbers to facilitate handling. Two men apply and remove the paper, rolling up as much as 300 to 400 ft. per hr. Paper can be used in the curing of horizontal surfaces in buildings as well as pavement and sidewalk surfaces.

Compounds.—Compounds are available in liquid form that may be sprayed on the surface of the concrete as soon as the last finishing operation is completed. These seal the surface and prevent evaporation of moisture from the concrete (Fig. 9-25). Just enough compound is applied to give complete coverage. A small amount of coloring is added to the curing compound by the manufacturer to aid in determining when there is complete coverage.

Ponding.—A method now rarely used is to build dikes across and along the pavement and to place water between the dikes. The chief objections to the method are that the dikes are easily broken; they may need to be high or close together because of the slope of the pavement; and the amount of water is excessive compared to the other methods.

Sprinkling.—The surface of the concrete may be kept wet by continuous or intermittent sprinkling. This method has not found general application for pavements.

Calcium Chloride.—Occasionally flake calcium chloride, a deliquescent salt, is applied at the rate of 2 lb. per sq. yd. of surface. It has the advantage of not requiring further attention once it is applied.

Water-glass Curing.—Water glass may be applied to the surface of concrete pavements as a method of curing. The effect is to seal up the surface and thus prevent evaporation. Application is made on the morning following pouring. This method has been chiefly used on vibrolithic-concrete pavements. This method has the same advantages as mentioned for calcium chloride.

Bituminous Coverings.—In this method a bituminous material is sprayed on the surface of the concrete either shortly after the finishing operation is completed or on the following day. The purpose of the bituminous coating is to seal the surface of the concrete and prevent any loss of moisture. The bitumen remains in place until worn away by traffic. When the bitumen is not applied until the day after placing, the concrete must be kept moist by other means. Burlap kept saturated seems to be the best medium.

Study Questions

1. What is the usual maximum length of time permitted between mixing and placing of concrete? How long is the interval between mixing and placing, which tests have shown is not harmful for the remixing of concrete?

2. What is the distinction between central proportioning and central mixing of concrete?

3. Name the two types of trucks used for the hauling of ready-mixed (or central-mixed) concrete from the mixer to the job. Which of the two types is generally considered better on long hauls?

4. What is meant by chuting of concrete? Is it generally considered good or bad practice? What objection is there to this method?

5. Under what conditions are the following methods of distribution on job used: elevator and buggies? overhead cableway? pumping?

6. Is it generally considered good practice to place concrete under water? What is the main objection? What is the name of the equipment normally used?

7. What is the purpose of vibrating concrete during placing? Name the two general types of vibrators. Does vibration increase the strength of concrete?

8. How may horizontal surfaces be finished? vertical surfaces? What is the objection to a steel-trowel finish on a public, concrete sidewalk?

9. John Early is noted for what in the concrete field? What is meant by terrazzo? Stucco? Gunite?

10. What is meant by a broom finish? Purpose of using broom?

11. What is meant by scaling? Cause of scaling?

12. What are the reasons for protecting concrete? How is it done?

13. What is meant by curing?

14. Name and explain various ways of curing concrete used for:

a. Sidewalks
b. Pavements
c. Walls
d. Floor slabs in buildings
e. Concrete drain pipe
f. Bridge piers, both above and below water level

CHAPTER 10

DURABILITY, WORKABILITY, AND WATERPROOFNESS

Durability of a material is that property which indicates whether or not the material will endure, even though it may not be subjected to loads sufficient to destroy it. Durability of concrete is affected by (1) alternate wetting and drying, (2) freezing and thawing, (3) heating and cooling, (4) capillary water, (5) deposition of salts by percolating water, (6) dissolving of certain products (principally calcium hydroxide) by the percolating water, (7) the dissolving of the cement by certain acids, and (8) chemical reaction between certain constituents of aggregates and the alkalies in high-alkali portland cements. Concrete is a construction material subjected to many of these items at times.

The first three of these items cause volume changes in the concrete, thus setting up stresses in the concrete when the entire concrete mass cannot expand or contract freely. Owing to the fact that the interior concrete is not drying out or changing temperature as rapidly as that on the exterior, stresses are developed and if the concrete is not strong enough to withstand them, cracks will form. This often happens when the surface of concrete dries very rapidly and the interior does not.

Maximum density of water occurs at 4°C., and as soon as that temperature is reached during a period of lowering temperature, the water in the concrete will begin to expand thus tending to crack the concrete. Concrete subjected to freezing should contain as little water as possible and also have strength to resist the expanding force of the water.

Capillary water is water that will rise in a material against the force of gravity, owing to the small pores in the material. Freshly made concrete, as a rule, contains all the water it can hold, and there is no movement through the capillary pores unless evaporation takes place at a surface exposed to dry air. If there is a source of water at some other surface of the concrete more water will be drawn into the concrete by capillarity. Capillary water may cause the same effects as percolating water.

Percolating water containing alkalies (sulfates) in solution may cause disintegration owing to the combining of the alkalies with certain constituents of the hardened cement, thus forming new compounds of considerably greater volume. It is necessary in certain parts of the

United States and Canada to produce a concrete that is impervious to percolating water. Pure water may dissolve slowly certain products (principally calcium hydroxide), and the action may not seem serious at first, but the pores through which the water is moving become constantly larger.

Deterioration of a large submerged shipway in the southeastern United States shortly after its construction has been ascribed (1) to a chemical reaction between the cement paste and carbon dioxide present in high concentration in the sea water percolating through the structure; and (2) to a reaction between the hydrated cement and sulfates and/or other substances normally present in sea water. The first process caused a local softening or even complete disintegration of the concrete, while the second process caused expansion of the concrete in the interior, which led to cracking at the surface.[1]

In many industrial plants and in sewer pipes the concrete is subjected to acid waters of varying strengths. Here it is especially important that the concrete be impervious to liquids and that aggregates be selected that are not soluble or very slowly soluble in the acids encountered. If the acid is limited to the surface of the concrete, the disintegration will be much slower than if the attack can be made over a greater area on the inside of the concrete.

Tests on puzzolans indicate that the corrosion resistance of concretes can be increased by the inclusion of puzzolanic materials.[2] There are two types of corrosion: (1) dissolving of the cement by acids, in which the free lime is attacked first and then the other constituents; and (2) combination of sulfates with aluminates to form calcium sulfoaluminate, which has a considerably greater volume than the original calcium aluminate. Puzzolans greatly retard these chemical changes by combining with the compounds before the corrosive agents have an opportunity to act on the cement. Once combined with the puzzolan there is very little reaction with the acids or the alkalies (sulfates). The reaction of the puzzolans with certain cement compounds forms new compounds that make the cement paste less permeable.

Some attention is being given to the thermal properties of the coarse aggregate in relation to the thermal properties of the mortar in which the coarse aggregate is to be used. If the thermal properties are not the same, or very nearly so, the resultant differences in expansion or

[1] TERZAGHI, RUTH D., "Concrete Deterioration in a Shipway," *Proc. Am. Concrete Inst.*, Vol. 44, p. 977.

[2] SCRIPTURE, EDWARD W., JR., "The Possibilities of Puzzolanas in Mortars and Concretes," *Eng. News-Record*, Vol. 115, pp. 563–567 (1935).

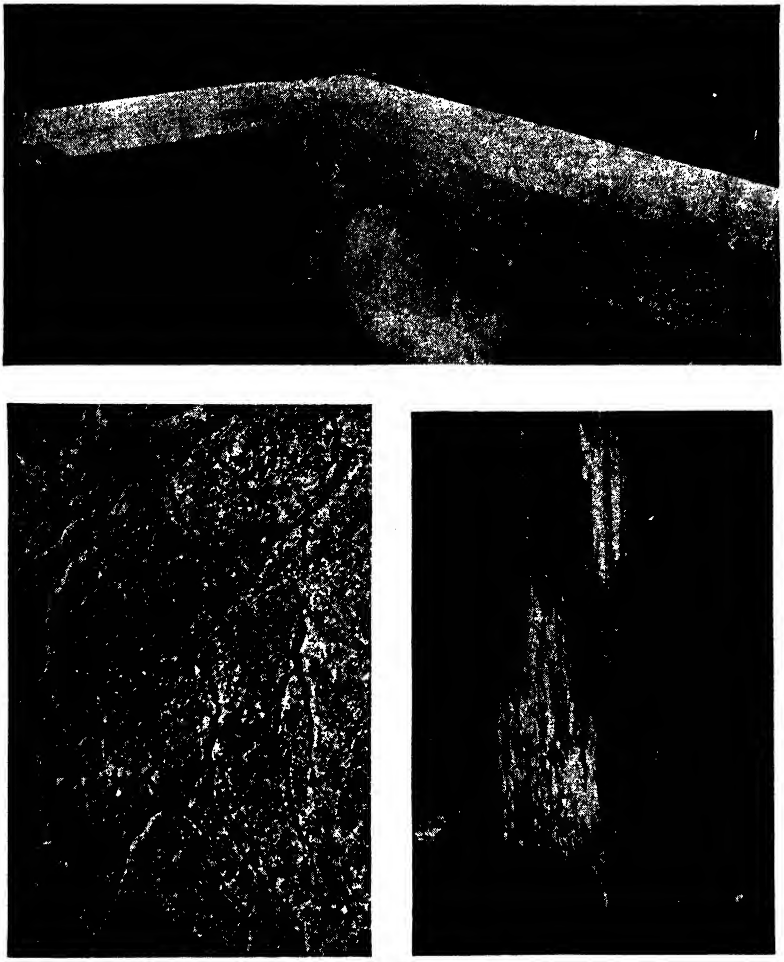


FIG. 10-1.—Examples of unsound concrete.

Above, culvert in eastern part of the United States where unsound aggregates are quite prevalent. The expansive effect of these aggregates is responsible for the expansion and checking shown.

Lower left, pier between two arches of a bridge in Illinois. The severe checking and cracking are the result of expansion of unsound aggregates. The coarse aggregate used was identified as a rather porous weathered dolomite. The source of the aggregates used in this bridge was located and samples obtained for laboratory test. Specimens representative of the best material in the quarry barely passed the sodium sulfate test as now generally applied. Twenty per cent of the specimen at five cycles had definitely cracked and 60 per cent showed surface flaking.

Lower right, closeup of a portion of the concrete which was chipped away and taken to the laboratory for study. The state of disintegration here is somewhat more advanced than in the picture to the left. Conditions were probably complicated by porosity due to other causes.

contraction as the temperature of the concrete changes may cause stresses sufficient to crack the concrete.

Cement-aggregate Reaction.—In 1940 T. E. Stanton[1] published information that some concrete in California was deteriorating because of chemical interaction between alkalies released during the hydration of high-alkali portland cement and certain rock and mineral constituents of the aggregates. Since then evidence of similar deterioration has been found in Arizona, Nebraska, Oregon, New York, Colorado, Kansas, Virginia, Washington, and Wyoming.[2]

Concrete deteriorating from this cement-aggregate reaction loses strength, expands significantly, and cracks at the surface.

High-alkali cements are those that contain 1 per cent or more of sodium oxide (Na_2O) and potassium oxide (K_2O). When the aggregate to be used contains constituents that will react with the cement alkalies, the alkali content of the cement is normally limited to 0.6 per cent.

The use of a suitable puzzolanic addition is another effective way to correct or dissipate any tendency to excessive expansion through a cement-aggregate reaction.[3]

Aggregates that have been found to react with high-alkali cements include opaline silica, highly siliceous rocks, including siliceous limestones, chalcedony, and some cherts, and acid to intermediate volcanic rocks.[4] Positive identification of this reaction usually requires laboratory study and tests of cores drilled from the concrete, including the making of test specimens using the aggregate involved. Blanks and Meisner report that "invariably cores from affected concrete when stored in the presence of moisture will develop gelatinous exudations and whitish amorphous deposits on their surfaces. These gel deposits are also found in pores in the concrete mass particularly adjacent to pieces of reactive aggregate. Chemical analyses of the gels show them to be composed essentially of sodium and potassium silicates."[5] Work is being done on the development of a test for the identification of these undesirable rocks.

[1] "Expansion of Concrete Through Reaction Between Cement and Aggregate," *Proc. Am. Soc. Civil Engrs.*, Vol. 66, pp. 1781–1811.

[2] See pp. 127–128 of Vol. 44, *Proc. Am. Concrete Inst.*, for a bibliography on cement-aggregate reaction.

[3] STANTON, T. E., "Durability of Concrete Exposed to Sea Water and Alkali Soils—California Experience," *Proc. Am. Concrete Inst.*, Vol. 44, p. 835.

[4] BLANKS, R. F., and H. S. MEISNER, "Deterioration of Concrete Dams Due to Alkali-aggregate Reaction," *Proc. Am. Soc. Civil Engrs.*, Vol. 71, pp. 3–18.

[5] *Ibid.*

FIG. 10-2.—Examples of alkali-aggregate reaction. (*Courtesy of U.S. Bureau of Reclamation.*)

Upper left, cracks like these appeared on the surface of Parker Dam within 2 years.

Upper right, siliceous gel body and white deposit of calcium sulfoaluminate. The gel shows desiccation cracks.

Lower left, siliceous gel body and aggregate grain showing darkened reaction rim. The large crack passing through the aggregate was produced by breaking out sample with a hammer.

Lower right, sodic-silica exhudation on a 10-in. core drilled from Parker Dam. After storage in fog room for several months, this toadstool-like gel growth appeared. It had a hollow interior and grew as the exuding material rose and cverflowed from top.

Designing Concrete for Durability.—Concrete should be designed for maximum durability for the conditions where it is to be used. Concrete, for this discussion, may be divided into the aggregate and the cement paste, either one or both of which may cause trouble. There is no way of making an unsound aggregate sound, and it is therefore necessary to choose only sound aggregates. This topic is discussed in Chap. 4 on aggregates, and procedures are given in Part II for the performance of soundness tests on the aggregates. One instance is reported, however, of the bad effects of an unsound aggregate being reduced by the use of air entrainment in the concrete in which the aggregate was used.[1]

The durability characteristics of the paste can be varied by the relative amounts of water and cement, by the entrainment of air in the paste, and by the mixing, placing, and curing of the concrete. The durability of the paste is affected by its ability to resist the flow of water through it.

Results of tests shown in Fig. 10-3 indicate that the permeability of the paste is a function of the water-cement ratio. Norton and Pletta[2] note this same relationship and indicate that it is influenced considerably by consistency and in the leaner mixes by the gradation of the aggregate. They observe further that permeability decreases as strength or the cement-voids ratio increases, the latter being the best indicator of permeability.

C. H. Scholer[3] recommends that concrete subjected to a severe exposure should have a water-cement ratio of less than 6 gal. per bag of cement. Values recommended by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete are given in Table 6-1.

Concrete to be durable must be well mixed, with the cement paste distributed uniformly through the aggregate. Mixing time should be at least 1 min., and 1½ to 2 min. would be better. In the handling of the concrete subsequently to mixing, care must be exercised not to undo the work of the mixer. Thorough compaction of the concrete may eliminate some of the mixing water, but care must be exercised in order to prevent seams in the concrete, which contain mostly clay and silt from the aggregate and laitance from the cement. These seams always occur

[1] BUGG, S. L., "Effect of Air Entrainment on the Durability Characteristics of Concrete Aggregates," *Proc. Highway Research Board*, Vol. 27, p. 156.

[2] "Permeability of Gravel Concrete," *Proc. Am. Concrete Inst.*, Vol. 27, pp. 1093–1132 (1931).

[3] "The Durability of Concrete," *Kansas State College, Eng. Exp. Sta., Bull.* 28, (1931). See also SCHOLER, "Some Accelerated Freezing and Thawing Tests on Concrete," *Proc. A.S.T.M.*, Vol. 28, Part II, p. 472.

where water is brought to the surface. In general, if there is water gain, the consistency of the concrete should be made drier. When water gain is noticed, special efforts must be made to remove the layer of silt, clay, and laitance before additional concrete is placed.

Care must be exercised in compacting the concrete not to permit any segregation. Vibration is a great aid in placing dense, watertight concrete, but vibration should not continue after the first evidence appears of moisture coming to the surface. If a vibrator is used, which is not

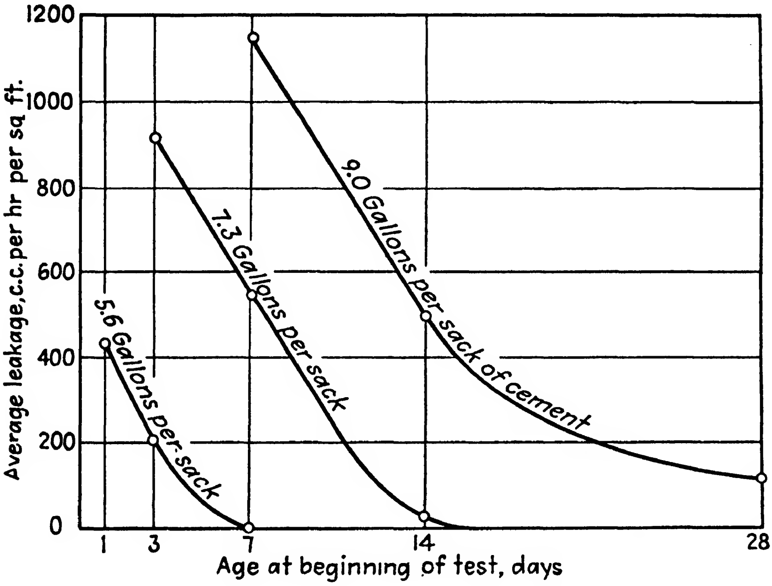


FIG. 10-3.—Effect of water content on the permeability of concrete. (*From McMillan, "Basic Principles of Concrete Making," McGraw-Hill Book Company, Inc.*, 1929.)

capable of handling the quantity of concrete to be consolidated, segregation may exist when the concrete has hardened. Vibration is not a cure-all for placement difficulties.

Figure 10-4 shows a wall that has been very poorly consolidated. There is evidence of too much mixing water as well as flowing of the concrete in the forms at the time of placement.

Proper curing is also an important item in the development of a durable concrete. A certain proportion of mixing water is required for hydration of the cement. Hydration continues over a long period of time, becoming slower with the later ages, and it is necessary to keep the mixing water in the concrete in order for it to combine with the cement. Figure 10-5 shows the composition of various mixes of a uniform consistency (slump 3 to 4 in.). It is the purpose of curing to increase the amount of combined water, thus increasing the amount of solid matter, which in

FIG. 10-4.—Showing segregation in poured concrete wall due to wet concrete, lack of spading, and flowing of concrete in forms.

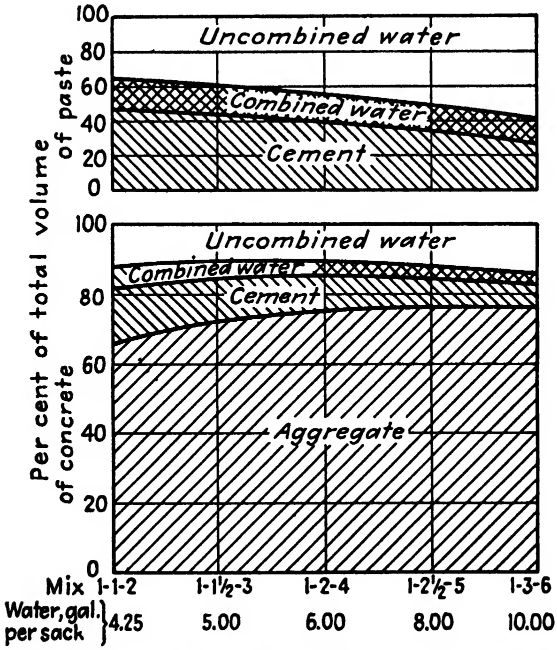


FIG. 10-5.—Composition of various mixtures of uniform consistency (slump 3 to 4 in.). In the upper portion the composition of the paste in the corresponding concrete is given. (*From McMillan, "Basic Principles of Concrete Making," McGraw-Hill Book Company, Inc.*, 1929.)

turn reduces the pore space. Figure 10-6 shows the results of some tests for permeability for four cements at two curing ages and indicates the reduction in permeability due to the increased curing.

Air Entrainment.—Entrainment of a small amount of air in the cement paste has been found to improve considerably the durability of concrete. This air must be in very small bubbles, well distributed throughout the cement paste.

The amount of entrained air is normally expressed as a percentage of the volume of the concrete, for simplicity, although it might be better to express it as a percentage of the volume of the cement paste. Indications are that the effective practical minimum is about 3 per cent of the volume of the concrete, and that percentages in excess of 6 per cent do not add

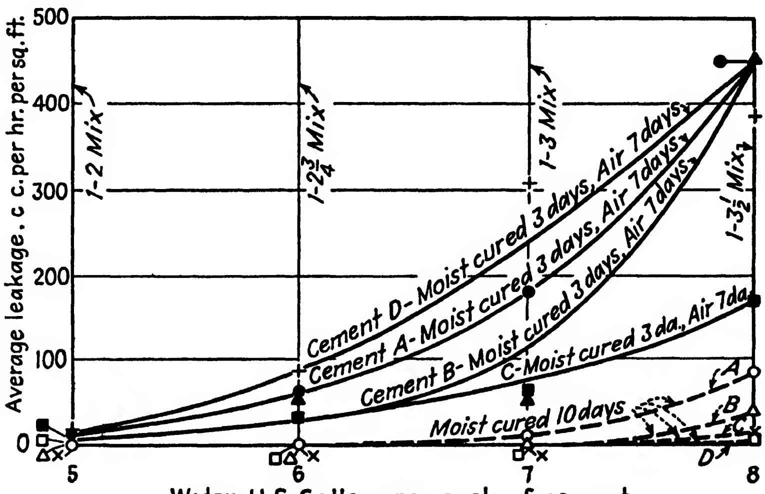


FIG. 10-6.—Effect of length of curing in the permeability of concrete for four cements and two curing periods. Note that increasing the curing period decreases the leakage through the concrete. (*From McMillan, "Basic Principles of Concrete Making," McGraw-Hill Book Company, Inc.*, 1929.)

enough durability to be worth while. The range normally specified is from 3 to 5 per cent or from 3 to 6 per cent. There is some reduction in strength, the amount being greater with the higher air contents, and thus it is important not to entrain more air than will be effective for durability purposes.

Air entrapped in the particles of aggregate does not count as entrained air in the concrete. It is desirable, however, to have some air in the particles. Aggregates secured from underwater deposits may be almost completely saturated and in this condition may disintegrate with only a few cycles of freezing and thawing. Aggregates secured from above-water deposits are normally not highly saturated. The critical degree of saturation appears to be in the neighborhood of 85 per cent.

In certain areas of Kansas, Nebraska, Missouri, and Iowa natural coarse aggregates are scarce, and concrete for construction projects is made using an aggregate with a maximum size of 3/8 in. and containing a large amount of particles that pass the No. 4 sieve. This concrete when made without air entrainment has air contents of 3 to 4 per cent. Use of air-entraining portland cement increases the air contents to 8 to

FIG. 10-7.—View on Archer Avenue, Chicago, Ill. (*Courtesy of Illinois Division of Highways.*)

Shown in the foreground is concrete which has badly disintegrated while concrete in the background beyond the streetcar tracks is in excellent condition. Concrete in the foreground had no air entrained in it, while that shown in the background had a small amount of air entrained in it. Otherwise everything was the same. Picture taken less than 4 years after construction.

13 per cent. It is the air content produced by the air-entraining agent that gives the concrete durability.[1]

Entrainment of air in concrete is secured either by the use of air-entraining portland cement or the use of an air-entraining admixture, mentioned previously in Chaps. 3 and 4.

[1] KLIEGER, PAUL, "Effect of Entrained Air on Concretes Made with So-called 'Sand-Gravel' Aggregates," *Proc. Am. Concrete Inst.*, Vol. 45, p. 149.

WORKABILITY

Workability is that property of freshly mixed concrete which is measured in terms of ease of placing, handling, and finishing. The degree of workability necessary will depend upon the nature of the work being done. Concrete to be placed in narrow forms and around reinforcing steel requires one degree of workability, while on the other extreme, concrete to be used in massive sections with no steel need not be particularly workable. Each user of concrete must decide for himself what is necessary. The following discussion is intended to aid in arriving at the final answer.

There are a number of factors affecting workability:

1. Cement
2. Water
3. Aggregate:
   a. Gradation
   b. Shape
4. Mixing
5. Admixtures

It is at once apparent from the number of factors involved that it is not possible to derive any mathematical relationships between them and workability. The question of workability is tied in with that of strength and economy of the mixture. Not always is the most workable mix the strongest or most economical, and in many cases workability must come ahead of economy.

The most workable concretes are secured when the maximum size of any of the dry materials is comparatively small in relation to the mass. Workability is improved by increasing the amounts of fine materials in the mixture, but no more fine materials should be used than are necessary to produce the desired workability.

In thinking of plasticity and workability, the concrete engineer will find certain definitions from soils physics of value. Atterberg, a Swedish scientist, has defined the lower plastic limit of a soil as that moisture content at which the soil can be rolled into threads ⅛ in. in diameter, and the upper plastic limit, or the liquid limit, as that water content at which the soil will begin to flow when jarred lightly. The difference between the two limits is known as the plasticity index.

There is a comparable range of water contents for concrete in which the concrete can be considered as plastic. At the lower limit, the freshly placed concrete has a minimum change of shape without crumbling when the supporting mold is removed, as in the slump test. At the other extreme, the concrete will flow readily upon removal of the supporting mold and will show evidence of segregation. The plastic range of the concrete depends to a large extent upon the plasticity index of the materials passing a No. 40 sieve. This material includes the cement, the admixture when used, and the finer particles of sand. When the plastic range of the concrete is large, the workability or ease of placing should be greater.

Effect of Cement.—Cement is an exceedingly fine material, about 85 to 100 per cent passing the No. 200 sieve. Increasing the fineness of grinding should improve to a limited extent the workability of the concrete. The cost of increased fineness is so great that it is not worth while as a medium for increasing the workability of concrete. Increased fineness improves the strength-producing quality and is worth while from that standpoint.

Increasing the amount of cement used in the concrete will increase its workability. In addition to improving workability, strength, durability, and watertightness are improved. If these latter qualities are necessary in addition to that of workability, increasing the cement content of the concrete will accomplish these results. If workability is the only one desired, other methods may prove more economical.

Effect of Water.—For a given mix and materials, the workability may be varied within narrow limits by changing the amount of mixing water. A certain amount of water is necessary in order to make the mixture dense and strong as well as placeable. There is a small range of amounts of mixing water that produces workable concretes. Beyond this range the concrete becomes unworkable as the amount of mixing water is increased. Some construction men think that the only way to secure workability is to add mixing water, whereas beyond a certain point the addition of water makes unworkable concrete. There is a correct amount of water for each combination of materials, and often the use of less mixing water will make a more workable concrete.

Often it is necessary to haul mixed concrete in trucks distances up to about 5 miles. If the concrete is too wet, there will be a segregation of the materials in the truck due to jolting, the coarse materials settling to the bottom and the water and fine materials rising to the surface. For concrete to be hauled any distance it is important that the correct amount of water be used to lessen segregation. The correct amount can best be determined by trial on the job.

Effect of Aggregates.—Gradation and shape of the aggregate have a bearing on the problem of workability. Sometimes the gradation need be varied in order to counterbalance the effect of shape.

Gradation.—The gradation of an aggregate gives the proportions of the various sizes of particles. Aggregate is used with cement paste to cheapen its cost. The best gradation from this standpoint is the one that extends the cement paste the most. This gradation, however, may not produce a concrete that can be handled and placed easily and cheaply. A balance must be struck between workability and amount of concrete produced.

For the moment, consider the problem as one in which the volume of cement and water are kept constant, and the gradation of the aggregate varied to see what the effects upon workability and amount of concrete are. The cement paste is mixed first, and then aggregates of different gradations are added until the desired workability is secured.

In the first case only sand is added. A workable mix is secured, but not much concrete is produced. Suppose that in the next case only aggregate larger than ¼ in. is used. The mix is so unworkable that it is out of the question for use in construction. Next let us try equal parts of sand and coarse aggregate. The concrete is workable, and the quantity is much larger than in the first case. Observation indicates that the proportion of coarse aggregate may still be increased without sacrificing workability. In the fourth trial make the amount of coarse aggregate 1½ times the amount of sand. Again the concrete is workable, and the amount is greater than in the preceding case. It is observed, however, that the proportion of coarse aggregate may not be increased much more without sacrificing some workability. For the fifth trial use twice as much coarse as fine aggregate. The concrete will be workable for some purposes, and the amount in most cases will be a little larger than before. If another trial is made with 3 times as much coarse as fine aggregate, it will be observed that the workability and amount of concrete are much reduced. It would appear then that the amount of coarse aggregate should be from 1½ to 2 times the amount of fine aggregate. Proportions as used today lie within that range.

A similar problem may be tried in which the maximum size of aggregate is varied from ¼ to 2½ in. The aggregate in each case should be graded between the maximum and minimum sizes. As the maximum size is increased, the workability of the concrete may be decreased, while the amount produced will be increased. Somewhere between ¼ and 2½ in. will be found the maximum size that can be used for various kinds of work. For reinforced concrete the maximum size is often limited to ¾ or 1 in., while for pavements 2 or 2½ in. is usually set as the limit. On some reinforced-concrete work it would be possible to increase the maximum size of aggregate without making the concrete unworkable.

In order to use drier consistencies and larger coarse aggregate in heavily reinforced members on the Wacker Drive improvement in Chicago, mortar mixes were placed first in the bottom of columns and walls. The same water-cement ratio was used as in the concrete, and sand was added to the cement paste until the desired consistency was secured. This mixture was placed in the forms first in sufficient quantity for the entire wall or column. Concrete was then poured into the mortar and puddled so that the former settled to the bottom. As the concrete was added, the mortar rose higher and higher and filled in around the steel and into the corners of the forms. The mortar was placed first in the beams and slabs to a depth that covered the reinforcing steel. Smooth surfaces were secured, and the steel was thoroughly embedded in the concrete.

There has been some increase in recent years in the percentages of sand required to pass the Nos. 50 and 100 sieves, with the idea in mind that an increased amount of fine sand particles would result in increased workability. In some instances it has been necessary for contractors to purchase a very fine sand to blend with the coarser concrete sand they would normally have used.

Shape of Aggregate.—Practically all research work on concrete has been done with sand as the fine aggregate and pebbles as the coarse aggregate, and therefore, much of our knowledge is based on rounded particles. Crushed stone is often used as the coarse aggregate, and the question is often asked which is the better. Each has certain characteristics that make it desirable in certain cases. The rounded particles of the pebbles produce a more workable concrete than do the angular pieces of crushed stone when the two materials have the same gradation. When crushed stone is used as a coarse aggregate, the gradation of the aggregate may need to be changed in order to produce the same degree of workability. It will be necessary to increase the proportion of fine aggregate, and ordinarily the slight change in gradation may be made without any noticeable effect on the quantity of concrete produced (see Fig. 6-4).

Effect of Mixing.—The purpose of mixing concrete is to secure a uniform distribution of the cement paste through the aggregate. For any given mixer the thoroughness is a function of the length of mixing time. Most specifications call for 1 min. of mixing. Increased workability may be secured by increasing the time of mixing. When concrete is hauled from a central-mixing plant, increasing the time of mix will produce a more workable concrete with less water. Decreasing the amount of mixing water cuts down on the amount of segregation due to hauling and increases the strength of the concrete.

Effect of Admixtures.—Certain admixtures are available for inclusion in concrete for the purpose of improving the workability. Some of these admixtures are extremely fine materials and without question do make the lean mixes more workable. The richer mixes contain more cement and hence cannot have their workability improved as much. If the admixtures are used in small quantities, no decrease in strength is likely to result. Emphasis has been placed on the value of increasing the coarseness of the aggregate, with the result that much in the way of workability has been sacrificed in order to increase the compressive strength a slight amount. The increase in coarseness of aggregate has in many cases been carried so far that unworkable mixes have resulted, and now various remedies are being advocated to cure the evil.

The powdered admixtures used for improving workability include hydrated lime and diatomaceous earth. The former is used in amounts up to 5 lb. per bag of cement, and the latter usually at the rate of 2 to 3 lb. per bag.

Contractors using admixtures report that they get, especially with the leaner mixes, more uniform concrete from batch to batch than when they do not use the admixtures. Because of the extreme fineness of these materials they reduce to a minimum the effects of small variations in amounts of mixing water on the consistency of the concrete. Moisture contents in aggregates vary from batch to batch and can be compensated by changing the amount of water added.

Another group of workability admixtures consists of water-reducing agents, such as organic dispersing agents, which promote plasticity by their effect on the early-hydration products of the portland cement.

Air entrainment, either by means of air-entraining portland cement or by the admixture, functions also to make concrete more workable. The mass holds itself together better, yet may be worked around reinforcing steel into the forms easier. Air-entrained concrete can also be hauled in nonagitating trucks with less segregation occurring. Since air entrainment causes only a small reduction in strength and may be secured at practically no increase in cost, it is being used because of its workability value where durability is of minor concern.

The use of an admixture requires additional attention at the mixer and is objectionable from that standpoint. Ordinarily, however, no additional help is necessary. Admixtures are added dry as the other materials are being placed in the drum.

Measuring Workability.—A number of investigators have worked on the development of an apparatus to measure the workability of freshly made concrete. One apparatus, developed by Smith and Conahey at the U. S. Bureau of Standards,[1] used the amount of energy necessary to drive a rod 11 in. into the concrete as the measure of workability. The apparatus is shown in Fig. 10-8.

Another test has been developed by T. C. Powers[2] and is known as the remolding test. A standard slump cone is set in a cylinder 12 in. in diameter and 8 in. in height, the cylinder being mounted rigidly on a

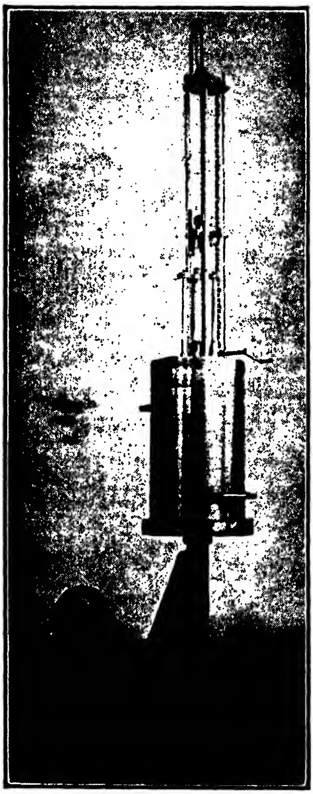


FIG. 10-8.—Penetration type of workability apparatus developed by Smith and Conahey at the U. S. Bureau of Standards.

flow table set for a ¼-in. drop. Inside this cylinder is placed a smaller one, known as the inner ring, which is 8¼ in. in diameter and 5 in. in height. The distance between the bottom of the inner ring and the bottom of the outer cylinder varies in ⅛-in. intervals from 2⅝ in. to

[1] SMITH, G. A., and G. CONAHEY, "Workability," *Proc. Am. Concrete Inst.*, Vol. 24, pp. 24–42 (1928).

[2] POWERS, T. C., "Studies of Workability of Concrete," *Proc. Am. Concrete Inst.*, Vol. 28, pp. 419–448 (1932).

FIG. 10-9.—Views of Powers remolding apparatus. *Left,* apparatus ready to receive the sample of concrete. *Right,* after the slump cone has been filled and removed, and the rider assembly set in place. The next step in the procedure is the operation of the flow table.

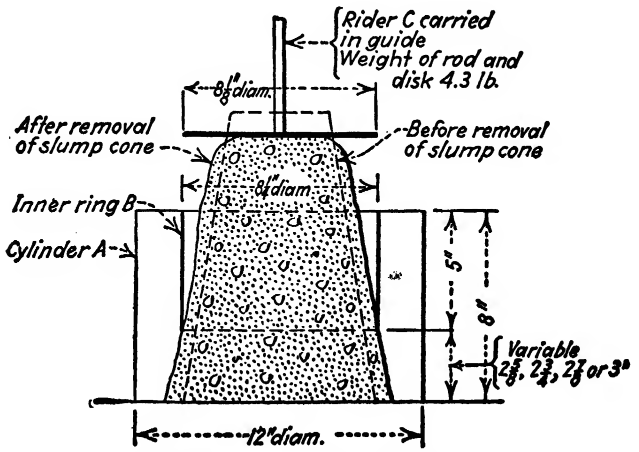


FIG. 10-10.—Cross-sectional sketch of the Powers remolding apparatus for measuring workability of concrete. Portion shown is held rigidly on a flow-table apparatus set for a ¼-in. drop. Remolding effort is indicated by the number of jigs of the flow table to bring the rider down to a plane 3⅜ in. above bottom of cylinder *A*.

3 in., as the tester may desire. The slump cone is filled in three or more increments, each increment being rodded just sufficiently to bring the paste to the surface. As soon as filled, the cone is removed, and the rider weighing 4.3 lb. is brought into contact with the surface of the concrete. The flow table is jigged until the bottom of the rider is $3\frac{3}{16}$ in. above the bottom of the container. Several pictures and a sketch of the apparatus are shown in Figs. 10-9 and 10-10.

According to the author:

> The test measures the relative effort required to change a mass of concrete from one definite shape to another by means of jigging. The amount of effort, called *remolding effort*, is taken as the number of jigs required to complete the change.

The method is not suggested as a direct measure of workability, which is defined as

> . . . that property of a plastic concrete mixture which determines the ease with which it can be placed, and the degree to which it resists segregation.

It does aid in the study of the mobility of masses of concrete made with varying amounts of different constituent materials.

The slump and flow tests are not suited for measuring workability. Their use is largely limited to the control of consistency on construction work. Two concretes of the same slump may have much different workability values owing to any one of the various items discussed above.

WATERPROOFNESS

Waterproofness of concrete may be accomplished in any of the following ways:

1. Special waterproof cements
2. Admixtures
3. Richer mixes and careful gradation of the aggregate
4. Small amounts of mixing water
5. Proper curing
6. Application of bituminous coatings to the surface

Waterproofing of concrete is desirable in order to increase the durability of the concrete or is necessary in order that it may be used to hold water. Concrete that absorbs water easily is likely to disintegrate, owing to the wetting and drying action or to freezing and thawing while wet. Concrete is often used where it is necessary to hold the water either inside or outside the structure, in which case flow of water through the concrete must be prevented. Various methods will be discussed briefly in the following paragraphs.

Waterproof Cements.—As indicated in Chap. 3, there are available certain cements that have a waterproofing material added to the clinker as it is being ground. Waterproof cements are used in the same manner as the standard brands. Care should be exercised, however, in selection of materials, mixing, placing, and curing. Waterproof cement alone will not make waterproof concrete.

Admixtures.[1]—There are a number of patented admixtures on the market, which are claimed to increase the watertightness of the concrete in which they are used. Hydrated lime is also used for this purpose. Normally, 3 to 5 lb. per bag of cement are used for waterproofing purposes.

Richer Mixes and Careful Gradation of the Aggregate.—Passage of water through, or into, concrete is normally through the cement paste and not through the aggregate. A 1:2:4 mix, which is rated as 2,000 lb. concrete at 28 days, is almost universally used for reinforced concrete and as prepared on many jobs is not watertight. Improving the quality of the cement paste and increasing its thoroughness of distribution through, and bonding to, the aggregate will increase the imperviousness of the concrete. By carefully grading the aggregate and then mixing it thoroughly with a cement paste of good quality, a watertight concrete may be made.

Smaller Amounts of Mixing Water.—The quality of the cement paste mentioned above may be increased for waterproofing purposes by using a minimum amount of mixing water. Small amounts of mixing water produce concretes that do not segregate in handling and that may be easily compacted into a solid dense mass. The excess water forms voids in the cement paste, which permit the flow of water through the paste. By using a stiff consistency and thus eliminating excess mixing water, more waterproof concrete can be secured. On the other hand, the amount of mixing water must not be decreased to such an extent that a dry, porous concrete results.

Proper Curing.—Proper curing aids materially in the developing of a watertight concrete. If the concrete is permitted to dry out soon after pouring, the cement paste does not become so dense as when it is kept wet. The denser the cement paste, the greater will be the resistance to the flow of water through the concrete.

[1] See Chap. 4 for discussion of admixtures.

Application of Bituminous Coatings.—Concrete may be waterproofed also by the application of bituminous coatings to the surface, which is wet at first. A light, water-gas tar may be used, which penetrates somewhat into the concrete, or heavier tars or asphalts may be applied that form an impervious layer over the surface.

Study Questions

1. What is meant by durability?

2. What factors affect durability of concrete?

3. What can happen to the concrete if water can move through it by percolation of capillary action?

4. When water at the surface evaporates, how does water from the interior replace that evaporation, provided the water is not under a head?

5. What is meant by corrosion of concrete? What are two types? How can resistance to corrosion be improved?

6. What is meant by the term "cement-aggregate reaction"? What is the special feature of cement for this reaction to take place? special feature of the aggregate?

7. What are the features that become apparent when there is a cement-aggregate reaction?

8. What is the practical solution of the cement-aggregate-reaction problem when such aggregate is the only material available?

9. Name several things that can be done to secure durable concrete for paving work in the northern part of the United States.

10. What range of air content is permitted on work requiring entrained air? How may air entrainment be secured?

11. Does air in aggregate particles count as entrained air? Is it desirable to have a small amount of air in the aggregate particles?

12. What is meant by workability of concrete?

13. Is cement ever made differently in order to provide additional workability for the concrete?

14. How may cement serve as an aid to workability?

15. How may water be used to serve as an aid in promoting workability?

16. What properties of aggregate influence workability? What has been the trend in requirements for the percentages of sand passing the Nos. 50 and 100 sieves?

17. How may the item of mixing have an effect on workability?

18. Name three groups of admixtures that may be used to assist in securing additional workability?

19. What devices have been developed for measuring workability? Describe each briefly.

20. Are the slump and flow tests suitable for measuring workability?

21. What factors affect the waterproofness of concrete?

CHAPTER 11

FIELD CONTROL OF CONCRETE

The discussion of field control of concrete is more or less intimately connected with that on production. Methods of production and their relationship to the quality of the concrete produced have been explained in Chaps. 8 and 9. Ways of controlling quality of materials and methods of construction are treated in this chapter.

During the period beginning about 1915, and especially since 1920, there have been many developments in the field control of concrete. Practices are not standardized today and probably never will be, yet there is much similarity in the work and the ideas of various engineers. The purpose of field control is to secure concrete of the desired qualities. It is not sufficient simply to specify that the contractor shall produce concrete of a given quality. Each shipment of materials must be checked, and every detail of construction must be supervised in order to secure the desired results every time. At first, contractors generally resented strict field control of their work but have since learned that intelligent supervision of their work helps them to produce better work, frequently at less cost.

The public is being educated by various agencies on the necessity of testing by properly qualified testing organizations. Much of our advertising today consists in giving results of tests on the materials being advertised. Materials associations, through their promotion men, are urging public officials to test the materials that they are using and to supervise thoroughly the construction work. The state highway departments have developed large organizations for field control. Consulting testing engineers are available to the communities and concerns that cannot build up organizations of their own.

The Bureau of Reclamation, the Army, Navy, and the Air Forces have developed engineering organizations to handle the work in their respective fields of activity. The Tennessee Valley Authority maintained a close check on the concrete during the construction of the concrete dams that were a part of their program.

Field control of concrete involves the testing of the materials, supervision of the methods of construction, and the testing of samples of concrete prepared from the concrete being used. Inspection is the critical observation of the quality of materials or a process of construction. The operation of field control on a large scale may include the work of a number of inspectors and testing engineers. On smaller jobs all the operations may be handled by one person.

Field Control of State Highway Work.—In most of the state highway organizations the field control of the materials is in the hands of a bureau or division of materials. This bureau generally has complete charge of all work relating to materials. Inspectors are placed at the various materials plants from which material is being obtained for any state work. These men remain at the plants during the construction season and have no other duties during that time. Usually the highway department will have a contact man to visit the inspectors at frequent intervals to check up on their work and to settle any difficulties that may have arisen between the plant men and the inspector.

Cement Inspection.—A complete set of tests on portland cement may require 28 days, if the 28-day strength requirement is included. The present A.S.T.M. specifications provide the 28-day strength shall not be obtained unless the purchaser specifically calls for it, and therefore, the total time required for a complete set of tests is not more than about 10 days. Where the results of previous tests have been satisfactory, it is often the policy to go ahead with shipments and usage of the cement without waiting for all the test results. Whenever the purchaser feels there may be some question about the acceptibility of cement, he most always will require the results of all the tests before using the cement.

A sample of cement never represents more than 2,000 bags. Several samples may be combined to form what is known as a composite sample. For instance, samples are combined for the autoclave soundness test, the composite sample representing 12,000 bags.

Aggregate Inspection.—Once the quality of the material from a given pit or quarry is established, the only tests necessary in the field are for deleterious substances and for gradation. In some cases the former test is waived on each carload if the results of previous tests have been satisfactory. A sieve-analysis determination is easily and quickly made, and thus the pit or quarry operator knows usually before the car has started on its journey whether the material is satisfactory or not. In the case of aggregates it is customary to place a "satisfactory" card on the car.

Reports.—The inspectors keep complete records of all of their tests. Reports are sent each day to the resident engineers or inspectors, as the case may require, on the materials that are shipped or tested that day.

Duplicate copies should also be sent to the main office of the bureau of materials and to the field man in charge of the inspection of materials. Generally, the men placed on the inspection service are nontechnical men or the younger engineers who are just beginning with the department. These men need careful supervision, and the system of reports should furnish a check on what they are doing.

Construction Inspection.—Construction inspection is the most important part of the field-control work. Unless the materials are properly put together, the structure may fail. With concrete the quality is not known at once, and in the interval while it is gaining strength other portions of the structure are added. The concrete in each portion must be of the proper quality, otherwise the structure may fail when it is finished or nearly finished. Even though a failure in a pavement may not result in loss of life or damage to property, it is desirable to do the work correctly the first time. In city work it is often difficult to secure funds for either the original construction or for renewals.

Many highway departments divide the paving work into sections varying from about 4 to 12 mi. in length. An inspector is necessary at the batching plant and one at the point where the concrete is deposited. The inspector at the plant on central mixing can easily handle both the weighing and the mixing. If the mixing is done on the road, that inspector may have more than he can attend to thoroughly. He should not have duties that will take him away from the work except for short intervals.

The inspector at the batching plant should check each batch to see that it has the proper amounts of materials in it. Most specifications require the use of weighing devices for the aggregate and the cement, if the amount required is not a whole number of bags. The scales are set and a telltale indicator shows when the right amount is in the weighing hopper. With a little experience it is not difficult for the operator to weigh out the correct amounts of materials. Water is measured by volume, using either a tank or a metering device, both of which can be set to deliver the same amount of water to the mixer batch after batch.

If the mixing is done at the batching plant, the inspector must also check on the time of mix, the charging and unloading of the drum, and on the consistency of the concrete. Timing devices are ordinarily required, which lock the discharge apparatus until the proper mixing time has elapsed. Occasional checking of the timing apparatus is all that is necessary. All specifications provide that the materials for one batch shall not be placed in the mixer until all of the previous batch has been discharged. In order to speed up operations there is a tendency on the part of the mixer operator to start the materials for one batch into the mixer before all the concrete of the previous batch is out. This may not be serious if the quantities are small, but it should be watched.

Practically all highway work is done with the proportions of dry materials and the amount of mixing water given to the men on the job by some one from the central laboratory. A number of states now have a man on the job, known as the proportioning engineer, who does all of the job testing and determines the exact amounts of materials to go into

FIG. 11-1.—Field engineer with a sample of paving concrete. Unit-weight test has been made and measure is being emptied. Slump cone is inverted just beyond the concrete sample; forms for casting a beam and several cylinders are to the right. Bucket was used to carry sample of concrete from point of sampling. (*Portland Cement Association.*)

each batch. Even though the proportions are sent out from the central laboratory, it is usually necessary to make small variations from time to time owing to changes in materials.

Consistency determinations are desirable on all jobs, if for no other reason than as a matter of record. The slump test is the one most often used in the field. On jobs where the amount of mixing water is not specified, the slump test will help to keep a more uniform consistency. On jobs where the water-cement ratio is specified and the desired consistency is to be obtained through a variation in the quantity and gradation of the aggregate, the slump test is a material aid in securing the desired results. In large organizations the men in responsible charge need to know what is going on, on the job, and the furnishing of consistency-test results will do this as far as this item is concerned.

Several state highway departments are specifying the exact amounts of water and cement and are requiring that the consistency be regulated by means of the gradation and quantity of the aggregate.

It is necessary to determine the moisture contents from time to time in order to correct the amount of water being added separately. Variations usually occur during rainy weather or when the material is taken at random from cars or stock pile. Often there is a difference in the moisture content of the sand in the car and in the stock pile. More supervision is required for this method than is usually given under arbitrary proportioning, with the result that better and more uniform concrete is secured.

In other cases, arbitrary proportions and consistency are specified, and once the amount of water required to give that consistency has been determined, the same amount is used in all subsequent batches. The field-control operations then are the same as given in the preceding paragraph. Contractors at first objected to the water-cement-ratio specification because they did not have this information when they made their bids. The latter method overcomes this objection to some extent.

The inspector at the point where the concrete is being placed must check up to see that the correct amounts of concrete are being placed, that the reinforcing steel is properly placed, and that the concrete is properly finished and cured. Proper methods for each particular job should be described in the specifications. Most highway departments supplement their specifications with a field manual.

The inspector, if given careful supervision, need not be a graduate engineer. Most of his work is the checking of certain items in a given manner. Ordinarily, the inspector will not have any authority to make any changes in the regular procedure to fit special occasions. Most road jobs where the contractor develops any speed in construction will require the service of an engineer to lay out the work. The inspector then will be under the direct supervision of the resident engineer.

Frequently, there are a number of jobs close enough to each other that it is possible to place one man in charge of several sections. This man will spend all of his time giving general supervision to work. It has been found that the man who visits the job occasionally can do much to keep things going properly. Coming on the job fresh and looking it over as a whole, he can catch points that are being overlooked by the inspectors. New situations and conditions are continually arising, which the inspector often is not capable of handling. Occasionally, the inspector and contractor have difficulties with each other and need straightening out.

Field Control on City Paving Work.—The problems encountered on city paving work are similar to those on the country road, and here the necessity of control is as great in the city as in the country. As a rule, however, not so much is exercised in the cities, largely because of a lack of finances. The larger cities will have enough work to employ testing engineers, inspectors, and construction engineers all year, and it is only in the smaller cities that very little or nothing is done in field control. Some of the larger cities carry on research work as well and use the same organization for both purposes.

For the smaller cities unable to develop their own organizations for field control, there are consulting engineering firms specializing in testing of materials and inspection of construction. In many cities all of the engineering work is done by consulting firms that handle all phases, including estimates, plans, specifications, contracts, inspection of materials, and supervision of construction.

Very often the construction inspector knows nothing of concrete work. Often some property owner along the street is employed, or the job is given to someone to repay a political debt. An inspector who is not familiar with concrete may do more harm than good and often unnecessarily causes the contractor extra expenses.

Much better results are secured when the inspectors are employed regularly and are given some training and lots of supervision. Many cities can employ their inspectors for a season at least, and thus it is worth while to spend some time and effort in a systematic training course. Often these men are available for a number of years in succession, and if they are satisfactory, they should be employed largely because of their experience.

It is necessary to give the inspectors daily supervision, the same as in the country road work. The jobs ordinarily are closer together, and one man can handle more inspectors.

Field Control on Building Construction.—The same items need control on building construction as on the highway work. The problem is different in that the amount of work under the control of an engineering or an architectural firm may be comparatively small, and ordinarily no large organization is developed. If the firm has a number of jobs going at the same time, one may may be used to supervise, in a general way, all of the work. An inspector is placed on the job who supervises the handling, measuring, and mixing of the materials, and the transportation, placing, finishing, and curing of the concrete. All these operations usually take place in a small area and can be controlled by a small number of inspectors.

Not so much is ordinarily done in the checking of materials for building construction as for the highway work. Architects receive practically no testing training in college, and unless they secure an appreciation of its value through sad experiences, not much attention is paid to the selection of materials.

Job Test Specimens.—It is becoming more and more common to make specimens for testing purposes as the concrete is being placed in the forms. As a rule, these specimens are cured in the field under the same conditions as the concrete in the structure. Tests are made at various ages to determine the strengths being developed. Frequently, use of the structure is permitted when the test specimens show certain strengths. This is particularly true in connection with highways where the beam test has been developed for use in the field. The strength required before opening to traffic in the case of the pavement will depend upon the thickness of the slab, its design, and the loads likely to be imposed. No certain strength can be prescribed as essential in every case. Interpretation and use of field test data should be limited to men of experience in that work.

Methods of preparing and testing these specimens are described in the chapter on testing. Extreme care should be exercised to secure representative concrete and then to cure the specimens under conditions similar to those on the job.

Testing of specimens of concrete in the field furnishes a valuable fund of information for the men on the job and enables them to do their work better. Oftentimes it is possible to develop a little competition between gangs, which will improve the quality considerably. Use of a structure when it is ready may reduce construction costs, and the only way to determine its readiness is to test the concrete. Tests may also prevent premature use, an item that is equally valuable.

CHAPTER 12

SPECIFICATIONS

Specifications are prepared by the engineer to describe the materials to be furnished and the methods to be followed in making or building something. The specifications set up all the requirements that each material is to meet, both chemical and physical. In most cases the engineer limits himself to physical requirements, although there are times when chemical limits are established. The engineer must also specify how tests are to be made to determine if the material meets the requirements given.

The field of engineering materials has become so large and complex that there are few who have intimate, personal knowledge concerning all the materials that may be used in a construction project. The A.S.T.M. has prepared many specifications for materials, methods of testing, and for testing equipment, assigning the duties to members who are specialists in particular fields. These specifications are published and have such a wide distribution throughout the world that it is common practice for engineers to specify many materials by a simple referral to the necessary A.S.T.M. specification. Some state highway departments print their specifications in book form, and these as a rule include everything.

The A.S.T.M. specifications for cements and aggregates have been given in the chapters dealing with these materials. This chapter quotes the A.S.T.M. specification for Ready-mixed Concrete in order to provide the student with convenient access to one specification dealing with concrete. It should be studied primarily in connection with Chaps. 8 and 9. Specifications for specific projects, such as buildings, bridges, dams, highway and airport pavements, sewage-treatment works, waterworks, canal linings, etc., should be studied whenever available.

STANDARD SPECIFICATIONS FOR READY-MIXED CONCRETE

A.S.T.M. Designation: C 94 - 48[1]

1. **Scope.**—*a.* These specifications cover ready-mixed concrete for general use. Requirements for quality of materials and for proportions and quality of con-

[1] Prior to their present publication as standard, these specifications were published as tentative from 1933 to 1935. They were adopted in 1935, published as

crete shall be either as hereinafter specified or as specified by the purchaser by reference to applicable general specifications for concrete. In any case where the requirements of such general specifications are in conflict with these specifications, the requirements of the general specifications shall govern unless otherwise specified by the purchaser.

b. For the purpose of these specifications, ready-mixed concrete is portland-cement concrete manufactured for delivery to a purchaser in a plastic and unhardened state and delivered as hereinafter specified.

c. These specifications do not cover the placement, consolidation, curing, or protection of the concrete after delivery to the purchaser.

2. **Basis of Purchase.**—*a.* The basis of purchase shall be the cubic yard of plastic and unhardened concrete as delivered to the purchaser.

b. The volume of plastic and unhardened concrete in a given batch shall be determined from the total weight of the batch divided by the actual weight per cubic foot of the concrete. The total weight of the batch shall be calculated either as the sum of the weights of all materials, including water, entering the batch or as the net weight of the concrete in the batch as delivered. The weight per cubic foot shall be determined in accordance with the Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (A.S.T.M. Designation: C 138).

3. **Materials.**—*a.* In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

(1) *Portland Cement.*—Portland cement shall conform to the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150) or the Tentative Specifications for Air-Entraining Portland Cement (A.S.T.M. Designation: C 175). The purchaser should specify the type or types required, but if no type is specified, the requirements of type I or type II as prescribed in Specifications C 150 shall apply.

(2) *Aggregates.*—Aggregates shall conform to the Standard Specifications for Concrete Aggregates (A.S.T.M. Designation: C 33).

(3) *Water.*—Water shall be clear and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

b. Admixtures, if to be used, shall be provided for in the contract or in the designated applicable specifications for concrete.

4. **Quality of Concrete.**—In the absence of designated, applicable, general specifications, the purchaser shall select one of the two following alternate bases for specifying the quality of the concrete:

a. Alternate No. 1.—When the purchaser assumes responsibility for the design of the concrete mixture, he shall specify the following:

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standard from 1935 to 1942, being revised in 1938, but were further revised and issued as tentative in 1941, being revised in 1942, 1943, and 1944. They were again adopted in 1944 and published as standard from 1944 to 1947. The specifications were revised and republished as tentative in 1947. They were adopted as standard in 1948 without revision.

(1) Cement content in bags per cubic yard of concrete, or equivalent units.

(2) Designated size, or sizes, of coarse aggregate.

(3) Maximum allowable water content in gallons per bag of cement, or equivalent units, including surface moisture, but excluding water of absorption, of the aggregates (Note 1).

(4) Slump, or slumps, desired at the point of delivery (see Section 5 for acceptable tolerances).

(5) When an air-entraining cement or an air-entraining admixture is used, the maximum and minimum air content of the concrete as determined from samples taken from the transportation unit at the point of discharge (Note 2).

NOTE 1.—The purchaser, in selecting the requirements for water content, shall give consideration to requirements for durability, surface texture, and density, in addition to those for structural design. Table 1 suggests a basis for the selection of water content that will result in concrete suitable for various types of structures and conditions of exposure.

NOTE 2.—Tests for air content, both preliminary to construction and routine tests for control purposes during construction, are required. For the range in aggregate sizes commonly used in ready-mixed concrete, the air content specified should be from 3 to 6 per cent. Any amount less than 3 per cent may not give the required resistance to weathering, which is the primary purpose of using air-entraining concrete, whereas an air content in excess of 6 per cent may reduce the strength without contributing additional protection.

b. Prior to the actual delivery of the concrete, the manufacturer shall furnish a statement to the purchaser giving the proportions by weight (dry) of cement and of fine and coarse aggregates that will be used in the manufacture of each class of concrete ordered by the purchaser. Such proportions shall be subject to the approval of the purchaser.

Alternate No. 2. When the purchaser requires the manufacturer to assume responsibility for the design of the concrete mixture, the purchaser shall specify the following:

(1) Minimum, allowable compressive strength as determined on samples taken from the transportation unit at the point of discharge. The basis shall be the compressive strength at 28 days (Note 3). The purchaser shall specify the requirements for strength in terms of tests of standard specimens, cured under standard laboratory conditions for moist curing (see Section 18).

(2) Designated size, or sizes, of coarse aggregate.

(3) Slump or slumps desired at the point of delivery (see Section 5 for acceptable tolerances).

(4) When an air-entraining cement or an air-entraining admixture is used, the maximum and minimum air content of the concrete as determined from samples taken from the transportation unit at the point of discharge (Note 2).

NOTE 3.—The purchaser, in selecting the minimum, allowable compressive strength to be specified, shall give consideration to requirements for durability, surface texture, and density, in addition to those for structural design. Table 2 suggests a basis for the selection of minimum allowable compressive strengths, which, for average normal portland cement, will result in the use of water-cement ratios that will produce concrete suitable for various types of structures and conditions of exposure.

b. Prior to the execution of the contract, the manufacturer shall furnish a statement to the purchaser, giving the proportions by weight (dry) of cement and of fine and coarse aggregates that will be used in the manufacture of each class of concrete ordered by the purchaser. If required, he shall also furnish evidence satisfactory to the purchaser that the proportions selected will produce concrete of the quality specified.

5. **Tolerances in Slump.**—When the specified slump is 3 in. or less, the tolerance shall be plus or minus ½ in. When the specified slump is greater than 3 in., the tolerance shall be plus or minus 1 in.

6. **Measuring Materials.**—*a*. Cement shall be measured by weight or, if permitted by the purchaser, in bags of 94 lb. each. When cement is measured by

TABLE 1.—WATER-CEMENT RATIOS SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE[1]

NOTE.—Presented as information only and not as a part of the specifications. Taken from Table 1 of the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, June, 1940. Water-cement ratios are based on the use of nonair-entraining portland cement. When air-entraining cements or admixtures are used, the water-cement ratios will be reduced approximately ½ gal. per bag.

[1] Author's note.—This table is printed as Table 6-1 elsewhere in the book. The reader is referred to Chap. 6 for it.

weight, it shall be weighed on a scale separate from those used for other materials. When cement is measured in bags, no fraction of a bag shall be used unless weighed.

b. Aggregate shall be measured by weight. Batch weights shall be based on dry materials and shall be the required weights of dry materials plus the total weight of moisture (both absorbed and surface) contained in the aggregate.

c. Water shall be measured by volume or by weight. The device for the measurement of the water shall be readily adjustable and, under all operating conditions, shall have an accuracy within 1 per cent of the quantity of water required for the batch. The device shall be so arranged that the measurements will not be affected by variable pressures in the water-supply line. Measuring tanks shall be equipped with outside taps and valves to provide for checking their calibration, unless other means are provided for readily and accurately determining the amount of water in the tank. In the case of truck mixers, if wash water is permitted to be used as a portion of the mixing water for succeeding batches, it shall be accurately measured in a separate tank, provided for the purpose, and taken into account in determining the amount of additional mixing water required.

TABLE 2.—COMPRESSIVE STRENGTHS OF CONCRETE SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE

NOTE.—Presented as information only and not as a part of the specifications; adapted from Tables 1 and 2 of the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, June, 1940.

<table>
<tr><th rowspan="4">Type or location of structure</th><th colspan="10">Compressive strength, min., p.s.i., at 28 days</th></tr>
<tr><th colspan="5">Severe or moderate climate, wide range of temperatures, rain and long freezing spells or frequent freezing and thawing</th><th colspan="5">Mild climate, rain or semiarid, rarely snow or frost</th></tr>
<tr><th colspan="2">Thin sections</th><th colspan="2">Moderate sections</th><th rowspan="2">Heavy and mass sections</th><th colspan="2">Thin sections</th><th colspan="2">Moderate sections</th><th rowspan="2">Heavy and mass sections</th></tr>
<tr><th>Reinforced</th><th>Plain</th><th>Reinforced</th><th>Plain</th><th>Reinforced</th><th>Plain</th><th>Reinforced</th><th>Plain</th></tr>
<tr><td>A. At the waterline in hydraulic or water-front structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>In sea water</td><td>5,000</td><td colspan="2">4,500</td><td colspan="2">4,000</td><td>5,000</td><td colspan="2">4,500</td><td colspan="2">4,000</td></tr>
<tr><td>In fresh water</td><td>4,500</td><td colspan="2">4,000</td><td colspan="2">3,600</td><td>4,500</td><td colspan="2">4,000</td><td colspan="2">3,600</td></tr>
<tr><td>B. Portions of hydraulic or water-front structures some distance from the waterline, but subject to frequent wetting:</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>By sea water</td><td>4,500</td><td colspan="2">4,000</td><td colspan="2">4,000</td><td>4,500</td><td colspan="2">3,600</td><td colspan="2">3,200</td></tr>
<tr><td>By fresh water</td><td>4,000</td><td colspan="2">3,600</td><td colspan="2">3,600</td><td>4,000</td><td colspan="2">3,200</td><td colspan="2">2,800</td></tr>
<tr><td>C. Ordinary exposed structures, buildings, and portions of bridges not coming under above groups</td><td>4,000</td><td colspan="2">3,600</td><td colspan="2">3,200</td><td>4,000</td><td colspan="2">3,200</td><td colspan="2">2,800</td></tr>
<tr><td>D. Complete continuous submergence:</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>In sea water</td><td>4,000</td><td colspan="2">3,600</td><td colspan="2">3,200</td><td>4,000</td><td colspan="2">3,600</td><td colspan="2">3,200</td></tr>
<tr><td>In fresh water</td><td>3,600</td><td colspan="2">3,200</td><td colspan="2">2,800</td><td>3,600</td><td colspan="2">3,200</td><td colspan="2">2,800</td></tr>
<tr><td>E. Concrete deposited through water</td><td>...</td><td>...</td><td>4,500</td><td colspan="2">4,500</td><td>...</td><td>...</td><td>4,500</td><td colspan="2">4,500</td></tr>
<tr><td>F. Pavement slabs directly on ground:</td><td></td><td></td><td></td><td colspan="2"></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Wearing slabs</td><td>4,500</td><td>4,000</td><td>...</td><td colspan="2">...</td><td>4,000</td><td>3,600</td><td></td><td colspan="2"></td></tr>
<tr><td>Base slabs</td><td>3,600</td><td>3,200</td><td>...</td><td colspan="2">...</td><td>3,200</td><td>2,800</td><td></td><td colspan="2"></td></tr>
</table>

G. Special cases:

(*a*) For concrete exposed to strong sulfate ground waters, or other corrosive liquids or salts, the minimum compressive strength should be 5,000 p.s.i.

(*b*) For concrete not exposed to the weather, such as the interior of buildings and portions of structures entirely below ground, no exposure hazard is involved and the compressive strength should be selected on the basis of the structural design requirements.

d. Powdered admixtures shall be measured by weight, and paste or liquid admixtures by weight or volume, within a limit of accuracy of 3 per cent. When admixtures are used in small quantities in proportion to the cement, as in the case of air-entraining admixtures, mechanical dispensing equipment is strongly recommended.

7. **Batching Plant.**—*a.* Unless otherwise permitted by the purchaser, bins with adequate separate compartments for fine aggregates and for each required size of coarse aggregate shall be provided in the batching plant. Each compartment shall be designed to discharge efficiently and freely into the weighing hopper. Means of control shall be provided so that, as the quantity desired in the weighing hopper is being approached, the material may be added slowly and shut off with precision. A port or other opening for removing an overload of any one of the several materials from the hopper shall be provided. Weighing hoppers shall be constructed so as to eliminate accumulations of tare materials and to discharge fully.

b. The scales for weighing aggregates and cement may be of either the beam type or the springless-dial type. They shall be accurate within 1 per cent under operating conditions. Adequate, standard test weights shall be available for checking accuracy. All exposed fulcrums, clevises, and similar working parts of scales shall be kept clean. When beam-type scales are used, provision shall be made for indicating to the operator that the required load in the weighing hopper is being approached; the device shall indicate at least the last 200 lb. of load. All weighing and indicating devices shall be in full view of the operator while charging the hopper, and he shall have convenient access to all controls.

8. **Mixers and Agitators.**—*a.* Mixers may be stationary mixers or truck mixers. Agitators may be truck mixers or truck agitators. Each mixer and agitator shall have attached thereto in a prominent place a metal plate or plates on which is plainly marked, for the various uses for which the equipment is designed, the capacity of the drum or container in terms of the volume of mixed concrete and the speed of rotation of the mixing drum or blades. Stationary mixers shall be equipped with an acceptable timing device that will not permit the batch to be discharged until the specified mixing time has elapsed. Truck mixers shall be equipped with means by which the number of revolutions of the drum or blades may be readily verified.

b. The mixer, when loaded to capacity, shall be capable of combining the ingredients of the concrete within the specified time into a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as indicated in paragraph *d.*

c. The agitator, when loaded to capacity, shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as indicated in paragraph *d.*

d. The purchaser may, from time to time, make slump tests of individual samples taken at approximately the one-quarter and the three-quarter points of the load, and if the slumps differ by more than 2 in. the mixer or agitator shall not be used, unless the condition is corrected, except as provided in paragraph *e.*

e. If the requirements of Paragraph *d* are not met by mixers when operated at the minimum, specified mixing time and loaded to capacity, or by agitators when loaded to capacity, the equipment may still be used when operation with a longer mixing time or with a smaller load will permit the requirements of paragraph *d* to be met.

f. Mixers and agitators shall be examined daily for changes in condition due to accumulations of hardened concrete or mortar or to wear of blades. When any such change of condition is found, the tests described in paragraph *d* should be repeated.

9. **Mixing and Delivery.**—*a.* Ready-mixed concrete shall be mixed and delivered to the point designated by the purchaser by means of one of the following combinations of operations:

(1) Mixed completely in a stationary mixer and the mixed concrete transported to the point of delivery in a truck agitator or in a truck mixer operating at agitator speed or, in certain cases (see Section 10) when the purchaser permits, in approved non agitating equipment (known as "central-mixed" concrete).

(2) Mixed partially in a stationary mixer, and the mixing completed in a truck mixer (known as "shrink-mixed" concrete.)

(3) Mixed completely in a truck mixer (known as "transit-mixed" concrete).

b. Mixers and agitators shall be operated within the limits of capacity and speed of rotation designed by the manufacturer of the equipment.

c. When a stationary mixer is used for the complete mixing of the concrete, the mixing time for mixers having capacities of 1 cu. yd. or less shall be not less than 1 min. For mixers of larger capacities, this minimum shall be increased 15 sec. for each cubic yard or fraction thereof of additional capacity. Mixing time shall be measured from the time all cement and aggregates are in the drum. The batch shall be so charged into the mixer that some water will enter in advance of cement and aggregate, and all water shall be in the drum by the end of the first one-fourth of the specified mixing time.

d. When a stationary mixer is used for partial mixing of the concrete (shrink mixing), the mixing time in the stationary mixer may be reduced to the minimum required (about 30 sec.) to intermingle the ingredients.

e. When a truck mixer is used either for complete mixing or to finish the partial mixing done in a stationary mixer, each batch of concrete shall be mixed for not less than 50 nor more than 100 rev. of the drum or blades at the rate of rotation designated by the manufacturer of the equipment as mixing speed. Additional mixing, if any, shall be at the speed designated by the manufacturer of the equipment as agitating speed.

f. When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed in a stationary mixer, mixing during transportation shall be at the speed designated by the manufacturer of the equipment as agitating speed.

g. When a truck mixer or agitator is used for transporting concrete, the concrete shall be delivered to the site of the work and discharge shall be completed within 1½ hr. after the introduction of the mixing water to the cement and aggregates, or the introduction of the cement to the aggregates, unless a longer time is specifically authorized by the purchaser. In hot weather, or under conditions contributing to quick stiffening of the concrete, a time less than 1½ hr. may be specified by the purchaser. When a truck mixer is used for the complete mixing of the concrete, the mixing operation shall begin within 30 min. after the cement has been intermingled with the aggregates.

h. Concrete delivered in outdoor temperatures lower than 40°F. shall arrive at the work having a temperature not less than 60°F. nor greater than 90°F., unless otherwise specified or permitted by the purchaser.

10. **Use of Nonagitating Equipment.**—Central-mixed concrete may be transported in nonagitating equipment only when provision for such method of transportation is made in the contract (Note). When the use of nonagitating equipment is so permitted, the following limitations shall apply:

a. Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that will permit of control of the discharge of the concrete. Watertight covers shall be provided for protection against the weather when required.

b. The concrete shall be delivered to the site of the work in a thoroughly mixed and uniform mass and discharged with a satisfactory degree of uniformity as prescribed in paragraph *c.* Discharge shall be completed within 45 min. after the introduction of the mixing water to the cement and aggregates.

c. Slump tests of individual samples taken at approximately the one-quarter and the three-quarter points of the load during discharge shall not differ by more than 2 in.

NOTE.—The use of nonagitating equipment for the transportation of concrete may result in segregation and difficulty in discharge. Well-proportioned plastic mixtures, short hauls, and smooth roads are favorable for the use of such transportation equipment.

11. **Inspection.**—Proper facilities shall be provided for the purchaser to inspect ingredients and processes used in the manufacture and delivery of the concrete. The manufacturer shall afford the inspector representing the purchaser all reasonable facilities, without charge, for securing samples to determine whether the concrete is being furnished in accordance with these specifications. All tests and inspections shall be so conducted as not to interfere unnecessarily with the manufacture and delivery of the concrete.

12. **Sampling.**—Samples of concrete shall be obtained in accordance with the Standard Method of Sampling Fresh Concrete (A.S.T.M. Designation: C 172), except in the case of individual samples secured to determine uniformity of consistency. In securing individual samples to determine uniformity of consistency as provided in Sections 8*d* and 10*c*, of these specifications, Method C 172 shall be followed, but the requirements shall be so modified as to permit of obtaining two samples, one at the one-quarter point and one at the three-quarter point of the load.

13. **Slump and Air Content.**—Slump tests shall be made at the option of

the purchaser. Determinations of air content shall be made at the option of the purchaser if air-entraining cement or an air-entraining admixture is used. If the measured slump or air content falls outside the limits specified, a check test shall be made. In the event of a second failure the purchaser may refuse to permit the use of the load of concrete represented.

14. **Certification.**—The manufacturer of the ready-mixed concrete shall furnish to the purchaser, for each type of concrete and when any change in composition is made, a statement showing the quantities of materials used in making the concrete.

15. **Strength.**—*a.* When strength is used as a basis for acceptance of concrete made in accordance with these specifications, standard tests (see Section 18) shall be made frequently by the purchaser and, in general, not less frequently than one strength test for each fifty loads of each class of concrete, except that in no case shall a given class of concrete be represented by less than three tests.

b. For a strength test three standard test specimens shall be made from a composite sample secured as required in Section 12. The test result shall be the average of the strengths of the three specimens, except that, if one specimen in a test shows manifest evidence of improper sampling, molding, or testing, it shall be discarded and the remaining two strengths averaged. Should more than one specimen representing a given test show definite defects due to improper sampling, molding, or testing, the entire test shall be discarded.

c. The representative of the purchaser shall ascertain and record the exact location in the work at which each load represented by a strength test is deposited.

d. To conform to the requirements of these specifications, the average of all of the strength tests representing each class of concrete, as well as the average of any five, consecutive strength tests representing each class of concrete, shall be equal to, or greater than, the specified strength and no strength test shall have an average value less than 80 per cent of the specified strength.

16. **Alternate Strength Basis.**—The provisions of Section 15 may be waived, at the option of the purchaser, if the manufacturer can furnish evidence satisfactory to the purchaser that concrete of the proportions and made with the materials that he proposes to use will have the specified strength.

17. **Failure to Meet Strength Requirements.**—In the event that concrete tested in accordance with the requirements of Section 15 fails to meet the strength requirements of these specifications, the manufacturer of the ready-mixed concrete and the purchaser shall confer to determine whether agreement can be reached as to what adjustment, if any, shall be made. If an agreement on a mutually satisfactory adjustment cannot be reached by the manufacturer and the purchaser, a decision shall be made by a panel of three qualified engineers, one of whom shall be designated by the purchaser, one by the manufacturer, and the third chosen by these two members of the panel. The question of responsibility for the cost of such arbitration shall be determined by the panel. Its decision shall be binding, except as modified by a court decision.

18. **Methods of Sampling and Testing.**—Methods of testing ready-mixed

concrete shall be in accordance with the following methods of the American Society for Testing Materials:

a. Compression Test Specimens.—Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (A.S.T.M. Designation: C 31), except that Section 7*c* of Method C 31 shall not apply to specimens used as a basis for acceptance.

b. Compression Tests.—Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (A.S.T.M. Designation: C 39).

c. Yield and Air Content.—Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (A.S.T.M. Designation: C 138).

d. Slump.—Standard Method of Slump Test for Consistency of Portland-cement Concrete (A.S.T.M. Designation: C 143).

e. Sampling Fresh Concrete.—Standard Method of Sampling Fresh Concrete (A.S.T.M. Designation: C 172).

CHAPTER 13

SAMPLING

Sampling is the process of selecting small, representative quantities of a given material for purposes of examination or testing. Since the quality of a large amount of material is to be determined on the basis of the sample selected, it is exceedingly important that the portion taken be representative. Much is often left to the judgment of the person doing the sampling as to whether the material is accepted or rejected.

Cement, aggregates, and water are the only concrete materials to be sampled, with the possible exception of curing agents and admixtures. Methods for sampling and testing of cement and aggregates are prescribed by the American Society for Testing Materials and are usually followed by engineers.

Cement.—Cement is normally sampled by the purchaser, most often at the manufacturing plant of the producer. Occasionally, samples are taken when the shipment is received by the purchaser, but this practice delays use of the cement during the interval while the samples are being tested. There are times too when a quantity of cement has been in storage for a period of time and should be checked for quality before being used. The rules for taking samples are given in the A.S.T.M. specifications for sampling, which are quoted in this chapter.

Aggregates.—Before using aggregates from any pit or quarry for concrete, the general quality of the material in the deposit should be determined. Knowledge should be obtained of the durability, strength, wearing qualities, and soundness. The deposit in a pit or quarry may vary considerably from place to place, and hence a large number of samples should be secured before removal operations are begun, or the deposit should be watched and checked occasionally as work progresses. Knowledge of material contained in neighboring pits or quarries is helpful in judging the quality of the material in question.

After the materials in any pit or quarry have been accepted for quality, certain other tests must be made on each carload. Gradation and cleanness are the items needing constant control. Sand, because of its size and moisture content, is rather uniform as loaded into a car. Coarse aggregate has a tendency to segregate according to size of particles.

The coarser ones roll down to the edge of the pile and the finer ones concentrate in the center under the unloading spout.

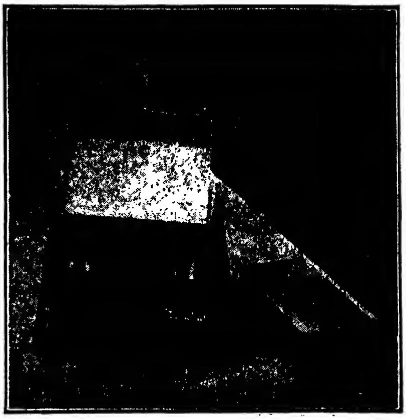

FIG. 13-1.—Sample splitter for securing representative test samples of sand.

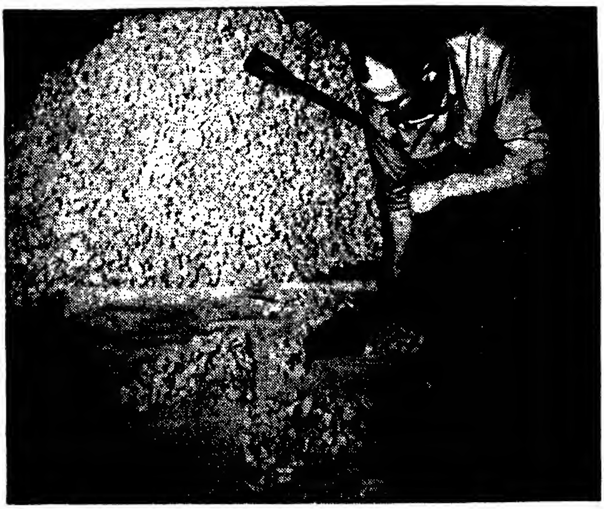

FIG. 13-2.—Selecting a test sample by the quartering method. In the background is the stockpile of crushed stone, from which is taken a quantity larger than the required test sample. This quantity of stone is spread out on a piece of canvas and thoroughly mixed. By means of a large trowel or shovel the sample is divided into two parts, then each part is divided, and so on until one portion is the quantity needed. (*Portland Cement Association.*)

Preparing Samples for Testing.—The samples as selected must be further reduced in size before the individual tests can be made. Again, special efforts are made to select representative portions for testing.

Cement should be thoroughly mixed and passed through a No. 20 sieve. Aggregates should be well mixed, which may be done with a shovel or trowel. The portion for testing is selected by quartering method. The original sample is spread in an even layer and then divided into two parts. One of these parts is divided in two and the process continued until a part is secured that has the required amount in it for the test. In case sample splitters are not available, the division may be made with a shovel or a trowel.

Specifications for Sampling.—The A.S.T.M. specifications for sampling cement and aggregates are quoted in full.

STANDARD METHODS OF SAMPLING HYDRAULIC CEMENT

A.S.T.M. Designation: C 183 – 46

1. Scope.—These methods cover the procedures for sampling hydraulic cement.

2. Size and Number of Samples; by Whom Taken.—*a.* Samples for purposes of tests shall weigh at least 4 lb. each when they are to be composited. Individual test samples, on which all specified tests are to be made, shall weigh at least 8 lb.

b. Test samples shall be either individual or composite samples, as may be specified, and one test sample shall represent not more than 2,000 bags unless otherwise specified by the purchaser.

c. The sampling shall be done by, or under the direction of, a responsible representative of the purchaser.

3. Sampling.—The cement may be sampled by any of the methods described in the following paragraphs *a* to *d*:

a. From the Conveyer Delivering to Bulk Storage.—One sample of 4 lb. or more shall be taken from at least each 2,000 bags passing over the conveyer, except that the sample shall represent not more than 6 hr. of cement production. This may be secured by taking the entire test sample at a single operation, known as the "grab method," or by combining several portions taken at regular intervals, known as the "composite method." When obtaining a composite sample, it shall be secured by combining approximately equal weights of the cement taken at regular intervals, each portion representing approximately 40 bags. Automatic samplers may be used in obtaining samples.

b. From Bulk Storage at Points of Discharge.—Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before the drawing of the cement is started. One 4-lb. sample shall be taken for at least each 2,000 bags, by either the grab or composite method as described in paragraph *a*.

c. From Bulk Storage by Means of Proper Sampling Tubes.—When the methods described in paragraphs *a* and *b* cannot be applied and when the depth of the cement to be sampled does not exceed 10 ft., samples may be obtained by proper tubes inserted vertically to the full depth of the cement. Samples so taken shall be obtained from points well distributed over the area of storage.

d. In all other cases, samples shall be taken from each 50 bags, or portion thereof in the lot, and combined to form test samples. In the case of samples from trucks where the cement is being trucked from one mill, it is permissible to combine the samples from several trucks to form a test sample representing not more than 2,000 bags. When bulk shipments are sampled, representative samples shall be taken from well-distributed points.

4. Preparation of Sample.—*a.* Samples shall be packed by the purchaser in moistureproof, airtight containers, which shall be crated, if necessary, by the manufacturer and shipped at the expense of the purchaser. Before testing, samples shall be thoroughly mixed and then passed through a No. 20 sieve in order to break up lumps and remove foreign materials.

b. Composite samples for the tests as required in Section 5 shall be prepared by arranging all test samples in groups, each group representing the number of bags required by the test or tests for which the composite sample is intended. From each of the test samples in a group, equal portions shall be taken, sufficient in amount to form a composite sample large enough to permit making the required physical or chemical determinations. The composite sample thus prepared shall be thoroughly mixed before using.

5. Number of Tests.—*a.* All physical tests required by the purchase specifications shall be made on each test sample taken from cars and trucks, with no test sample representing more than 2,000 bags.

b. Physical tests on samples taken from bins, boats, warehouses, etc., shall be required as follows:

(1) *Time of Setting*, each test sample representing each 2,000 bags.

(2) *Air Content* (A.S.T.M. Specification C 175), composite sample representing each 4,000 bags.

(3) *Fineness* (surface area or 200-mesh fineness as required by the purchase specifications), composite sample representing each 4,000 bags.

(4) *Strength*, composite sample representing each 4,000 bags.

(5) *Soundness* (autoclave-expansion or steam-pat test as required by the purchase specifications), composite sample representing each 12,000 bags.

c. Chemical determinations shall be required as follows:

(1) *Sulfur Trioxide* (SO_3), composite sample representing each 4,000 bags.

(2) *All Specified Chemical Determinations* (*except* SO_3), composite sample representing each 20,000 bags.

d. When the total number of bags sampled is less than that specified for any one of the above test or composite samples, all of the respective physical and chemical tests shall be made on the quantity sampled.

TENTATIVE METHODS OF SAMPLING STONE, SLAG, GRAVEL, SAND, AND STONE BLOCK FOR USE AS HIGHWAY MATERIALS

A.S.T.M. Designation: D 75 - 46 T

1. Scope.—These methods are intended to apply to the sampling of stone, slag, gravel, sand, and stone block for the following purposes:

Preliminary investigation of sources of supply
Acceptance or rejection of source of supply
Inspection of shipments of materials
Inspection of materials on the site of the work

2. Securing Samples.—*a.* Samples of all materials for test, upon which is to be based the acceptance or rejection of the supply, shall be taken by the purchaser or his authorized representative. Samples for inspection or preliminary test may be submitted by the seller or owner of the supply.

b. Sampling is equally as important as the testing, and the sampler shall use every precaution to obtain samples that will show the true nature and condition of the materials which they represent.

STONE FROM LEDGES OR QUARRIES

3. Inspection.—The ledge or quarry face of the stone shall be inspected to determine any variation in different strata. Differences in color and structure shall be observed.

4. Sampling and Size of Sample.—Separate samples of stone weighing at least 50 lb. each of unweathered specimens shall be obtained from all strata that appear to vary in color and structure. When the toughness or compression test is required, one piece of each sample shall be not smaller than 4 by 5 by 3 in. in size with the bedding plane plainly marked, and this piece shall be free of seams or fractures. Pieces that have been damaged by blasting shall not be included in the sample.

5. Record.—In addition to the general information accompanying all samples, the following information shall accompany samples from local ledges that are not commercial sources:

(1) Name of owner or seller

(2) Approximate quantity available (if quantity is very large this can be recorded as practically unlimited)

(3) Quantity and character of overburden or stripping

(4) Haul to nearest point on road where the material is to be used

(5) Character of haul (kind of road and grade)

(6) Some detailed record of the extent and location of the material represented by each sample

NOTE.—A sketch, plan, and elevation, showing the thickness and location of the different layers is recommended for this purpose.

FIELD STONE AND BOULDERS

6. Inspection.—A detailed inspection of the deposits of field stone and boulders over the area where the supply is to be obtained shall be made. The different kinds of stone and their condition in the various deposits shall be recorded.

7. Sampling.—Separate samples shall be selected of all classes of stone that visual inspection indicates would be considered for use in construction.

8. Record.—Records accompanying samples of field stone and boulders, in addition to general information, shall contain the following:

(1) Location of supply.

NOTE.—The plotting of the field stone and boulder area on a U. S. topographic or similar map is recommended for this purpose.

(2) Approximate quantity available.

(3) The percentages of different classes of stone that were sampled, and the percentages of material that can be rejected by visual examination and may therefore have to be handled and rejected.

SAND AND GRAVEL

ROADSIDE PRODUCTIONS

9. Description of Term.—Roadside production shall be understood to be the production of materials with portable or semiportable crushing, screening, or washing plants established or reopened in the vicinity of the work on a designated project for the purpose of supply materials for that project.

10. Sampling.—*a.* Samples shall be so chosen as to represent the different materials that are available in the deposit. An estimate of the quantity of the different materials shall be made.

b. If the deposit is worked as an open-face bank or pit, the sample shall be taken by channeling the face so that it will represent material that visual inspection indicates may be used. Care shall be observed to eliminate any material that has fallen from the face along the surface. It is necessary, especially in small deposits, to excavate test holes some distance back of, and parallel to, the supply. The number and depth of these test holes depend on the quantity of material that is to be used from the deposit. Material that would be stripped from the pit as overburden, etc., shall not be included in the sample. Separate samples shall be obtained from the face of the bank and from test holes; and if visual inspection indicates that there is considerable variation in the material, separate samples shall be obtained at different depths. If information on the variations in the pit is desired, each of the samples shall be tested, but if the average condition only is desired, the separate samples may be mixed into a composite sample and reduced by quartering to the size required for test. If the material being sampled consists of sand, a sample weighing at least 25 lb. shall be obtained. If the material being sampled consists of a mixture of sand and gravel, the sample shall be large enough to yield not less than 25 lb. of the lesser constituent.

c. Deposits that have no open face shall be sampled by means of test holes. The number and depth of these test holes will depend on local conditions and the amount of material to be used from the deposit. A separate sample shall be obtained from each test hold; and if information on the variations in the deposit is desired, each of these samples shall be tested; but if the average condition only is desired and visual examination indicates no radical difference in size of grain, color, etc., the separate samples may be mixed into a composite sample and reduced by quartering to the size required for test.

d. It is very difficult to secure a representative sample from a stock pile, and if conditions require sampling from this source, it is recommended that separate samples be taken from different parts of the pile, care being taken to observe any segregated areas and bearing in mind that the material near the base of the pile is likely to be segregated and coarser than the average of the material in the pile. In sampling sand, the outer layer of material shall be removed until damp sand is reached.

11. Record.—In addition to the general information accompanying all samples from roadside productions, the detailed information prescribed in items 1 to 6 of Section 5 shall be supplied.

SAND, GRAVEL, STONE, AND SLAG

COMMERCIAL SOURCES

12. Sampling for Quality.—*a.* Where practicable, samples from commercial sources shall be obtained from the finished product. Otherwise the sample shall be taken in accordance with the procedure described in Section 10.

b. Samples to be tested for abrasion loss by the Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (A.S.T.M. Designation: C 131) of the American Society for Testing Materials shall be obtained from commercially prepared material.

13. Sampling at Plant.—A general inspection of the plant and a record of the screening facilities shall be made. The sample shall preferably be obtained from cars or boats during the loading from stock piles or bins. In order to determine variations in the grading of the material, separate samples shall be obtained at different times while the material is being loaded. If the samples are obtained from a bin, they shall be taken from the entire cross section of the flow of material as it is being discharged. Approximately 2 to 5 tons of material should be allowed to flow from the bin before the sample is obtained. The testing of separate samples will give a better idea of the variations that occur, but samples shall be mixed and reduced by quartering when the average condition is desired.

14. Sampling at Delivery.—*a.* Where it is not practicable to visit the plant, samples for both quality and size may be obtained at the destination, preferably while the material is being unloaded. The sampler should realize that segregation of different sizes is very likely to occur, and samples shall be so chosen as to show any differences which occur, both in quality and size of material. Separate samples shall be taken from three or more points of each unit of the shipment, each sample representing, as nearly as possible, the average of the unit as indicated by careful observation (Note). These separate samples shall be mixed to form a composite sample, and this sample shall, if necessary, be reduced by quartering, but if information on variation is desired, the separate samples shall be tested.

NOTE.—Samples from stock piles should be taken at, or near, the top of the pile, at, or near, the base of the pile, and at an intermediate point. A board shoved into the pile just above the point of sampling will aid in preventing further segregation during sampling. Samples from railroad cars should be taken from three

TABLE 1.—SIZE OF SAMPLES

Nominal maximum size of particles, passing sieve	Minimum weight of field samples, lb.	Minimum weight of sample for test,[a] g.
Fine aggregate		
No. 10	10	100
No. 4	10	500
Coarse aggregate		
3/8 in.	10	1,000
1/2 in.	20	2,500
3/4 in.	30	5,000
1 in.	50	10,000
1 1/2 in.	70	15,000
2 in.	90	20,000
2 1/2 in.	100	25,000
3 in.	125	30,000
3 1/2 in.	150	35,000

[a] The sample for test shall be obtained from the field sample by quartering or other suitable means to insure a representative portion.

or more trenches dug across the car at points which appear on the surface to be representative of the material. The bottom of the trench should be at least 1 ft. below the surface of the aggregate at the sides of the car and approximately 1 ft. wide at the bottom. The bottom of the trench should be practically level. Equal portions should be taken at nine equally spaced points along the bottom of the trench by pushing a shovel downward into the material and not by scraping horizontally. Two of the nine points should be directly against the sides of the car. Fine aggregate may be sampled from either stock piles, trucks, or railroad cars by the same procedure or by means of a sampling tube approximately 1¼ in. in diameter by 6 ft. which, with a little practice, will be found to hold damp sand forced into it when inserted into the fine aggregate to be sampled. Five to eight insertions of the tube into the unit to be sampled will furnish approximately 10 lb. of fine aggregate.

b. Where test is to be made for size only, it is recommended that tests be made in the field in order not to delay decision on the use of the material. Samples shall also be sent to the laboratory for check tests.

15. Number and Size of Samples.—*a.* The number of samples required depends on the intended use of the material, the quantity of material involved, and the variations both in quality and size of the aggregate. A sufficient number of samples shall be obtained to cover all variations in the material. It is recommended that each sample of crushed stone, gravel, slag, or sand represent approximately 50 tons of material.

b. Samples of crushed stone, gravel, slag, and sand which are to be subjected to a mechanical analysis in accordance with the Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (A.S.T.M. Designation: C 136) shall conform to the weight requirements prescribed in Table 1.

Bank-run Sand and Gravel

16. Size of Samples.—*a.* Samples of run of bank (where the sand and gravel are combined) shall weigh at least 100 lb. when the gravel content is 50 per cent or more of the whole. If the gravel is less in percentage, the sample shall be increased in proportion.

NOTE: *Example.*—When the gravel percentage is 25 per cent of the whole, the sample should weigh 200 lb.

b. Samples for mechanical analysis shall conform to the requirements for size of sample as prescribed in Table 1.

Miscellaneous Materials

17. Sampling.—Samples of slag sand, stone sand, screenings, mine tailings, and all other materials used instead of sand and gravel or broken stone, shall be inspected in the same manner, and samples shall be taken in the same manner as prescribed for the materials of similar size and classification.

Stone Block

18. Place of Sampling.—Samples of stone block shall be taken either at the quarry or at the destination as directed by the purchaser. Blocks that would be rejected by visual inspection shall not be included in the sample.

19. Size of Sample.—The sample shall consist of at least six blocks, and the bedding plane shall be marked on at least two of these.

Marking and Shipping Samples

20. Marking.—Each sample or separate container shall be accompanied by a card or regular form, preferably in the container, giving the following information:

(1) By whom taken, and the official title or rank of the sampler.

(2) By whom submitted.

(3) Source of supply, and in case of commercial supplies, daily production.

(4) Proposed use for the material.

(5) Geographic location and shipping facilities (name of railroad, canal, river, or other common carrier).

21. Shipping Samples.—*a. Stone and Slag.*—Samples of ledge stone, crushed stone, and slag shall be shipped in a secure box or bag.

b. Gravel, Sand, etc.—Samples of run-of-bank gravel, sand, screenings, and other fine material, shall be shipped in a tight box or closely woven bag so there will be no loss of the finer particles.

c. Stone Block.—Samples of stone block shall be securely crated.

STANDARD METHOD OF SAMPLING FRESH CONCRETE

A.S.T.M. Designation: C 172 - 44

1. Scope.—This method covers the procedure for obtaining samples of fresh concrete from mixers, hoppers, or transportation units.

2. Size of Sample.—The sample shall be representative of the batch. Where feasible, it shall consist of portions from different points in the batch. The composite sample shall consist of not less than 1 cu. ft. when the sample is to be used for acceptance tests. Smaller samples may be permitted for routine slump tests.

3. Procedure for Sampling.—*a. From Mixers Used in Construction, Other than Paving or Truck Mixers.*—The sample shall be obtained by passing a receptacle or receptacles through the discharge stream of the mixer at about the middle of the batch. Care shall be taken not to restrict the flow from the mixer in such a manner as to cause the concrete to segregate.

b. From Paving Mixers.—The contents of the paving mixer shall be discharged upon the subgrade, and the sample shall be collected from a sufficient number of points in the batch to be representative.

c. From Revolving-drum Truck Mixers or Agitators.—The sample shall be taken in three or more regular increments throughout the discharge of the entire batch. To permit sampling, the rate of discharge of the batch shall be regulated by the rate of revolution of the drum and not by the size of the gate opening.

d. From Open-top Truck Mixers and Agitators.—The sample shall be taken directly from the mixer and shall consist of portions from not less than three points in the batch.

e. From Receiving Hoppers, Buckets, etc.—Samples shall be taken by whichever of the procedures described in paragraphs *a*, *b*, or *c* is most applicable under the conditions.

4. Mixing Composite Sample.—The composite sample shall be mixed with a shovel sufficiently to insure homogeneity and immediately molded into test specimens.

CHAPTER 14

TESTING

Testing is the process of determining certain facts or qualities about a material. Every material that is used in construction must have certain given qualities in order to do its part in the structure. Laboratory and field tests have been devised to determine these qualities in a comparatively short interval of time. Many tests used by the engineer in securing the materials he desires do not measure directly the particular quality desired. When test results lie within a certain range, the engineer knows that in most cases the material will be satisfactory. For example, the engineer knows that portland cement that passes the arbitrary time-of-setting test will in nearly all instances have satisfactory setting characteristics when used in construction.

The results of tests can frequently be varied by varying the method of doing the test. In order to prevent such deviations, specifications must be written for the method to be followed. The American Society for Testing Materials has prepared methods of testing for practically all the tests commonly used on concrete materials. These specifications are a great convenience to the engineer, and because of their wide use they make it possible for the manufacturers to supply a larger number of users. Even with the methods carefully specified, there are often wide variations in test results, many of which are caused by failure of the tester to observe all of the details.

Tests on Materials.—Instructions for the performance of all the regular tests on portland cement and aggregates are given in detail in Part II.

Tests on Concrete.—A series of tests on concrete, Nos. 29 to 38, have been planned to acquaint the student with some of the factors affecting concrete strengths, to furnish data that can be used as the basis for making the calculations and preparing the graphs that are more commonly made in connection with concrete, and to give the student some idea of the problems involved in concrete research. Not all of the projects can be done in one term, but certain ones can be selected to fit local needs and desires.

There are two types of strength test known as the "compression test" and the "beam or flexure test." In the former, specimens in the form of cylinders are loaded in direct compression until failure occurs. Strengths are expressed as the unit load at failure in pounds per square inch. In the flexure test the concrete is molded into a beam and tested as such. Strengths are expressed as the modulus of rupture in pounds per square inch.

On the following pages general instructions are given, which are applicable to all the concrete tests. In general they follow the methods of test as outlined by the American Society for Testing Materials, and as much of the material as possible is quoted directly.

Preparation of Compression Test Specimens

These instructions are given in accordance with the Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (A.S.T.M. Designation: C 192 - 47 T).

Size of Specimens.—Compression test specimens shall be cylindrical with a length equal to twice the diameter. Standard cylindrical specimens shall be 6 in. in diameter by 12 in. in length if the coarse aggregate does not exceed 2 in. in nominal size. Smaller test specimens shall have a ratio of diameter of specimen to maximum size of aggregate of not less than 3 to 1, except that the diameter of the specimen shall not be less than 3 in. for mixtures containing aggregate more than 5 per cent of which is retained on a No. 4 sieve. For concrete containing aggregates larger than 2 in. nominal size, cylindrical specimens shall have a diameter at least three times the maximum nominal size of the aggregate. The oversize of any nominal-size aggregate used shall not exceed the requirements prescribed in the Standard Specifications for Concrete Aggregates (A.S. T.M. Designation: C 33).

Molds.—Molds for compression test specimens shall be of metal and shall be provided with a machined-metal base plate. Means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall be watertight and shall be oiled with mineral oil before use.

NOTE.—Satisfactory molds may be made from cold-drawn, seamless-steel tubing or from steel pipe machined on the inside. These tubular sections shall be cut to the proper length, split along one element, and fitted with a circumferential metal band and bolt for closing. Satisfactory molds may also be made from iron or steel castings. In general, molds made from formed sheet metal are not satisfactory.

Number of Specimens.—Three or more test specimens for each variable shall be made for each period or condition of test. Specimens involving any given variable in the mix shall be made from at least three separate batches. An equal number of specimens for each variable shall be made on any given day. When it is impossible to make at least one specimen for each variable in the mix on a given day, the mixing of the entire series of specimens shall be completed in as few days as possible, and one of the mixes shall be repeated each day as a standard of comparison.

NOTE.—Test periods of 7 and 28 days are recommended for compression tests. Flexure specimens are frequently tested at 14 and 28 days. For longer test periods, 3 months and 1 year are recommended.

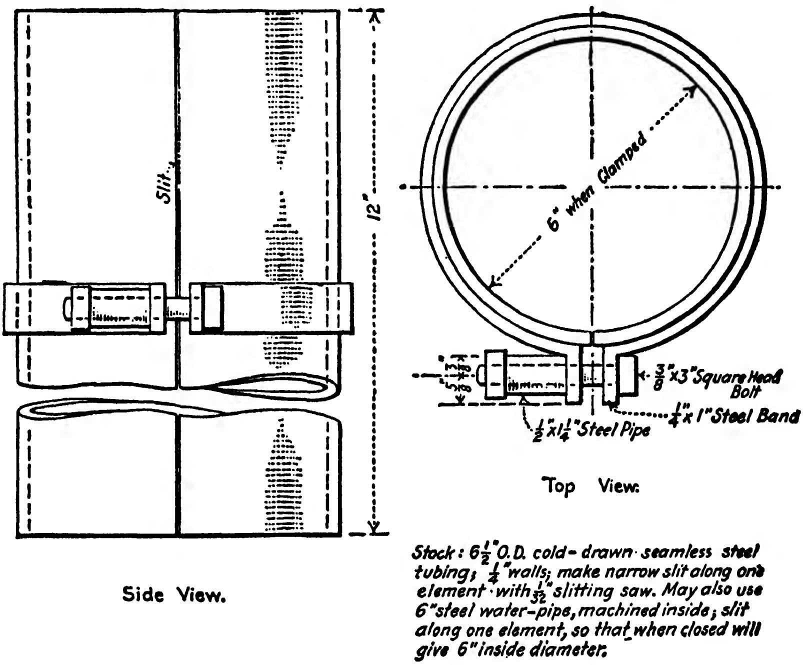

FIG. 14-1.—Concrete cylinder mold.

MATERIALS

Materials to be used in the concrete tests should be available to the students for the tests on the individual materials. In this way the student secures the usual set of test results as well as all the necessary data on materials needed for computations in connection with the concrete experiments.

Preparation of Materials.—Materials shall be brought to room temperature (preferably 65 to 75°F.) before beginning the tests.

Cement.—Cement shall be stored in a dry place in moistureproof containers, preferably made of metal. The cement shall be thoroughly mixed in order that the sample may be uniform throughout the tests. It shall be passed through a No. 16 sieve and all lumps rejected.

Aggregates.—Aggregates for each batch of concrete shall be of the desired gradation. In general, coarse aggregates shall be separated into two or more size fractions, depending upon the maximum size of aggregate used, and recombined for each batch in such a manner as to produce the desired gradation. Fine aggregate shall be separated into different sizes if unusual gradations are being studied. Aggregates shall be treated before use to ensure a definite and uniform condition of moisture by one of the three following procedures:

(1) They shall be brought to a saturated, surface-dry condition.

(2) They shall be brought to a saturated condition with surface moisture in sufficiently small amounts to preclude loss by draining and shall be so maintained until used. When using this method, the amounts of surface moisture on the coarse and fine aggregates shall be determined prior to making concrete specimens.

(3) The aggregates in a saturated condition shall be immersed in water and shall be weighed under water. The required immersed weight may be calculated as follows:

$$W_w = \frac{W_a\ (G - 1)}{G}$$

where W_a = desired weight in air of aggregate in a saturated condition
G = bulk specific gravity of aggregate in a saturated condition
W_w = weight in water

Upon removal of the aggregate from the water an additional weighing in air of aggregate and surface water will be necessary to determine the amount of surface water in the aggregate.

In student work, where hours for laboratory work are definitely limited, weighing of aggregate under water may require too much time.

Quantities of Materials.—Before it is possible to compute quantities of materials needed for a batch of concrete, the following decisions must be made:

a. Size of test specimen to be used

b. Number of specimens to be made from one batch

c. Proportions of materials that are to be used

It is recommended that the batch be "of such size as to leave about 10 per cent excess after molding test specimens." If concrete is desired for any other purpose, such as an air-content determination, the necessary amount of concrete must be added.

A satisfactory method of securing the weights of the various materials is as follows: Compute the volume of the concrete needed for all purposes, including the 10 per cent excess. Assume that the freshly made concrete weighs 150 lb. per cu. ft., and compute the weight of concrete needed. Then make the weights of all the materials to be used add up to this figure, keeping each in its proper proportion to the others.

Example: Figure the quantities for a batch of concrete sufficient to fill three 6- by 12-in. cylinder molds, make an air determination requiring 0.2 cu. ft. of concrete and with 10 per cent excess. The water-cement ratio is to be 6¾ gal. per bag, and the aggregate-cement ratio is to be 6. The percentage of the total aggregate which is to be sand is 35.

The volume of three molds is 0.59 cu. ft. Add 0.2 cu. ft. for the air determination and 0.08 cu. ft. for the excess. The total is 0.87 cu. ft. At 150 lb. per cu. ft. the weight of the batch is 130.5 lb.

If the water-cement ratio is 6¾ gal. per bag, the ratio by weight is 0.60. Adding the parts by weight for cement, aggregate, and water, (1.00 + 6.00 + 0.60) the total is 7.60. Dividing 130.5 by 7.60, the weight of cement is secured as 17.17 lb. The total weight of aggregate is 6 times the weight of cement or 103.02 lb. The weight of sand is 35 per cent of the weight of total aggregate, or 36.06 lb. The weight of coarse aggregate is 65 per cent of the total weight of aggregate, or 66.96 lb. The weight of water is 0.60 of the weight of the cement, or 10.31 lb.

Weighing Materials.—All materials shall be weighed on scales meeting the requirements for sensibility reciprocal and tolerances prescribed by the National Bureau of Standards.[1] Noncompensating spring scales shall not be used. Where the scales are graduated in decimals of a pound instead of ounces or where the metric system is used, the equivalent, percentage, sensibility reciprocal and tolerances shall apply.

The author has found that all the materials for a batch, except the water, may be conveniently weighed in a single pan, cumulating the weights as materials are added. If a special pouring-spout end is built on the pan, two persons can easily empty the contents into the mixer. Water must be weighed separately in a container.

MIXING

General.—Concrete shall be mixed either by hand or in a suitable laboratory mixer in batches of such size as to leave about 10 per cent excess after molding test specimens.

Hand Mixing.—The batch shall be mixed in a watertight, clean, damp, metal pan, with either a blunted bricklayer's trowel or a shovel, whichever is more convenient, using the following procedure:

(1) The cement and fine aggregate shall be mixed until they are thoroughly blended.

(2) The coarse aggregate shall be added and the entire batch mixed until the coarse aggregate is uniformly distributed throughout the batch.

(3) Water shall be added and the mass mixed until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is required, because of the addition of water in increments while adjusting the slump, the batch shall be discarded and a new batch made without interrupting the mixing to make trial slump tests.

[1] "Specifications, Tolerance, and Regulations for Commercial Weighing and Measuring Devices," *Handbook H* 29, Nat. Bur. Standards, Section I-2, p. 122 and Section J-2, p. 130.

Machine Mixing.—The procedure specified for hand mixing shall be followed unless a different procedure is better adapted to the mixer being used. Precautions shall be taken to compensate for mortar retained by the mixer so that the finished batch as used will be correctly proportioned. To eliminate segregation machine-mixed concrete shall be deposited in a watertight, clean, damp metal pan and remixed by shovel or trowel.

NOTE.—It is difficult to recover all of the mortar from certain types of mixers, particularly those of the revolving-drum type, and when such conditions obtain, one of the following procedures is suggested to insure the correct final proportions in the batch:

(1) *"Buttering" the Mixer.*—Just prior to mixing the test batch, the mixer should be "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to prevent loss of mortar from the test batch. The discharged test batch may be adjusted to proper weight by the addition or subtraction of mortar.

(2) *"Overmortaring" the Mix.*—The test mix may be proportioned by the use of an excess of mortar to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

The author has found a small electrical-drive, tilting-drum mixer quite satisfactory. Materials are weighed as explained previously. The mixer may be buttered with a batch of mortar having approximately the same composition as the mortar in the concrete to be mixed. Water is placed in the mixer first and then all the dry materials. Mixing is usually done for 2 min., and the entire batch is emptied into a watertight metal pan.

The first batch may be overmortared by an amount that can only be determined by trial. The first trial batch through the mixer should be handled just as the first batch will be in the regular series, and the net weight remaining determined before the concrete is put into the molds. The difference between this weight and the original weight is the weight of mortar used in coating the mixer and the other equipment. A second trial batch should be made with the basic weights increased by the amounts that the previous trial batch indicated were used to coat the mixer and equipment. The weight of this batch remaining for molding should be determined to check on the amount used for coating purposes. Other trial batches should be made until it is determined how much mortar is needed for coating the mixer and equipment.

Special effort must always be made to remove all the batch from the mixer. A special metal scraper has been found helpful. Attention must also be given to the pans, containers, shovels, and trowels to see that mortar does not accumulate on them.

Molding Compression Specimens

The compression test specimens shall be formed by placing the concrete in the mold in three layers of approximately equal volume. In placing each scoopful of concrete, the scoop shall be moved around the top edge of the mold as the concrete slides from it in order to ensure a symmetrical distribution of the concrete within the mold. The concrete shall be further distributed by a circular motion of the tamping rod. Each layer shall be rodded 25 strokes of a ⅝-in. round rod, approximately 24 in. in length, and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately ¼ in. The strokes shall be distributed uniformly over the cross section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel and covered with a glass or metal plate to prevent evaporation.

When molding several specimens from a batch of concrete, it is well to put the first third in all of the molds before putting the second third in any, and to finish the second third before putting the final third in any. This will help in securing more uniform cylinders. Another detail, which the author feels is helpful in maintaining uniformity in the cylinders, is to stir the concrete in the pan first and then begin removing concrete along one edge. As concrete is removed from the pan, the concrete that remains is constantly stirred. The concrete is scraped from the areas in the pan where the concrete has been removed. A considerable amount of the mortar will be left in the pan unless removed from the edges during the molding of the cylinders.

Capping Cylinders

The test specimens may be capped with a thin layer of stiff, neat cement paste after the concrete has ceased settling in the molds, generally from 2 to 4 hr. or more after molding. The cap shall be formed by means of plate glass not less than ¼ in. in thickness or a machined-metal plate not less than ½ in. in thickness and having a minimum surface dimension at least 1 in. larger than the diameter of the mold. It shall be worked on the cement paste until its lower surface rests on top of the mold. The cement for capping shall be mixed to a stiff paste 2 to 4 hr. before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by coating them with oil or grease.

Specimens not capped with neat cement paste as described above shall be ground or capped before testing. In all cases the capped or ground surface shall not depart from a plane by more than 0.001 in. and shall be at right angles to the axis of the specimen. Caps shall be made as thin as practicable and shall not flow or fracture when the specimen is tested.

NOTE.—Neat portland or alumina cement and suitable mixtures of sulfur with granular materials are recognized as suitable for capping hardened concrete specimens. Sulfur caps should be allowed to harden for at least 1 hr. before applying load; cement caps for a sufficient period to comply with the requirements prescribed in the preceding paragraph.

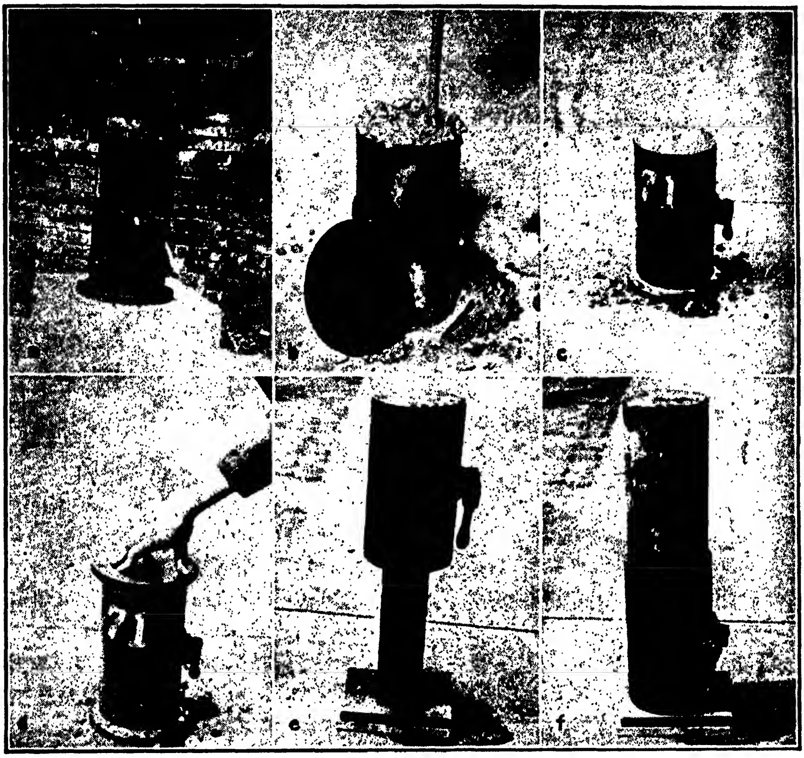

FIG. 14-2.—Preparation of cylinders. *a*, The mold; *b*, filled with concrete; *c*, cement paste for cap in place; *d*, forming the cement-paste cap; *e*, on pedestal ready to remove form; *f*, form removed.

CURING SPECIMENS

The test specimens shall be removed from the molds not earlier than 20 hr. nor later than 48 hr. after molding and stored in a moist condition (Note 1) at a temperature within the range of 55 to 75°F. until the time of test. Specimens shall not be exposed to a stream of running water. If storage in water is desired, a saturated lime solution shall be used.

NOTE 1.—Moist condition is that in which free water is maintained on the surface of the specimens at all times.

NOTE 2.—Attention is directed to the fact that the temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

Before placing the test specimens in damp storage, an identification mark must be placed on each. These marks may be written most conveniently on the smooth cap with a pencil having an extra-large-diameter lead. Each person must work out his own system of marking. Markings that provide some information about the specimens without consulting a master list are desirable.

PREPARATION OF FLEXURE TEST SPECIMENS

These instructions are given in accordance with the Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (A.S.T.M. Designation: C 192 - 47 T).

Size of Specimens.—The cross section of the flexure test specimen shall be 6 by 6 in. if the coarse aggregate does not exceed 2 in. in nominal size. For larger coarse aggregate, the minimum cross-sectional dimension shall be not less than three times the maximum nominal size of the coarse aggregate. The oversize of any nominal size used shall not exceed the requirements prescribed in the Standard Specifications for Concrete Aggregates (A.S.T.M. Designation: C 33).

Molds.—Molds for flexure test specimens shall be rigid and nonabsorptive and shall be at least 3 in. longer than the required span length as prescribed in Section 3 of the Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-point Loading), (A.S.T.M. Designation: C 78). Means shall be provided for securing the base plate to the mold. The assembled mold and base plate shall be watertight and shall be lightly oiled with a mineral oil before use.

Molding Specimens.—The test specimen shall be formed with its long axis horizontal. The concrete shall be placed in layers approximately 3 in. in depth, and each layer shall be rodded 50 times for each square foot of area. The top layer shall slightly overfill the mold. After each layer is rodded, the concrete shall be spaded along the sides and ends with a mason's trowel or other suitable tool. When the rodding and spading operations are completed, the top shall be struck off with a straightedge and finished with a wood float. The test specimen shall be made promptly and without interruption and covered with a double layer of wet burlap, which shall be kept wet until the specimen is removed from the mold. While in the molds the specimens shall be kept within the temperature range specified previously for the materials under the preparation instructions for cylinders (room temperature, preferably between 65 and 75°F.).

Curing Specimens.—Flexure test specimens shall be cured as prescribed for the compression test specimens.

TESTING FLEXURE SPECIMENS

Instructions for the laboratory testing of flexure specimens are given in Standard Method of Test for Flexural Strength of Concrete (Using

Simple Beam with Third-point Loading), (A.S.T.M. Designation: C 78 - 44).

Apparatus.—The third-point loading method shall be used in making flexure tests of concrete employing bearing blocks, which will insure that forces applied to the beam will be vertical only and applied without eccentricity. A diagram of an apparatus which accomplishes this purpose is shown in Fig. 14-3.

NOTE.—Sometimes nonstandard methods of load application are used in the field. If such methods are used, the results should be correlated with those ob-

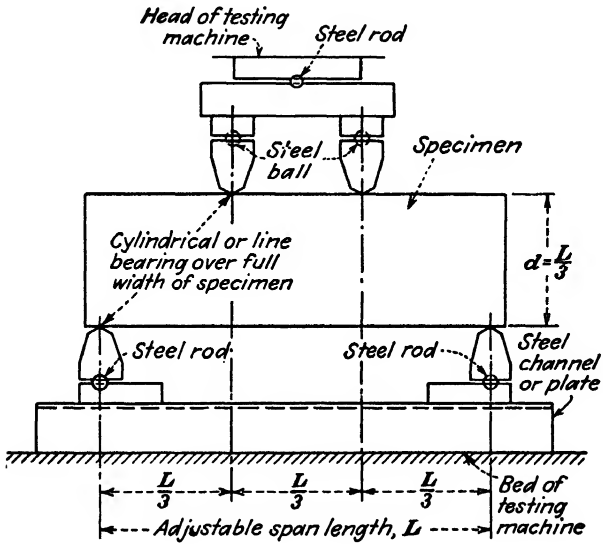

FIG. 14-3.—Diagrammatic view of apparatus for flexure test of concrete by third-point loading method. (*Courtesy of the American Society for Testing Materials.*)

tained with standard methods. Apparatus for making flexure tests of concrete should be designed to incorporate the following principles:

(1) The distance between supports and points of load application should remain constant for a given apparatus.

(2) The load should be applied normal to the loaded surface of the beam and in such a manner as to avoid eccentricity of loading.

(3) The direction of the reactions should be parallel to the direction of the applied load at all times during the test.

(4) The load should be applied at a uniform rate and in such a manner as to avoid shock.

(5) The ratio of distance between point of load application and nearest reaction to the depth of the beam should be not less than one.

The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings, and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

Test Specimen.—The test specimen shall have a span as nearly as practicable three times its depth as tested.

Procedure.—The test specimen shall be turned on its side with respect to its position as molded and centered on the bearing blocks. The load-applying blocks shall be brought in contact with the upper surface at the third points between the supports. If full contact is not obtained between the specimen and the load-applying blocks and the supports, due to the surfaces of the specimen being out of plane, the surfaces of the specimen, where they are in contact with the blocks or supports, shall be ground or capped (Note) to produce substantially full contact. The load may be applied rapidly up to approximately 50 per cent of the breaking load, after which it shall be applied at such a rate that the increase in extreme fiber stress does not exceed 150 p.s.i. per min.

NOTE.—Neat portland or alumina cement and suitable mixtures of sulfur with granular materials are recognized as suitable for capping hardened concrete specimens. Sulfur caps should be allowed to harden for at least 1 hr. before applying load, cement caps for a sufficient period to insure their resistance to cracking or flowing under the applied load.

Measurement of Specimens after Test.—Measurements to the nearest 0.1 in. shall be made to determine the average width and average depth of the specimen at the section of failure.

Calculations.—*a*. If the fracture occurs within the middle third of the span length, the modulus of rupture shall be calculated as follows:

$$R = \frac{Pl}{bd^2}$$

where R = modulus of rupture, p.s.i.
P = maximum applied load indicated by the testing machine, lb.
l = span length, in.
b = average width of specimen, in.
d = average depth of specimen, in.

NOTE.—Weight of the beam is not included in the above calculation.

b. If the fracture occurs outside of the middle third of the span length by not more than 5 per cent of the span length, the modulus of rupture shall be calculated as follows:

$$R = \frac{3Pa}{bd^2}$$

where a = distance between line of fracture and the nearest support measured along the center line of bottom surface of beam, in.

c. If the fracture occurs outside of the middle third of the span length by more than 5 per cent of the span length, the results of the test shall be discarded.

Variables Affecting Strength.—As in all testing there are certain items that might be varied in performing the flexure test, which affect the test result. A flexure strength value without information concerning some of the details of how the test was made may not be of great value.

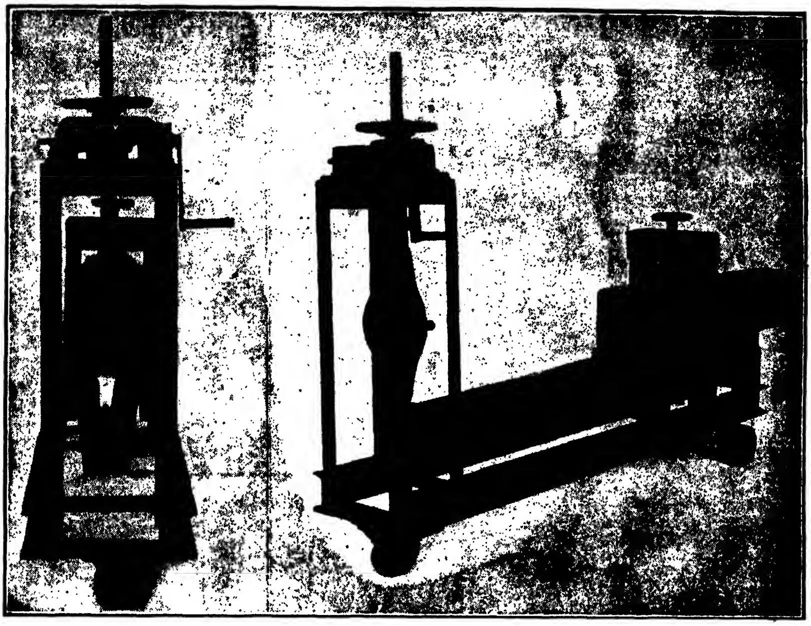

FIG. 14-4.—Transverse testing machine designed by the Illinois Division of Highways and used first during construction season of 1928. Weight of machine is approximately 200 lb.

Various reports of beam tests indicate that the following testing-procedure items have an effect on the test results:

1. Depth of beam
2. Method of loading
   a. Either single or two-point in simple beams
   b. Whether or not there is any restraint in concrete in beam test
3. Span length
4. Type of beam—either as a simple or cantilever beam
5. Rate of application of load

Field Testing.—Because of the cost and inconvenience of sending test specimens to a central laboratory to be tested, highway departments have developed relatively lightweight machines, which can be transported easily from place to place and which are not too expensive to produce. One such machine is shown in Fig. 14-4.

Computations.—The computations necessary in connection with a test made in the Illinois machine shown in Fig. 14-4 are given here. A knowledge of the principles of mechanics is necessary to their understanding (see Fig. 14-5).

The load is applied upward at C from a roller bearing on the arm de. The pivot d is immediately under the reaction B. The pull at the end of the arm is recorded on the dynamometer and is designated P.

Taking moments about the point b, we have $M_E = Ft$, but $F = (l/t)P$, or the external moment on the beam M_E is lP.

The internal moment is equal to (SI/C), in which S is the stress at extreme fiber of beam, in pounds per square inch, I is the moment of inertia of the beam, which is $(1/12)bd^3$, and C is the distance from the neutral axis to the extreme fiber. The internal and external moments

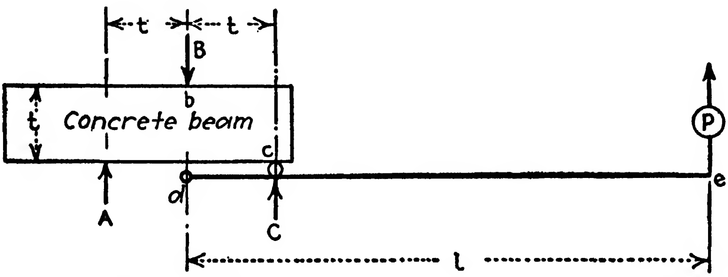

FIG. 14-5.—Diagram of forces acting on concrete beam when tested in the machine designed by the Illinois Division of Highways (shown in Fig. 14-4).

must be equal when there is no rotation of the beam. Therefore,

$$\frac{SI}{C} = lP$$

For our beam of square cross section, $I = \frac{1}{12}t^4$, and $C = \frac{1}{2}t$. Now we can write

$$S = \frac{6lP}{t^3}$$

The Illinois machine is designed for a 6-in. square beam and in order to make computations easy, l was made 36 in., in which case

$$S = P$$

When the beam is not exactly 6 in. in cross section, it is necessary to substitute in the basic formula. Since variations in dimensions are not large, it is possible to prepare a small table of correction factors for various sizes, by which P may be multiplied to give the correct value of S.

Relation between Flexure and Compressive Strengths.—There is no well-defined relationship between flexure and compressive strengths, as is shown by an examination of Fig. 14-6, and it is impossible to estimate one from the other with any degree of accuracy.

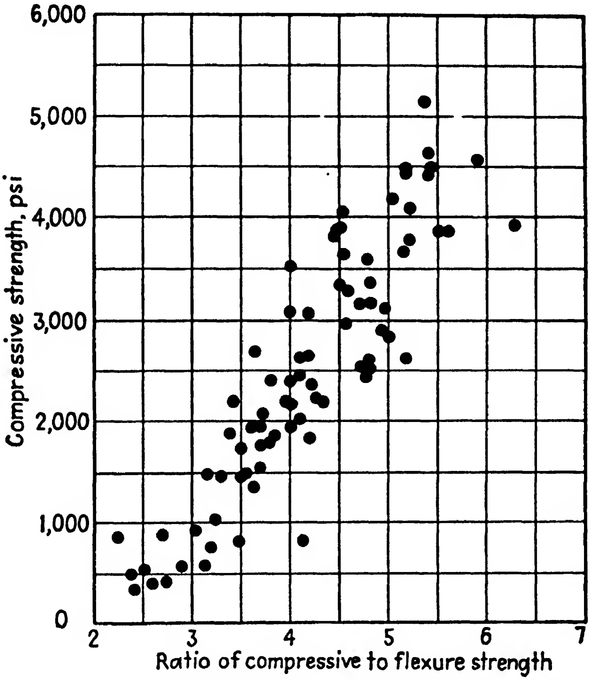

FIG. 14-6.—Showing the effect of strength upon the ratio of compressive to flexure strengths. Test made by the author's classes in plain concrete, using a 1:2½:4 mix with a water-cement ration of 0.9. Various cements were used and the concrete was tested at ages ranging from 1 to 28 days.

TESTING COMPRESSION SPECIMENS

Instructions for the testing of the concrete cylinders are given in Standard Method of Test for Compressivê Strength of Molded Concrete Cylinders, (A.S.T.M. Designation: C 39 - 44).

Apparatus.—The testing machine may be of any type of sufficient capacity, which will provide the rate of loading prescribed under procedure given later. The testing machine "shall conform to the requirements of Section 27 of the Standard Methods of Verification of Testing Machines (A.S.T.M. Designation: E - 4). The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note), one of which is a spherically seated block that normally will bear on the upper surface of the specimen and the other a plain rigid block on which the specimen will rest.

The bearing faces shall be at least as large as, and preferably slightly larger than, the surface of the specimen to which the load is applied. The bearing faces, when new, shall not depart from a plane by more than 0.0005 in. at any point, and they shall be maintained within a permissible variation limit of 0.001 in.

In the spherically seated block the diameter of the sphere shall not greatly exceed the diameter of the specimen and the center of the sphere shall coincide with the center of the bearing face. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

NOTE.—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than C 60.

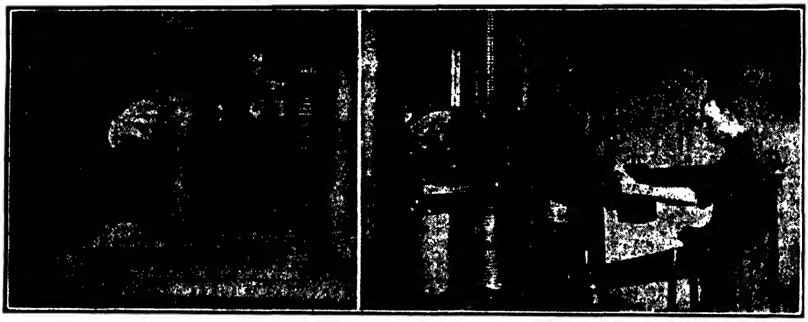

FIG. 14-7.—Testing concrete cylinders. *Left*, centering under spherical bearing block. *Right*, applying load, the amount being registered on the weighing device at the right.

Test Specimens.—Compression tests of moist-cured specimens shall be made as soon as practicable after removal from the curing room. Test specimens, during the period between their removal from the moist room and testing, shall be kept moist by a wet-burlap or blanket covering. They shall be tested in a moist condition. The diameter of the test specimen shall be determined to the nearest 0.01 in. by averaging two diameters measured at right angles to each other near the center of the length of the specimen. This average diameter shall be used for calculating the cross-sectional area. The length of the specimen including caps shall be measured to the nearest 0.1 in.

Procedure.—*Placing the Specimen.*—The plain (lower) bearing block shall be placed with its hardened face up on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. The bearing face shall be wiped clean and the test specimen placed on it. The axis of the specimen shall be carefully aligned with the center of thrust of the spherically seated block. As the spherically seated block is brought to bear on the specimen, its movable portion is hand rotated gently so that uniform seating is obtained.

Rate of Loading.—The load shall be applied continuously and without shock. In testing machines of the screw type, the moving head shall travel at a rate of about 0.05 in. per min. when the machine is running idle. In hydraulically operated machines the load shall be applied at a constant rate within the range 20 to 50 p.s.i. per sec. During the application of the first half of the maximum load a higher rate of loading shall be permitted.

The load shall be increased until the specimen fails, and the maximum load carried by the specimen during the test shall be recorded. The type of failure and the appearance of the concrete shall be noted.

Calculation.—The compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described previously and shall be expressed to the nearest 10 p.s.i.

Effect of Temperature on Maximum Loads.—Not much is known about the effect of temperature on the maximum load that can be carried by a concrete specimen. The following results were secured by the author on specimens made from a 1:2½:4 mix by volume and with a water-cement ratio of 7½ gal. per bag. The specimens remained 1 day in the molds, 26 days in a moist room, and during the twenty-eighth day were brought to the testing temperature.

FIG. 14-8.—Typical breaks of concrete cylinders.

Testing temperatures, °F.	*Maximum loads, p.s.i.*
70	3,970
45	4,060
10	6,440
220*	3,230
200	3,040

* Heated in an oven on the twenty-eighth day, tested dry. All other cylinders were tested wet.

Effect of Rate of Applying Load. From tests by Jones and Richart[1]

[1] JONES and RICHART, "The Effect of Testing Speed on Strength and Elastic Properties of Concrete," *Proc. A.S.T.M.*, Vol. 36, Part II, pp. 380–391.

it is observed that a fairly definite relationship exists between the rate of applying load and the strength of the concrete, an increase in rate of loading being accompanied by an increase in strength approximately proportional to the logarithm of the load rate. The ratio of strengths at the highest and lowest loading rates used was as much as 1⅓ to 1. Loading periods varied from 1 sec. to 4 hr.

CONSISTENCY TESTS

There are two consistency tests in general use, known as the "slump test" and the "flow test." There are A.S.T.M. specifications for both tests.

Slump Test

The slump-test procedure is given in accordance with the Standard Method of Slump Test for Consistency of Portland-Cement Concrete (A.S.T.M. Designation: C 143 - 39), which "covers the procedure to be used both in the laboratory and in the field."

Apparatus.—The test specimen shall be formed in a mold of No. 16 gauge, galvanized metal in the form of the lateral surface of the frustrum of a cone with the base 8 in. in diameter, the top 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles as shown in Fig. 14-9.

Sample.—Samples of concrete for test specimens shall be taken at the mixer or, in the case of ready-mixed concrete, from the transportation vehicle during discharge. The sample of concrete from which test specimens are made shall be representative of the entire batch. Such samples shall be obtained by repeatedly passing a scoop or pail through the discharging stream of concrete, starting the sampling operation at the beginning of discharge and repeating the operation until the entire batch is discharged. The sample thus obtained shall be transported to the place of molding of the specimen, and to counteract segregation the concrete shall be mixed with a shovel until it is uniform in appearance. The location in the work of the batch of concrete thus sampled shall be noted for future reference. In the case of paving concrete, samples may be taken from the batch immediately after depositing on the subgrade. At least five samples shall be taken from different portions of the pile, and these samples shall be thoroughly mixed to form the test specimen.

Procedure.—The mold shall be dampened and placed on a flat, moist, nonabsorbent surface. From the sample of concrete obtained as previously described, the mold shall immediately be filled in three layers, each approximately one-third the volume of the mold. In placing each scoopful of concrete the scoop shall be moved around the top edge of the mold as the concrete slides from it, in order to insure symmetrical distribution of concrete within the mold.

Each layer shall be rodded with 25 strokes of a $\frac{5}{8}$-in. round rod, approximately 24 in. in length and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately $\frac{1}{4}$ in. The strokes shall be distributed in a uniform manner over the cross section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck

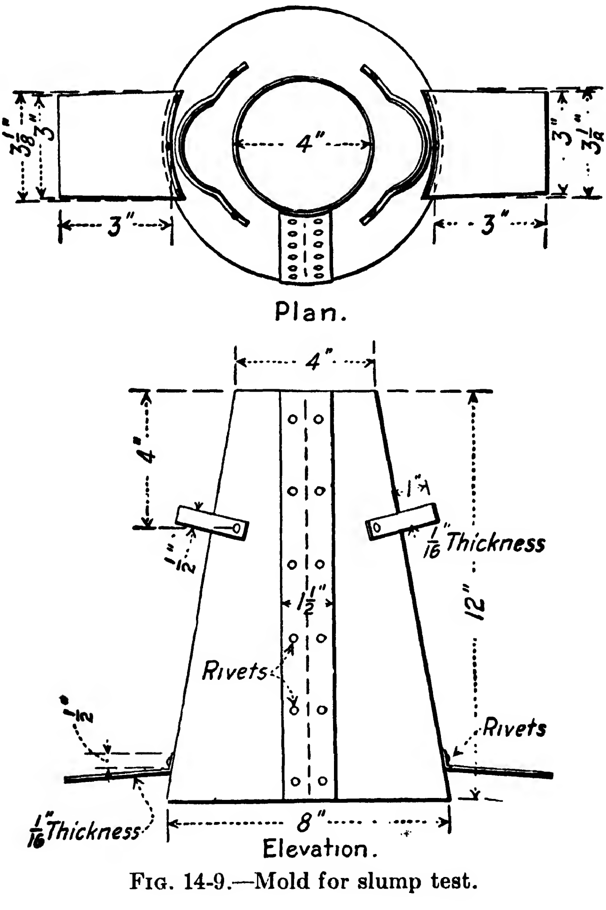

FIG. 14-9.—Mold for slump test.

off with a trowel so that the mold is exactly filled. The mold shall be immediately removed from the concrete by raising it carefully in a vertical direction. The slump shall then be measured immediately by determining the difference between the height of the mold and the height at the vertical axis of the specimen.

Slump Value.—The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump:

$$\text{Slump} = 12 - \text{inches of height after subsidence.}$$

NOTE.—After the slump measurement is completed, the side of the concrete frustrum shall be tapped gently with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of the cohesiveness, workability, and placeability of the mix. A well-proportioned, workable mix will gradually slump to lower elevations and retain its original identity, while a poor mix will crumble, segregate, and fall apart.

Flow Test

The flow-test procedure is given in accordance with the Standard Method of Test for Flow of Portland-cement Concrete by Use of the Flow Table (A.S.T.M. Designation: C 124 - 39).

FIG. 14-10.—Making slump test. *Left*, molding. *Right*, measuring amount of slump.

Apparatus.—*Mold.*—The mold shall be made of a smooth metal casting in the form of the frustum of a cone with a base 10 in. in diameter, upper surface 6¾ in. in diameter, and altitude 5 in.; the base and the top shall be open and at right angles to the axis of the cone. The mold shall be provided with handles.

Flow Table.—The flow table shall conform to the design shown in Fig. 14-12 and shall be mounted on, and bolted to, a concrete base having a height of 15 to 20 in. and weighing not less than 300 lb.

Sample.—Instructions concerning the sample are identically the same as for the sample in the slump test (see Slump Test p. 274).

Procedure.—Immediately preceding the test, the tabletop shall be wetted and cleaned of all gritty material and the excess water removed with a rubber squeegee. The mold, centered on the table, shall be firmly held in place and filled in two layers, each approximately one-half the volume of the mold.

Each layer shall be rodded with 25 strokes of a round, nonmetallic rod ⅝ in.

in diameter and 24 in. in length, having a bullet-pointed end. The strokes shall be distributed in a uniform manner over the cross section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel so that the mold is exactly filled. The excess

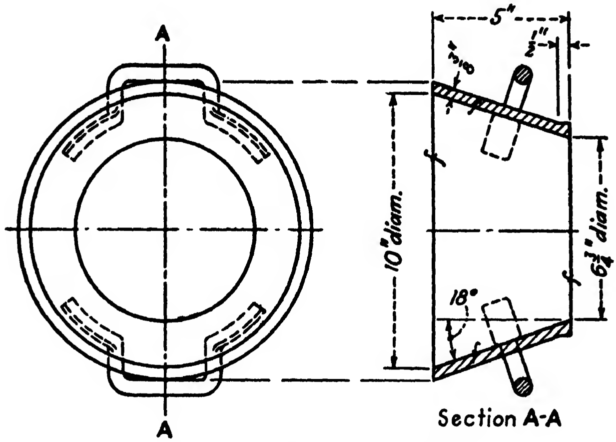

FIG. 14-11.—Mold for flow test.

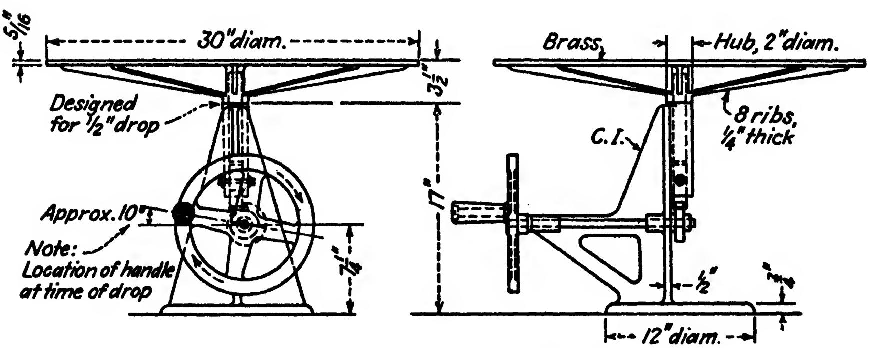

FIG. 14-12.—Flow-table apparatus.

concrete which has overflowed the mold shall be removed and the area of the table outside of the mold again cleaned.

The mold shall be immediately removed from the concrete by a steady, upward pull. The table shall then be raised and dropped ½ in. 15 times in about 15 sec. by revolving the actuating cam continuously at a uniform rate. The diameter of the spread concrete shall be the average of six symmetrically distributed caliper measurements read to the nearest ¼ in.

Flow.—The flow of the concrete shall be recorded as the percentage increase in diameter of the spread concrete over the base diameter of the molded con crete, calculated from the following formula:

$$\text{Flow per cent} = \frac{\text{spread diameter} - 10 \text{ in.}}{10 \text{ in.}} 100$$

Unit Weight

Determination of the unit weight of the concrete is necessary in order that calculation of many other values may be made. The unit-weight value secured is often called the actual unit weight to distinguish it from the unit-weight value calculated on an air-free basis.

Instructions given below follow the Standard Method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (A.S.T.M. Designation: C 138 - 44).

The apparatus consists of the following:

Balance.—A balance or scale sensitive to 0.1 lb.

Tamping Rod.—A straight ⅝-in. round metal rod, approximately 24 in. in length and tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately ¼ in.

Measure.—A cylindrical metal measure, preferably provided with handles. The measure shall be watertight, preferably machined to accurate dimensions on the inside. It shall be reinforced around the top with a No. 10 to 12, U.S. gauge steel band 1½ in in width. Depending upon the maximum nominal size of the coarse aggregate in the concrete, the measures required shall have capacities of ½ or 1 cu ft. and shall conform to the requirements prescribed in Table 14-1.

Calibration of Measure.—The measure shall be calibrated by accurately determining the weight of water at 62°F. required to fill it (Note). The volume of the measure shall be obtained by dividing the weight of water (in pounds) at 62°F required to fill the measure by the unit weight of water at 62°F., namely 62.355 lb.

Table 14-1.—Dimensional Requirements for Cylindrical Measures

Capacity, cu. ft.	Inside diameter, in.	Inside height, in.	Thickness of metal, U. S. gauge	Maximum nominal size of coarse aggregate
½	10.00	11.00	No. 10–No. 12	Up to 2 in. incl.
1	14.00	11.23	No. 10–No. 12	Over 2 in.

Note.—Accurate filling of the measure may be secured by the use of a glass cover plate.

Sample.—The sample of freshly mixed concrete shall be obtained in accordance with the Standard Method of Sampling Fresh Concrete (A.S.T.M. Designation: C 172 - 44).

Procedure.—*Sequence of Operations.*—The measure shall be filled to one-third of its capacity and the mass of concrete rodded with the number of strokes prescribed in the next paragraph, evenly distributed over the cross section. The measure shall then be tapped and filled to two-thirds of its capacity, the mass of concrete again rodded, the measure tapped as before, and finally filled to overflowing, rodded, and tapped as before.

Rodding.—In rodding the first layer the rod shall not strike forcibly the bottom of the measure. In rodding the second and final layers only enough force shall be used to cause the rod to penetrate the surface of the previous layer. When the ½-cu. ft. measure is used, each layer shall be rodded with 25 strokes, and when the 1-cu. ft. measure is used, each layer shall be rodded with 50 strokes.

Tapping.—The exterior surface of the measure shall be tapped smartly 10 to 15 times or until no large bubbles of air appear on the surface of the rodded layer.

Strike-off, Cleaning, and Weighing.—After consolidation of the concrete, the top surface shall be struck off and finished smoothly with a flat cover plate, using great care to leave the measure just level full. All excess concrete shall then be cleaned from the exterior and the filled measure weighed to the nearest 0.1 lb.

Calculation of Unit Weight.—The unit weight of the concrete in pounds per cubic foot, is calculated by dividing the net weight of concrete in the container in pounds by the volume of the container in cubic feet.

Determination of Air Content of Freshly made Concrete

Since the entrainment of a small amount of air in concrete is a desirable feature in many instances, rapid measurement of the air content of the concrete in the field is important. Methods developed may be divided into three general groups: (1) those that compress the air in the concrete under a definite pressure in a closed vessel; (2) those that determine the actual unit weight of the concrete and then determine or calculate the unit weight on an air-free basis; and (3) those that measure out a definite quantity of concrete, then wash out the air, and finally add water to refill the container, the water added being a measure of the amount of air. Those in group 1 are often referred to as a pressure method, or an air-meter method. Those in group 3 are often referred to as the volumetric method.

The idea for compressing the air in the concrete in a closed vessel originated with W. H. Klein, and any device now used making use of the pressure idea is known as a Klein air meter. Klein and Walker first investigated the possibilities of its use.[1] The bowl of the air meter is filled level full with concrete, the upper assembly is fastened tightly to the bowl, and filled with water to the zero mark on the indicator scale.

[1] KLEIN, W. H. and WALKER, "A Method for Direct Measurement of Entrained Air in Concrete," *Proc. Am. Concrete Inst.*, Vol. 42, pp. 657–668.

All valves are closed and the contents of the air meter subjected to the pressure for which the scale was calibrated. A bicycle or automobile-tire pump is used. The range of pressures in use varies from 5 to 15 p.s.i. When the desired pressure is secured, the per cent air is read on the scale. Normally there is some air in the aggregates, which does not count as entrained air in the concrete. The amount of the air in the aggregates is determined first for the materials used and a correction value obtained, which is subtracted from the air-meter reading for the concrete.

A variation of the air meter as described above eliminates the use of the water above the sample.[1] The bowl of known volume is filled level full with concrete. An air chamber is clamped on top of the bowl in such a way as to provide a small air space immediately above the concrete. With the valve closed between the air chamber and the bowl, the air pressure in the chamber is increased to some designated value (14 p.s.i.), the amount being read on a pressure gauge. The valve between the air chamber and the bowl is opened and the reduced pressure is read on the gauge. The amount of the reduction in air pressure is an indication of the air content of the concrete. Air contents can be marked directly on the face of the pressure gauge if desired.

In order to determine the reduced pressures for a range of air contents, the bowl is filled with water and an air pressure test is made. This gives the reduced pressure for zero air. Amounts of water equal to 1, 2, 3, 4, 5, etc., per cents of air are removed from the bowl and the reduced pressures secured.

This method has the advantages: (1) no water is required in the performance of the test; (2) the concrete is not harmed in any way to prevent use in other tests or in actual use; and (3) the results are not influenced by barometric pressure.

In the second group are the gravimetric and Indiana methods. In the third group are the modified Indiāna (or Ohio) method and the rolling methods.

Gravimetric Method.—In the gravimetric method the actual unit weight of the concrete is determined by testing a sample, using the standard unit-weight method. The weight on an air-free basis is calculated from the weights of the individual materials used and their specific gravities. (See Chap. 6 for an illustration of the calculations involved.)

Indiana Method.[2]—In the Indiana method the actual and air-free

[1] TREMPER, BAILEY, and W. L. GOODING, "Washington Method of Determining Air in Fresh Concrete," *Proc. Highway Research Board*, Vol. 28.

[2] BENHAM, S. W., "A Simple Accurate Method for Determining the Air Content in Fresh Concrete," *Proc. Am. Concrete Inst.*, Vol. 42, pp. 677–680.

unit weights are determined by test. The actual unit weight is determined in the standard way. Then a part of the sample is removed from the container and the part remaining weighed. Water is added to the concrete in the measure and the contents stirred vigorously to wash out the entrained air. Water is added until the level is at the top of a hook gauge, which is suspended from a metal bar laid across the top of the measure. Before any testing is done with concrete, the volume of the measure to the top of the hook gauge is determined by filling with water and weighing. From the weights secured it is possible to compute the unit weight of the concrete on an air-free basis. (See Chap. 6 for an illustration of the calculations involved and Test 26 for instructions for the performance of the test.)

Ohio Method.[1]—In the Ohio modification of the Indiana method the entire sample from the determination of the actual unit-weight test is removed from the container, and a new quantity amounting to ⅛ cu. ft. is weighed into the container and compacted. The actual weight to be used is computed from the actual unit-weight value just determined. Water is added above the concrete to the point on the hook gauge. A portion of the water is removed and saved. The concrete and remaining water are stirred vigorously to remove the entrained air. The water removed previously is now returned to the unit-weight container. Water is added from a graduated cylinder until the level is again at the point on the hook gauge. The amount of water added from the cylinder is a measure of the amount of air entrained. (See Chap. 6 for an illustration of the calculations involved and Test 27 for instructions for the performance of the test.)

A study by the author of the factors affecting the air-content value in the Ohio method leads to the conclusion that with a little experience the operator can estimate closely enough the actual unit weight of the concrete instead of making an actual determination. This unit-weight value is used to compute the actual volume of the concrete.

For routine testing it would be well to use the same amount of concrete every time a test is made. Since the actual volume of the concrete is 20 to 25 times the volume of the entrained air, small errors in the concrete volume caused by small errors in the unit weight of the concrete would have little effect on the entrained-air value.

In estimating the actual unit-weight value for the concrete, it is logical to assume smaller unit weights for higher air contents. Figure 14-13 has been prepared for a 30-lb. sample of concrete and on an assumption

[1] BARBEE, J. F., "Ohio Method of Determining the Amount of Air Entrained in Portland Cement Concrete," *Proc. A.S.T.M.*, Vol. 47, pp. 901–904.

that air-free concrete weighs 150 lb. per cu. ft. The diagram is more accurate for the lower air contents, but the maximum error for the maximum air content is not over 0.2 per cent air content.

Rolling Method.—In the rolling method, as developed by Menzel,[1] a bowl container similar to the one used on an air meter is filled with freshly made concrete and struck off level full. A similar empty bowl is clamped onto the filled one. The top of the upper bowl has a small opening which can be closed with a cap. After the upper bowl is in place, water is added until the bowl is full. The cap is applied and the

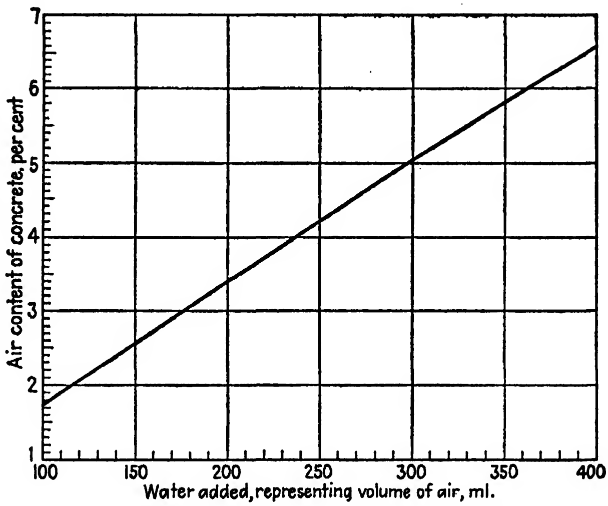

FIG. 14-13.—Showing the relationship between air content of concrete and the volume of water added when using a modified Ohio method. Air-content calculations are based on a sample weighing 30 lb. and an air-free unit weight of 150 lb. per cu. ft.

assembly rolled to wash out the air. The cap is removed and alcohol added to fill the bowl. Alcohol is used to dispose of the foam that accumulates on top. The rolling process can be repeated until no more alcohol need be added. As in the modified Indiana method the amount of alcohol added is a measure of the air content.

Comments on Various Methods.—The pressure method requires no weighings or calculations in the field—very desirable features. The total weight of the outfit and sample is not great when the outfit is made of a lightweight alloy. One such outfit weighs 21.5 lb. The total time

[1] MENZEL, CARL A., "Procedure for Determining the Air Content of Freshly Mixed Concrete by the Rolling and Pressure Methods," *Proc. A.S.T.M.*, Vol. 47, pp. 833–864.

to make a determination is short, being not over 10 min. The cost of an individual apparatus is not large, but when many units are necessary, the cost may be considerable. A single air meter retails for about $150. A number of state highway departments and federal bureaus had on hand a considerable amount of field equipment for the determination of unit weights when they were faced with the problem of controlling the amount of entrained air in their concrete. Possession of this equipment influenced a number of these organizations in their choice of method to be used.

In the Indiana method, use is made of unit-weight equipment. A number of calculations are required in the field that are tedious for the field engineer to make and are also sources of mistakes and errors. In order to reduce the number of weighings and calculations, Ohio modified the method. The Indiana method involves fairly large weights of concrete. The weight of the water that replaces the air is quite small in comparison. While the errors that occur in weighing the concrete may be small, they are quite large in terms of the air content. The Ohio modification of the Indiana method measures volumetrically the water which replaces the air.

The gravimetric method requires a number of calculations in connection with the unit weight of air-free concrete, which seem rather complicated at first. However, once the unit weight of air-free concrete is calculated for a given mix and materials, it need not be recalculated for each air determination. On a construction job the mix and materials are not changed frequently.

If no attempt is made to hold the total amount of mixing water constant, there will be need for frequent calculation of the air-free unit weight. When engineering supervision is given, however, it is customary to make surface-moisture determinations on the aggregate and adjust accordingly the amount of water added from the measuring tank or meter. The total amount of mixing water remains constant under these circumstances.

Accurate determinations of specific gravity of the individual materials are necessary, together with careful leveling off of the concrete, an accurate weighing of the concrete, and finally longhand or machine calculations.

Some of the tediousness of field weighings and calculations can be eliminated by counterbalancing the container used and by calculation of tables covering a range of values that can be expected.

The rolling method involves no weighings in the field, but the total weight of the outfit, sample, and water is sufficiently large enough to require special equipment for rolling. Total time for a determination may be quite long.

Study Questions

1. What is the relation between length and diameter for compression test cylinders? What is the relation between the diameter of the cylinder and the maximum size of aggregate?
2. What are the requirements for the mold, including base and cover plates?
3. What is the minimum number of specimens of a kind to be made for each age at testing?
4. What is the requirement concerning the temperature of the materials being used?
5. What is the requirement concerning the size of the batch? How are the materials to be measured?
6. What provisions are made for mixing the batch? What is meant by "buttering the mixer"? How may it be done? What is meant by "overmortaring the mix"?
7. What are the requirements for molding the test specimens?
8. What is meant by capping the cylinder? How is it done? What is the purpose?
9. What are the requirements concerning the removal of the cylinders from the molds? What are the requirements for curing the cylinders?
10. What is a spherically seated bearing block? Why should the block be spherically seated? Where is this block with reference to the test specimen during the testing of the cylinder?
11. What are the requirements concerning the wetness or dryness of the cylinders at time of test?
12. What is the rate of loading for (1) the screw type of testing machine? (2) the hydraulic type of testing machine?
13. What difference in compressive strength can be made by varying the rate of application of the load from the slowest to the fastest rates?
14. What are the size requirements for flexure test specimens? For molding? For curing?
15. What type of loading is used in laboratory flexure tests? In the Illinois field test?
16. How are flexure results expressed? Is there a well-established relationship between compressive and flexure strengths?
17. What is the size of the mold for the slump test? Explain the method of filling the mold with concrete. Why is it important to move the scoop around the top edge of the molding in filling the mold?
18. Explain how slump values are obtained and expressed.
19. What is the size of the mold for the flow test? Explain method of filling the mold with concrete.
20. Explain how a flow test is made and the flow value secured and expressed.
21. What sizes of measure are provided for the unit-weight test of concrete? What determines which one shall be used?
22. How is the volume of the measure secured?
23. What are the requirements for filling the measure with concrete?
24. How are unit weights given?

25. Give the three groups of test methods for determining the entrained-air content of concrete.

26. Who originated the pressure idea? Whose well-known law of physics is used?

27. Does air in the aggregate particles themselves count as entrained air in the concrete?

28. Explain what is meant by the gravimetric method.

29. Explain the Indiana method; the Ohio method.

30. Explain the rolling method.

31. What are the advantages and disadvantages of each with relation to the others, of the (*a*) pressure method; (*b*) Indiana method; (*c*) Ohio method; (*d*) gravimetric method; (*e*) rolling method; and (*f*) the author's modification of the Ohio method?

Part II

INSTRUCTIONS FOR THE PERFORMANCE OF LABORATORY TESTS

On the following pages instructions are given for the performance of the various tests on concrete materials and for a number of projects involving variables in the field of concrete proportioning. The tests on concrete materials are given ahead of the proportioning projects, since it seems logical to study the individual materials before any study is made of how to put those materials together into concrete. If the same cement and aggregates are used throughout all the tests, both on materials and concrete, the student may take with him a complete test record. It is the practice of the author to use the results, secured in such tests as specific gravity, unit weight, and sieve analysis, in the problems that are given the student to work and in the concrete-proportioning projects.

The methods outlined in this laboratory section are in accordance with those prescribed by the A.S.T.M., except in cases where this society has not prepared standard or tentative standard methods. The method followed is indicated under the title in each case.

The questions following the instructions for the various tests are intended to assist the student in studying the method of test, the purpose of the test, and the test results. In connection with the proportioning projects the student is asked to plot a number of curves, which should assist materially in studying the interrelationship of the many factors involved. The concrete-proportioning projects furnish data that may be used in making many calculations illustrating items mentioned in Chaps. 5 and 6.

While it is not expected that students will remember many of the exact numerical values used, sufficient attention should be given to these values; then, when values which are impossible or impractical are encountered, they will be quickly recognized. A person should realize, for instance, that a percentage of voids in excess of 100 is impossible.

Each student should know the general procedure for the performance of the various tests, but not necessarily in sufficient detail to do the test without reference to text material. He should give thought to the various factors in the performance of tests which have a bearing on the results secured.

TEST 1

DETERMINATION OF SPECIFIC GRAVITY OF HYDRAULIC CEMENT

A.S.T.M. Designation: C 188-44

Purpose

1. To determine the specific gravity of hydraulic cement. Specific gravity is normally defined as the ratio between the weight of a given volume of a material at a designated temperature and the weight of an equal volume of water at a designated temperature. Just which temperature is the designated temperature does not make much difference, but it is important that the temperature of the flask, liquid, and cement be held constant during the determination.

Apparatus

Balance
LeChâtelier flask (see Fig. 1)
Constant-temperature water bath

Liquids

Kerosene free from water, or
Naphtha having a gravity not lighter than 62°A.P.I.

Method

2. The specific gravity of cement shall be determined on the material as received, unless otherwise specified. If the specific-gravity determination on a loss-free sample is required, the sample shall first be ignited as described in the determination for loss on ignition in Section 20 of the Standard Methods of Chemical Analysis of Portland Cement (A.S.T.M. Designation: C 114).

3. Fill the flask with either liquid (kerosene or naphtha) to a point on the stem between zero and 1 ml. Dry the inside of the flask, above the level of the liquid, if necessary, after pouring.

4. Immerse the flask in the constant-temperature water bath, maintained at about room temperature, for a sufficient interval before making either of the readings so as to avoid variations greater than 0.2°C. in the temperature of the liquid in the flask.

NOTE.—Before the cement has been added to the flask, a loose-fitting, lead-ring weight around the stem of the flask will be helpful in holding the flask in an upright position in the water bath, or the flask may be held in the water bath by a burette clamp. It is advisable to use a rubber pad on the tabletop when filling and rolling the flask.

5. Check all readings until they are constant to ensure that the contents of the flask have reached the temperature of the water bath. Record the first reading after immersing as described above.

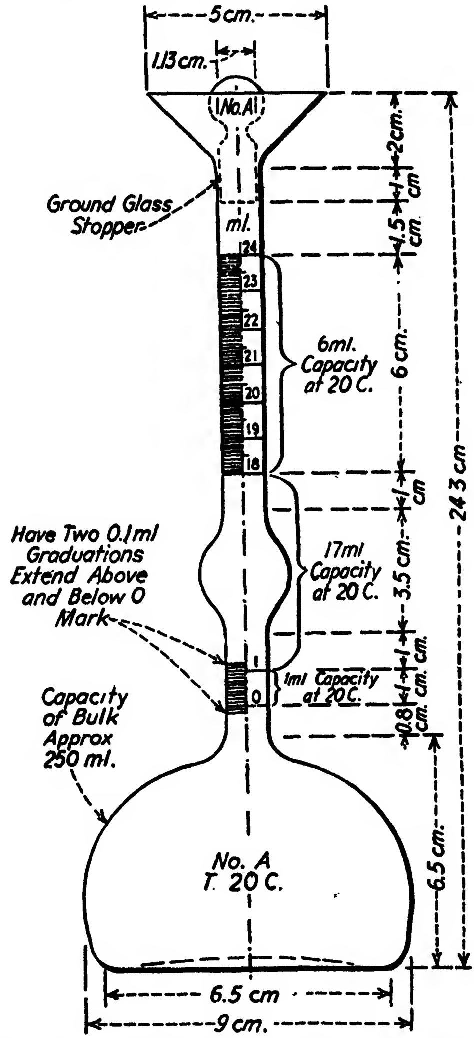

FIG. 1.—Le Châtelier flask for specific-gravity test. (*Courtesy of American Society for Testing Materials.*)

6. Introduce a weighed quantity of cement (about 64 g. for portland cement) into the flask in small amounts, being careful to avoid splashing and to see that the cement does not adhere to the inside of the flask above the liquid. The

temperature of the cement should be at the same temperature as the liquid. A vibrating apparatus may be used to accelerate the introduction of the cement into the flask and to prevent the cement from sticking to the neck.

7. After all the cement is in the flask, insert the stopper and roll the flask gently in an inclined position or gently whirl in a horizontal circle to free the cement from air until no further air bubbles rise to the surface of the liquid. If a proper amount of cement has been added, the level of the liquid will be in its final position at some point of the upper series of gradations.

8. Immerse the flask again in the constant-temperature water bath, in accordance with paragraph 4, before making the final reading.

9. The difference between the first and final readings is the volume of the liquid displaced by the weight of the cement used in the test. The weight of an equal volume of water is found by multiplying this difference (in milliliters) by the relative density of water (which may be taken as 1 in this test).

$$\text{Specific gravity} = \frac{\text{weight of cement used, g.}}{\text{weight of equal volume water, g.}}$$

10. Duplicate determinations of specific gravity by this method should agree within 0.01.

Questions

1. Define specific gravity.
2. If some of the test sample be lost after weighing, what is the effect on the specific-gravity value secured?
3. If some of the liquid be lost after the initial reading is taken, what is the effect on the specific-gravity value?
4. If the temperature of the liquid be higher at the time of the second reading than it was at the time of the first reading, what is the effect on the specific-gravity value?
5. Do kerosene and naphtha have higher or lower coefficients of expansion than water?

DATA RECORD—TEST 1

SPECIFIC GRAVITY OF HYDRAULIC CEMENT

1. Material		
2. Date		
3. Air temperature		
4. Weight of cement used, g.		
5. Initial reading of flask, ml.		
6. Final reading of flask, ml.		
7. Volume of cement particles, ml.		
8. Weight equals volume water, g.		
9. Specific gravity		

TEST 2

DETERMINATION OF THE FINENESS OF HYDRAULIC CEMENT BY THE NO. 200 SIEVE

A.S.T.M. Designation: C 184-44

Purpose

1. To determine the fineness of hydraulic cement by means of the No. 200 sieve.

Apparatus

Balance, 50-g. capacity and enclosed in glass case[1]
Weights[1]
No. 200 sieve meeting A.S.T.M. E 11 requirements and certified by the National Bureau of Standards[1]
Pan to be used under sieve, and a cover
Bristle brush (1- or 1½-in. brush with 10-in. handle)

Method

2. *Determination of Correction Factor.*—Not all sieves are exactly alike, and not all operators will do the work alike. The specification provides that a correction factor shall be obtained by sieving a cement standardized by the National Bureau of Standards in the manner hereafter provided for testing the cement. The difference between the percentage residue on the sieve and that assigned to the standard sample is the amount of the correction and shall be added or subtracted as necessary.

3. *Testing Sample. Hand Method.*—Weigh out a 50-g. sample, and place it on the clean, dry, No. 200 sieve with the pan attached. Do not use washers, shot, or slugs on the sieve. While holding the sieve and pan without cover in both hands, do the sieving with a gentle wrist motion until most of the fine material has passed through, and the residue looks fairly clean. This operation usually requires 3 or 4 min.

4. When the residue appears clean, place the cover on the sieve and remove the pan. With the sieve and cover held firmly in one hand, tap the side of the sieve gently with the handle of the brush used for cleaning the sieve. Dust adhering to the sieve will be dislodged, and the underside of the sieve may then be swept clean.

5. Empty the pan, and wipe out thoroughly with a cloth or waste. Replace the sieve in the pan, and carefully remove the cover. Return to the sieve any coarse material that has been caught in the cover during the tapping.

6. Continue the sieving (with cover removed) as described above for 5 or 10 min., depending upon the condition of the cement. The gentle wrist motion involves no danger of spilling the residue, which shall be kept well spread out on the sieve. Rotate the sieve during the sieving operation.

[1] See A.S.T.M. specification for further details.

7. This open sieving may usually be continued safely for 8 min. or more, but care should be taken that it is not continued too long. Replace the cover and clean the sieve as described above in paragraph 4. If the cement is in proper condition, there should now be no appreciable dust remaining in the residue nor adhering to sieve or pan.

8. Make 1-min. tests now as follows: Hold the sieve with pan and cover in one hand in a slightly inclined position. Move forward and backward in the plane of inclination, at the same time striking the side gently about 150 times per minute against the palm of the other hand on the upstroke. Perform the sieving over a white paper. Any material escaping from the sieve or pan and collected on the paper shall be returned to the sieve. After every 25 strokes turn the sieve about one-sixth of a revolution in the same direction. Continue the sieving operation until not more than 0.05 g. passes through in 1 min. of continuous sieving. Transfer the residue on the sieve to the balance, taking care to brush the sieve cloth thoroughly from both sides to ensure the removal of all the residue from the sieve.

NOTE.—Sieve covers may be marked with three straight lines through the center and intersecting at 60 deg. If one of the lines is marked with an arrowhead and the habit is formed of starting with this point under the right hand, one can easily follow the progress of the 1-min. tests.

9. *Calculation.*—The fineness value is expressed as the percentage of the sample which is retained on the No. 200 sieve. It is figured as follows:

$$\text{Fineness, \%} = \frac{\text{weight of residue, g.}}{50\text{ g.}}\, 100 + C$$

where C is the correction factor obtained under paragraph 2 above.

10. *Mechanical Sieving.*—Mechanical sieving devices may be used, but the

DATA RECORD—TEST 2

FINENESS OF HYDRAULIC CEMENT BY THE NO. 200 SIEVE

1. Material		
2. Date		
3. Air temperature		
4. Weight of sample used		
5. Method of shaking		
6. Weight retained on No. 200 sieve		
7. Per cent retained		
8. Correction factor		
9. Fineness value		

cement shall not be rejected if it meets the fineness requirement when tested by the hand method described above.

Questions

1. How is the fineness expressed when using the No. 200 sieve?
2. What effect does additional fineness of grinding have upon the strength of concrete? Upon the rate of development of strength?
3. Is there a requirement in the present specification for portland cement for this method of determining fineness?
4. How many openings are there per square inch in the No. 200 sieve?
5. What is the clear distance between wires in the No. 200 sieve?

TEST 3

DETERMINATION OF NORMAL CONSISTENCY OF HYDRAULIC CEMENT

A.S.T.M. Designation: C 187-44

Purpose

1. To determine the proper amount of mixing water to make a cement paste of normal consistency. The cement paste is of normal consistency when the Vicat needle penetrates 10 mm. in 30 sec. In making the soundness and time-of-set tests, cement paste of normal consistency is used. In making the tension test, the amount of mixing water used in making the mortar is based on the water required for normal consistency.

Apparatus

Scales (1,000-g. capacity)[1]
Weights[1]
Glass graduate (100- to 200-ml. capacity)[1]
Vicat apparatus, including conical ring[1] (see Fig. 1)
Pan, beaker, and trowel
Timepiece measuring seconds
Glass plate, 10 cm. square
Pair of rubber gloves

Method

2. The determination of the proper amount of mixing water is a cut-and-try process, several trials ordinarily being necessary. The percentage of water for normal consistency of most cements is between 21 and 28. For the beginner it often works better if the first trials are too wet rather than too dry. The amount of water to use in subsequent trials is based on the trials already made.

3. *Temperature.*—The temperature of the air in the vicinity of the mixing slab, the dry cement, molds, and base plates shall be maintained between 20 and 27.5°C. (68 and 81.5°F.). The temperature of the mixing water shall not vary from 21°C. (70°F.) by more than plus or minus 1.7°C. (3°F.).

[1] See A.S.T.M. specification for further details.

4. *Preparation of the Cement Paste.*—Weigh out 500 g. of cement, and place on a smooth, nonabsorbent surface. Form a crater. Pour a measured quantity of water into the crater, and by the aid of a trowel turn the cement on the outer edge into the crater within 30 sec. During an additional interval of 30 sec. for the absorption of the water, trowel the dry cement around the outer

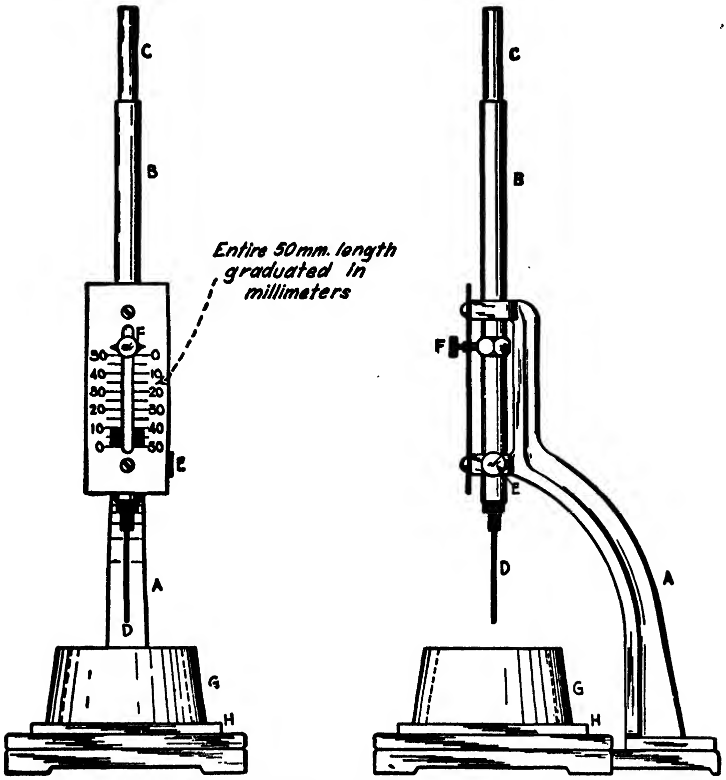

FIG. 1—test 3.—Vicat apparatus. The rod *B* should be reversed for normal consistency determination. Needle *C* should be used. Needle *D* is for the time-of-setting determination.

edge of the cone over the remaining mixture to reduce the evaporation losses and to promote absorption. Complete the mixing operation during the next 1½ min. by continuous, vigorous mixing, squeezing, and kneading with the hands. During the mixing operation protect the hands by snug-fitting rubber gloves.

5. *Molding Test Specimen.*—Quickly form the cement paste, prepared as outlined in paragraph 4, into a ball with the gloved hands and toss six times from one hand to the other, maintaining the hands about 6 in. apart. With the ball resting on the palm of one hand, press it into the larger end of the conical ring

held in the other hand, completely filling the ring with paste. Remove the excess paste at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the glass plate. Slice off the excess paste at the smaller end of the ring by a single oblique stroke of a sharp-edged trowel held at a slight angle with the top of the ring. Smooth the top, if necessary, with a few light touches of the pointed end of the trowel. During the above operations care shall be exercised not to compress the paste.

6. *Consistency Determination.*—The time interval between the finish of the mixing operation and the release of the needle in the consistency determination is 30 sec., which may seem rather short for the beginner. Fig. 1 shows the Vicat apparatus set up to use for the time-of-setting test. The movable rod must be reversed to use for the normal-consistency determination.

7. Center the paste confined in the ring under rod *B* and bring the plunger end *C* in contact with the surface of the paste. Tighten setscrew *E*. Set the movable indicator *F* to the upper zero mark of the scale, or take an initial reading. Release the rod 30 sec. after the completion of mixing. The apparatus shall be free of all vibrations during the test.

8. The paste is of normal consistency when the rod settles 10 mm. below the original surface in 30 sec. after being released.

DATA RECORD—TEST 3

TEST FOR NORMAL CONSISTENCY OF HYDRAULIC CEMENT

1. Material			
2. Date			
3. Air temperature			
4. Weight of cement used			
Trial	5. Per cent water used		
No. 1	6. Penetration		
Trial	7. Per cent water used		
No. 2	8. Penetration		
Trial	9. Per cent water used		
No. 3	10. Penetration		
Trial	11. Per cent water used		
No. 4	12. Penetration		
Trial	13. Per cent water used		
No. 5	14. Penetration		
15. Normal consistency occurs at			

9. Using fresh cement each time, repeat the test with varying percentages of water until normal consistency is obtained.

10. *Calculation.*—Calculate the amount of water required for normal consistency as a percentage of the dry weight of the cement.

Questions

1. What is the purpose of making this determination?
2. What is the range of values for most portland cements?
3. What detail of the procedure may affect the test result secured?

TEST 4

DETERMINATION OF THE SOUNDNESS OF HYDRAULIC CEMENT OVER BOILING WATER (PAT TEST)

A.S.T.M. Designation: C 189-44

Purpose

1. To determine the soundness of hydraulic cement by means of neat cement pats in steam at atmospheric pressure.

Apparatus

Pan, beaker, trowel
Graduate (100- to 200-ml. capacity)
Scales (1,000-g. capacity)
Glass plate, 4 in. square
Moist closet maintaining a relative humidity of 98 per cent at 70 ± 3°F.
Steam bath (see Fig. 1)
Pair of rubber gloves

Method

2. *Preparation of the Specimen.*—Make up a paste of normal consistency, as described in the test for the determination of normal consistency, using 500 g. of cement. The pat from the time of setting test may be used in this test.

3. Mold on the glass plate a pat 3 in. in diameter and ½ in. thick at the center, and taper out to a thin edge. In molding the pat, flatten the cement paste first on the glass plate, and then form by drawing the trowel from the outer edge toward the center to give a rounded surface. The edge of the pat should be clearly defined on the glass plate.

4. Place the pat immediately in the moist closet, where it is to remain for 24 hr. The pat should be marked for identification later on.

5. *Testing the Specimen.*—At the end of 24 hr. in the moist closet, place the pat in the steam bath for 5 hr. The temperature of the steam bath should be between 98 and 100°C. The pat should be 1 in. above the water.

6. Examine the pat within 1 hr. after it is removed from the steam bath. Unsoundness is usually manifested by change in volume, which causes dis-

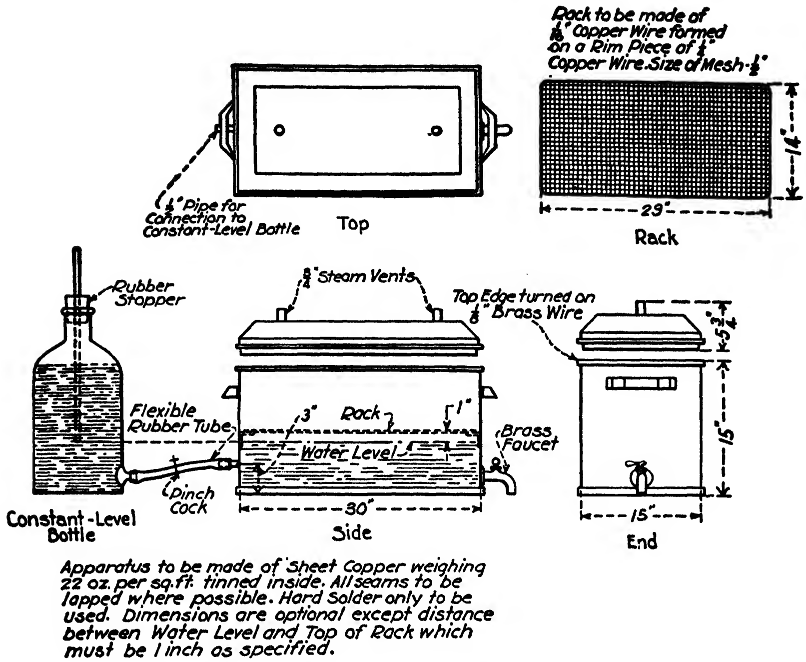

FIG. 1—test 4.—Apparatus for making soundness test of cement.

FIG. 2—test 4.—Correct method of forming cement pat.

tortion, cracking, checking, or disintegration, as illustrated in Fig. 3*b*. Should the pat leave the plate, distortion may be detected best with a straightedge applied to the surface that was in contact with the plate.

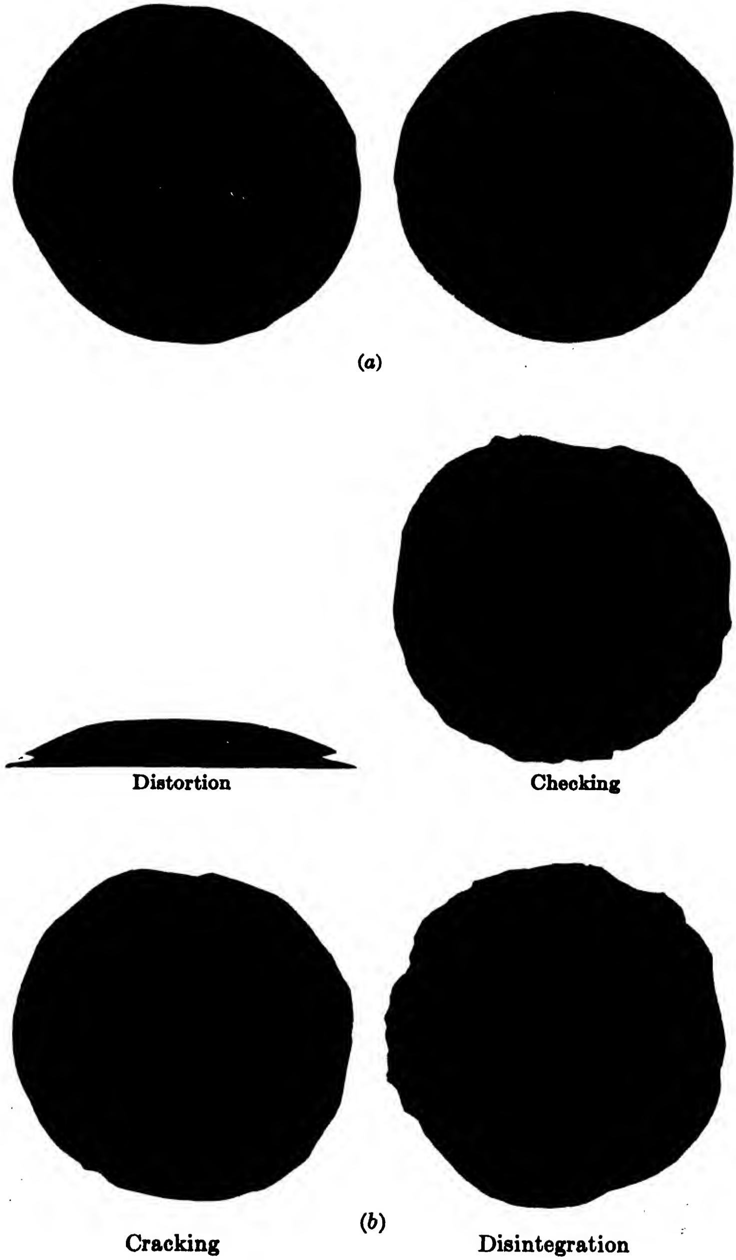

FIG. 3—test 4.—Soundness test pats. (*a*) Shrinkage cracks due to exposure of pats to dry air during setting; (*b*) typical failures in soundness test.

7. *Retesting.*—Cement is first tested as it is received. If natural cement fails to pass this test, a retest may be made on another sample taken any time within 28 days. If the retest is satisfactory, the cement may be used. The pat test is not specified for portland cement.

NOTE.—It is important that the specimens be 24 hr. old when placed in steam, since variations in their age will produce differences in the results of the steam tests. Particularly noticeable are the effects of steaming pats too soon, for many specimens steamed when only 10 or 12 hr. old give apparently satisfactory results, while failure would be observed if they were not placed in steam until 24 hr. old.

Questions

1. What is likely to cause unsound cement?
2. Why is it necessary to keep the cement paste moist in this test while it is setting?
3. What provision is made in the specification for natural cement should the cement fail to pass as received?

DATA RECORD—TEST 4

DETERMINATION OF SOUNDNESS OF HYDRAULIC CEMENT

1. Material		
2. Date		
3. Air temperature		
4. Weight of cement used		
5. Weight of water used		
6. Time when mixed		
7. Time placed in moist closet		
8. Time placed in steam bath		
9. Time removed from steam bath		
10. Interval in moist closet		
11. Interval in steam bath		
12. Condition of pat		

If unsound, give evidences of unsoundness:

TEST 5

DETERMINATION OF THE TIME OF SETTING OF HYDRAULIC CEMENT BY THE VICAT OR GILLMORE NEEDLES

A.S.T.M. Designation: C 191-44

Purpose

1. To determine the time of setting of hydraulic cement by means of the Vicat or Gillmore needles.

NOTE.—The Vicat method and the Gillmore method are alternate procedures, either of which may be used as specified.

Apparatus

Pan, beaker, trowel
Glass graduate (100- to 200-ml. capacity)[1]
Scales (1,000-g. capacity)[1]
Weights[1]
Moist closet (with at least 90 per cent relative humidity and temperature between 67 and 73°F.)
Pair of rubber gloves
Glass plate, 4 in. square
Gillmore needles (See Fig. 1)[1]
Vicat apparatus (See Fig. 1, Test 3)[1]
Conical ring

Method

2. *Preparation of Cement Paste.*—Prepare a cement paste of normal consistency, using 500 g. of cement, following the procedure as outlined in paragraph 4 of Test 3.

3. *Vicat Method. Molding Test Specimen.*—Quickly form the cement paste into a ball with the gloved hands, and toss six times from one hand to the other, maintaining the hands about 6 in. apart. Press the ball, resting in the palm of one hand, into the larger end of the conical ring, held in the other hand, completely filling the ring with paste. Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the glass plate, and slice off at the top of the ring the excess paste. The slicing shall be done with a single oblique stroke of a sharp-edged trowel held at a slight angle with the top of the ring. Smooth the top, if necessary, with a few light touches of the pointed end of the trowel. During these operations of cutting and smoothing, take care not to compress the paste.

4. Immediately after the molding, place the test specimen in the moist closet or a moist room where it shall remain, except when determinations of time of setting are being made. The test specimen shall remain in the conical mold supported by the glass plate.

5. *Time-of-setting Determination.*—Remove the test specimen from the moist closet and place on the base of the Vicat apparatus. Lower needle *D* of rod *B* (Fig. 1, Test 3) until it rests on top of a portion of the glass plate that projects beyond the ring. Set the adjustable indicator *F* to the lower zero mark of the scale, or take an initial reading of the indicator. Raise rod *B*. Bring needle *D* carefully in contact with the surface of the paste. Release the rod quickly.

6. *Initial set* shall be said to have occurred when the needle ceases to pass a point 5 mm. above the glass plate in 30 sec. after being released; and the *final set*, when the needle does not sink visibly into the paste.

[1] See A.S.T.M. specification for additional details.

7. *Precautions*—The test specimens shall be kept in the moist closet or moist room during the test. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point may increase the penetration. The time of setting is affected not only by the percentage and temperature of the water used and the amount of kneading the paste received but also by the temperature and humidity of the air, and its determination is, therefore, only approximate.

8. *Gillmore Method. Molding Test Specimen.*—From the cement paste prepared as described in paragraph 2, make a pat on a flat, clean glass plate about 4 in. square, about 3 in. in diameter, ½ in. in thickness at the center with a flat top and tapering to a thin edge (see Fig. 1*a*). In molding the pat, first

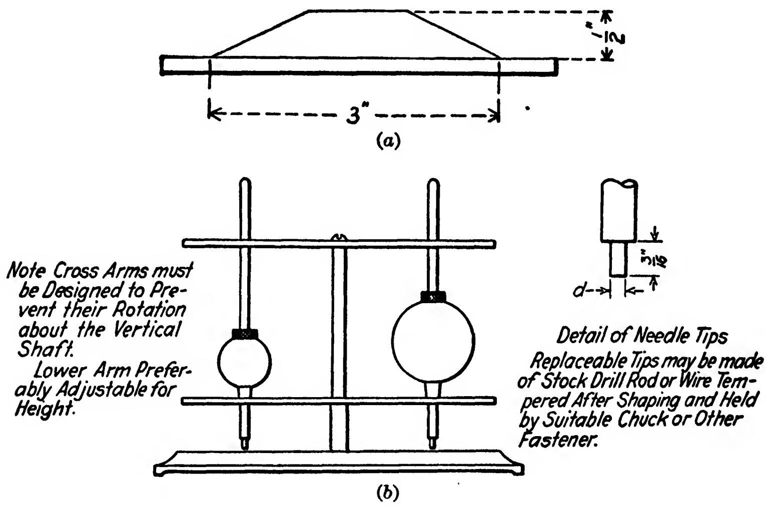

FIG. 1—test 5.—Apparatus for time-of-setting test. (*a*) Pat with top surface flattened for determining time of setting by Gillmore method; (*b*) Gillmore needles.

flatten the cement paste on the glass, then form the pat by drawing the trowel from the outer edge toward the center, and then flatten the top.

9. Immediately after making the pat, place it in the moist closet or moist room where it shall remain except when determinations of time of setting are being made.

10. *Time-of-setting Determination.*—In determining the time of setting, the needles shall be held in a vertical position and applied lightly to the surface of the pat.

11. The cement shall be considered to have acquired its ***initial set*** when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{12}$ in. in diameter, loaded to weigh ¼ lb. The cement shall be considered to have acquired its ***final set*** when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{24}$ in. in diameter, loaded to weigh 1 lb.

12. *Precautions.*—The appropriate precautions described in paragraph 7 above shall be observed.

Questions

1. How is the rate of setting of portland cement controlled in the manufacturing process?
2. What are the specification requirements for time of setting?
3. What is the difference in meaning of the two words, "setting" and "hardening"?

DATA RECORD—TEST 5

DETERMINATION OF TIME OF SETTING OF HYDRAULIC CEMENT

1. Material				
2. Date				
3. Air temperature				
4. Weight of cement used				
5. Weight of water used				
6. Clock time at beginning of mixing operation				
Gillmore needles	Initial set	7. Clock time		
		8. Interval		
	Final set	9. Clock time		
		10. Interval		
Vicat needle	Initial set	11. Clock time		
		12. Interval		
	Final set	13. Clock time		
		14. Interval		

TEST 6

DETERMINATION OF THE TENSILE STRENGTH OF HYDRAULIC-CEMENT MORTARS

A.S.T.M. Designation: C 190-44

Purpose

1. This method of test is intended for determining the tensile strength of hydraulic-cement mortars.

Apparatus

Pan, beaker, trowel
Glass graduate (large enough to measure full amount of water for a batch of mortar)[1]
Scales (1,000- or 1,500-g. capacity)[1]
Weights[1]
Sieves, Nos. 20 and 30[1]
Pair of rubber gloves
3-gang briquet molds (see Fig. 2)[1]
Moist closet[1]
Briquet testing machine[1]
Briquet storage tank[1]

2. *Standard Sand.*—The sand used for making test specimens shall be natural silica sand from Ottawa, Ill., graded to pass a No. 20 sieve and be retained on a No. 30 sieve. This sand shall be considered standard when not more than 15 g. are retained on the No. 20 sieve and not more than 5 g. pass the No. 30 sieve after 5 min. of continuous sieving of a 100-g. sample in the manner specified for sieving cement (see Test 2).

Method

3. *Temperature and Humidity.*—The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, and base plates shall be maintained between 68 and 81.5°F. The temperature of the mixing water, moist closet or moist room, and water in the briquet storage tank shall not vary from 70° ± 3°F. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 90 per cent.

4. *Test Specimens.*—The briquet test specimens shall conform to the dimensional requirements shown in Fig. 1. Three or more specimens shall be made for each period of test specified.

5. *Proportioning, Consistency, and Mixing of Mortars.*—The proportions of the standard mortar shall be 1 part cement to 3 parts standard sand by weight. The quantities of dry materials to be mixed at one time in the batch of mortar shall be not less than 1,000 nor more than 1,200 g. for making six briquets and not less than 1,500 nor more than 1,800 g. for making nine briquets.

6. The percentage of water used in the standard mortar shall depend upon the percentage of water required to produce a neat cement paste of normal consistency from the same sample of cement. Values shall be taken from Table 1. They are percentages of the combined dry weights of the cement and standard sand.

7. Weigh the dry materials and place upon a smooth nonabsorbent surface. Mix thoroughly and form a crater in the center. Pour the proper amount of

[1] See A.S.T.M. specification for further details.

clean water into the crater. Turn the material on the outer edge into the crater within 30 sec. by the aid of a trowel. After an additional interval of 30 sec. for the absorption of the water, during which interval the dry mortar around the outside of the cone shall be lightly troweled over the remaining mortar to reduce the evaporation losses and to promote absorption, complete the mixing

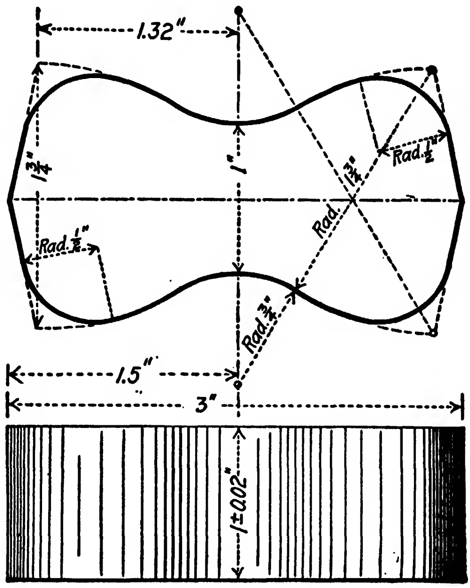

FIG. 1—test 6.—Details for briquet.

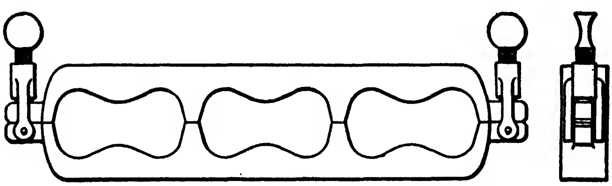

FIG. 2—test 6.—Briquet gang mold.

operation by continuous vigorous mixing, squeezing, and kneading with the hands for 1½ min. During the operation of mixing, the hands shall be protected by snug-fitting rubber gloves.

8. *Molding Test Specimens.*—Before filling the molds, cover them with a thin film of mineral oil. Place each on an unoiled glass or metal plate.

9. Immediately following completion of mixing of the mortar, fill the molds heaping full without compaction. Press the mortar in firmly with the thumbs, applying the force 12 times to each briquet at points to include the entire surface. The force shall be such that the simultaneous application of both thumbs will

register a force of 15 to 20 lb. Each application of the thumbs shall be maintained not longer than sufficient to attain the specified force.

10. Heap the mortar above the mold, and smooth off with a trowel. Draw the trowel over the mold in such a manner as to exert a force of not more than 4 lb.

Table 1.—Percentages of Water for Standard Mortars

Percentage of water for neat cement paste of normal consistency	Percentage of water for mortar of 1 part cement, 3 parts standard sand	Percentage of water for neat cement paste of normal consistency	Percentage of water for mortar of 1 part cement, 3 parts standard sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

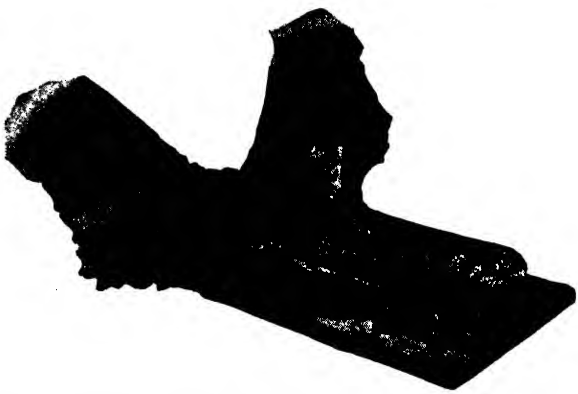

Fig. 3—test 6.—Correct method of filling briquet molds.

11. Cover the mold with a plane glass or metal plate that has been oiled with mineral oil. Holding the plates and mold together with the hands, turn them over, rotating the mold about its longitudinal axis.

12. Remove the top plate. Repeat the operation of heaping, thumbing, heaping, and smoothing off. No ramming or tamping shall be used, nor any troweling in excess of that required to smooth off the specimen.

13. *Storage of Test Specimens.*—All test specimens, immediately after molding, shall be kept in the molds on the base plates in the moist closet or moist room for from 20 to 24 hr. with their upper surfaces exposed to the moist air but protected from dripping water. If removed from the molds before 24 hr., they

FIG. 4—test 6.—Correct method of troweling surface of briquets.

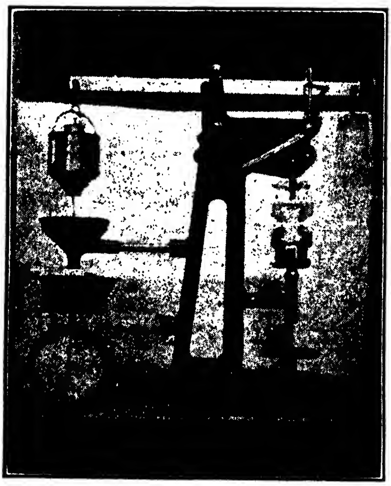

FIG. 5—test 6.—A type of briquet testing maching.

shall be kept on the shelves of the moist closet or moist room until they are 24 hr. old, when the specimens, except those for the 24-hr. test, shall be immersed in clean water in storage tanks constructed of noncorroding materials. The storage water shall be kept clean by frequent changing.

14. *Testing Specimens.*—Test the briquet specimens immediately after their

removal from the moist closet for 24-hr. specimens, and from storage water for all other specimens. If more than one specimen at a time is removed from the moist closet for the 24-hr. tests, cover these briquets with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, place these briquets in a pan of water at a temperature of 70 ± 3°F. and of sufficient depth to immerse completely each briquet until time of testing.

15. Wipe each briquet to a surface-dry condition, removing any loose sand grains or incrustations from the surfaces that will be in contact with the clips of the testing machine.

16. The bearing surfaces of the clips shall be clean and free of accumulations, and the pivots shall be kept in proper adjustment so that the clips may swing freely on the pivots without binding in the stirrups.

17. Center the briquets carefully in the clips, and apply the load continuously at the rate of 600 ± 25 lb. per min.

18. *Faulty Briquets and Retests.*—Briquets that upon removal from the molds do not conform to the requirements for thickness and width at the waist line (Fig. 1) or that are manifestly faulty or that give strengths differing by more

DATA RECORD—TEST 6

TENSION TESTS OF HYDRAULIC CEMENT

1. Material				
2. Date				
3. Air temperature				
4. Weight of cement used				
5. Weight of standard sand used				
6. Weight of water used				
7. Test results	7 days	1		
		2		
		3		
		Average		
	28 days	1		
		2		
		3		
		Average		
8. Specification requirements	days			
	days			

than 15 per cent from the average value of all test specimens made from the same sample and tested at the same period shall not be considered in determining the tensile strength (Note). After discarding briquets or strength values, if less than two strength values are left for determining the tensile strength at any given period, a retest shall be made.

19. Note.—Reliable strength results depend upon careful observance of all of the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed; for example, those covering the testing of the briquets, as prescribed in paragraphs 14 to 17.

Questions

1. At which ages are tensile-strength values specified for each of the five types of portland cement?
2. Are tensile-strength values specified for air-entraining cement?
3. If the purchaser does not specify which strength-test values shall apply, what does the specification say about requirements?
4. At which ages are tensile-strength values specified for natural cement? How do the requirements compare with those for type 1 portland cement?
5. What are the sieving requirements for the standard sand?
6. Why use a 1-size material in this test instead of a graded sand?

TEST 7

DETERMINATION OF THE COMPRESSIVE STRENGTH OF HYDRAULIC-CEMENT MORTARS

A.S.T.M. Designation: C 109-47

Purpose

1. To determine the compressive strength of hydraulic-cement mortars.

Apparatus

Scales (2,000-g. capacity)[1]
Weights[1]
Sieves, Nos. 100, 50, 30, and 16[1] pan and cover
Glass graduate (large enough to measure full amount of water for a batch of mortar)[1]
2-in.-cube molds and necessary base plates[1]
Mixing bowl (6- to 8-qt. capacity)[1]
Rubber glove for one hand
Flow table (10-in. top, ½-in. drop)[1]
Flow mold (4 in. inside diameter at bottom, 2.75 in. inside diameter at top, 2 in. height)[1]
Tamper (cross section, ½ by 1 in.; length, 5 or 6 in.)[1]

[1] See A.S.T.M. specification for additional details.

Trowel[1]
Testing machine (hydraulic or screw-type)[1]
Moist closet
Storage tank

Special Materials

Mineral oil or cup grease
Paraffin
Rosin

2. *Graded Standard Sand.*—The sand used for making test specimens shall be natural silica sand from Ottawa, Ill., graded as follows:

Sieve	*Percentage retained*
No. 100	98 ± 2
No. 50	72 ± 5
No. 30	2 ± 2
No. 16	None

NOTE.—The graded standard sand should be handled in such a manner as to prevent segregation, since variations in the grading of the sand cause variations in the consistency of the mortar. In emptying sacks of sand into bins or in scooping sand out of bins or sacks, care should be exercised to prevent the formation of mounds of sand or craters in the sand, down the slopes of which the coarser particles will roll. Bins should be of sufficient size to permit these precautions. Devices for drawing the sand from bins by gravity should not be used.

3. *Sieve Analysis of Sand.*—For checking the grading of the sand, make a sieving test of the sand on each of the four sieves specified above in paragraph 2. Thoroughly mix the contents of a full sack (100 lb.) of sand. Flatten or spread out the pile to minimize segregation during the following operation of quartering. Obtain a sample of about 700 g. by quartering the contents of the sack of sand. By quartering the 700-g. sample, obtain four samples of 100 g. each for the sieving test.

4. The sieving operation on each sample shall be performed as specified for hydraulic cement (Test 2), except that the sieving shall be continued until not more than 0.5 g. passes through in 1 min of continuous sieving. The sieve shall be thoroughly clean and dry. The weight of the residue on the sieve shall be expressed as a percentage of the weight of the original sample.

Method

5. *Number of Specimens.*—Three or more specimens shall be made for each period of test specified.

6. *Preparing Molds.*—Cover the interior faces of the molds with mineral oil or light cup grease. Cover thinly the contact surfaces of the halves of each mold with a heavy mineral oil or light cup grease such as petrolatum. After assembling the molds, remove excess oil or grease from the interior faces and the top and bottom surfaces of each mold.

[1]See A.S.T.M. specification for additional details.

7. Coat thinly with mineral oil, petrolatum, or light cup grease the plane, nonabsorptive base plates. Set molds on base plates.

8. Prepare a mixture of 3 parts of paraffin to 5 parts of rosin by weight. Heat to a temperature of 230 to 248°F., and apply at the outside contact lines of the molds and base plates so that watertight joints are effected between the molds and the base plates.

NOTE.—The mixture of paraffin and rosin specified for sealing the joints between molds and base plates may be found difficult to remove when molds are being cleaned. Use of straight paraffin is permissible if a watertight joint is secured, but due to the low strength of paraffin it should be used only when the mold is not held to the base plate by the paraffin alone. A watertight joint may be secured with paraffin alone by slightly warming the mold and base plate before brushing the joint. Molds so treated should be allowed to return to specified temperature before use.

9. *Proportioning, Consistency, and Mixing of Mortars.*—The proportions of dry materials of the standard mortar shall be 1 part of cement to 2.75 parts of graded standard sand by weight. The quantities of dry materials to be mixed at one time in the batch of mortar for making 6 cubes shall be 500 g. of cement and 1,375 g. of graded standard sand. The quantities of dry materials to be mixed at one time in the batch of mortar for making 9 cubes shall be 700 g. of cement and 1,925 g. of graded standard sand.

10. The amount of mixing water, measured in milliliters, shall be such as to produce a flow of between 100 and 115, as determined in accordance with paragraph 12, and shall be expressed as a percentage by weight of the cement.

11. Trial mortars shall be made with varying percentages of water until the specified flow is obtained. As a guide for the initial trial mortar, the percentage of water by weight of the cement to produce the specified flow will be about 49 to 50 per cent for portland cement containing air-entraining material, and about 50 to 52 per cent for portland cement not containing air-entraining material. Each trial shall be made with fresh mortar.

12. Wipe the inside of the mixing bowl with a damp cloth or sponge. Place the water in the bowl. Add the cement to the water and mix for 30 sec. Add approximately one-half of the sand and mix for 30 sec. Add the remainder of the sand, and mix for 1½ min. Mixing shall be done by vigorous and continuous stirring, squeezing, and kneading with one hand, which is protected by a snug-fitting rubber glove.

13. *Determination of Flow.*—Carefully wipe dry the top of the flow table and place the flow mold at the center. Immediately after completing the mixing operation, remove the mortar adhering to the mixing glove by striking the hand against the side or edge of the mixing bowl. Place a layer of mortar about 1 in. in thickness in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Fill the mold with mortar, and tamp as specified for the first layer. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge

of the trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold.

14. Lift the mold away from the mortar 1 min. after completing the mixing operation. Immediately drop the flow table through a height of ½ in., 25 times in 15 sec. The flow is the resulting increase in diameter of the mortar mass, expressed as a percentage of the original diameter.

15. *Molding Test Specimens.*—Immediately upon completion of the flow test return the mortar from the flow mold to the mixing bowl. Mix the entire batch for 15 sec. with one hand protected with a rubber glove, after which free the glove of adhering mortar. Within a total elapsed time of not more than 2 min. and 15 sec. after completion of the original mixing of the mortar batch, start molding the cubes.

16. Place a layer of mortar about 1 in. in thickness in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 sec., in four rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in Fig. 1. The tamping pressure shall be just sufficient to ensure uniform filling of the molds.

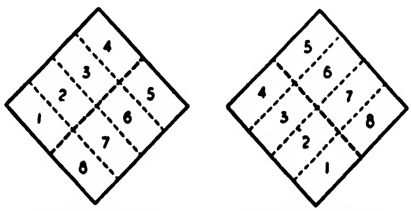

FIG. 1—test 7.—Order of tamping in molding of test specimens. (*Courtesy of American Society for Testing Materials.*)

17. Complete the four rounds of tamping (32 strokes) of the mortar in one cube before going to the next cube. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar, and tamp as specified for the first layer.

18. On completion of the tamping, the tops of all cubes should extend slightly above the tops of the molds. Using the trowel, bring into the molds the mortar that has been forced out onto the tops of the molds. Smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold.

19. *Storage of Test Specimens.*—All test specimens, immediately after molding, shall be kept in the molds on the base plates in the moist closet or moist room

from 20 to 24 hr. with their upper surfaces exposed to the moist air but protected from dripping water. If removed from the molds before 24 hr., they shall be kept on the shelves of the moist closet or moist room until they are 24 hr. old, when the specimens (except those for the 24-hr. test) shall be immersed in clean water in storage tanks constructed of noncorroding materials. The storage water shall be kept clean by frequent changing.

20. *Testing Specimens.*—Testing of the cube specimens shall be carried out immediately after their removal from the moist closet for the 24-hr. specimens and from storage water for all other specimens. If more than one specimen at a time is removed from the moist closet for the 24-hr. tests, these cubes shall be covered with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, these cubes shall be placed in a pan of water at a temperature of 70 ± 3°F. and of sufficient depth to immerse each cube completely until time of test.

21. Wipe each cube to a surface-dry condition, and remove any loose sand grains or incrustations from the faces that will be in contact with the bearing blocks of the testing machine. Check faces by application of a straightedge. If appreciable curvature is present, grind the face or faces to plane surfaces, or discard the specimen.

Note.—Results much lower than the true strength will be obtained by loading faces of the cube that are not truly plane surfaces. Therefore, it is essential that cube molds be kept scrupulously clean, as otherwise large irregularities in the surfaces will occur. Instruments for cleaning of molds should always be softer than the metal in the molds to prevent wear. In case grinding of cube faces is necessary, it can be accomplished best by rubbing the cube on a sheet of fine emery paper or cloth glued to a plane surface, using only a moderate pressure. Such grinding is tedious for more than a few thousandths of an inch; where more than this is found necessary, it is recommended that the cube be discarded.

22. Apply the load to cube faces that were in contact with the true plane surfaces of the mold. Carefully place the cube in the testing machine below the center of the upper bearing block. Do not use any cushioning or bedding materials. Apply the loading at any convenient rate up to 50 per cent of the expected maximum load (25 per cent for expected maximum loads of less than 4,000 lb. at ages of 7 days or less). Then load the specimen continuously to failure at a rate or rates which shall at no time be less than 1,000 nor more than 6,000 p.s.i. per min.

Note.—Reliable strength results depend upon careful observance of all of the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed; for example, those covering the testing of cubes as prescribed in paragraphs 21 and 22. Improper centering of cubes resulting in oblique fractures or lateral movement of one of the heads of the testing machine during the loading will often cause lower strength results. A cube so broken shall be considered as manifestly faulty if its strength differs by more than 10 per cent from the average of all test specimens made from the same sample and tested at the same period.

23. *Calculation.*—Record the total, maximum load indicated by the testing machine. Calculate the compressive strength in pounds per square inch by dividing the total load by the cross-sectional area of the cube. If the cross-sectional area of a cube varies more than 0.06 sq. in. from 4.00 sq. in., the actual area shall be used for the calculation of the compressive strength.

24. *Faulty Cubes and Retests.*—Cubes that are manifestly faulty or that give strengths differing by more than 10 per cent from the average value of all test specimens made from the same sample and tested at the same period shall not be considered in determining the compressive strength. After discarding cubes or strength values, if less than two strength values are left for determining the compressive strength at any given period, a retest shall be made.

Data Record—Test 7

Compression Tests of Hydraulic Cement

1. Material						
2. Date						
3. Air temperature						
4. Weight of cement used, g.						
5. Weight of graded standard sand used, g.						
6. Volume of water used, ml.						
7. Number of cubes molded						
8. Loaded area of cubes, sq. in.						
	Age	Specimen number	Total load, lb.	Unit load, lb. per sq. in.	Total load, lb.	Unit load, lb. per sq. in.
9. Test results	days	1				
		2				
		3				
		Average				
	days	1				
		2				
		3				
		Average				

Questions

1. At which ages are compressive-strength values specified for each of the five types of portland cement?
2. What is the requirement concerning an increase in strength with age?
3. Is compressive strength a requirement for natural cement?
4. What difficulties are there in connection with the handling of graded standard sand that are not present with the standard sand?

TEST 9

DETERMINATION OF AUTOCLAVE EXPANSION OF PORTLAND CEMENT

A.S.T.M. Designation: C 151-43

Purpose

1. To determine the soundness of portland cement by means of an autoclave test on a 1- by 1-in. neat-cement specimen.

Apparatus

Scales (1,000-g. capacity)[1]
Weights[1]
Glass graduate (150-ml. capacity)[1]
2 Molds (1- by 1- by 10-in. inside dimensions)[1]
Autoclave (high-pressure steam boiler, maximum pressure 295 p.s.i.)[1]
Length comparator[1]
Moist closet
Pair of rubber gloves
Thermometer
Trowel

Special Material

Mineral oil

Method

2. *Temperature and Humidity.*—The temperature of the molding room and dry materials shall be maintained at not less than 68°F. and not more than 81.5°F. The temperature of the mixing water and of the moist closet or moist room shall not vary from 70° ± 3°F. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 90 per cent.

3. *Preparation of Test Specimens.—Preparation of Molds.*—Cover the molds with a thin coating of mineral oil. Set the stainless steel or noncorroding metal reference points, taking care to keep them clean and free of oil.

4. *Mixing Cement Paste.*—During the operation of mixing and molding,

[1] See A.S.T.M. specification for further details.

protect the hands by rubber gloves. Make a standard batch of cement paste using 500 g. of cement and sufficient water to give a paste of normal consistency (see Test 3), doing the mixing exactly as outlined for the determination of normal consistency.

5. *Molding Specimens.*—Immediately following completion of mixing, mold the test specimen in one or two layers, compacting each layer with the thumbs or forefingers by pressing the paste into the corners, around the reference inserts, and along the surfaces of the molds until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the paste flush with the top of the mold and smooth the surface with a few strokes of the trowel.

6. *Storage of Test Specimens.*—After the mold has been filled, place it immediately in the moist closet or moist room. Allow specimens to remain in the molds in the moist closet or moist room for at least 20 hr. If removed from the molds before 24 hr., they shall be kept in the moist closet or moist room until tested.

7. *Testing Specimens.*—At 24 hr. ± 30 min. after molding, remove the specimens from the moist atmosphere, measure for length, and place in the autoclave at room temperature in a rack so that the four sides of each specimen will be exposed to saturated steam. The autoclave shall contain enough water to maintain an atmosphere of saturated steam vapor during the entire period of test. Ordinarily, 7 to 10 per cent of the volume of the autoclave should be occupied by the water.

8. To permit air to escape from the autoclave during the early portion of the heating period, leave the vent valve open until steam begins to escape. Close the valve then, and raise the temperature of the autoclave at such a rate as will bring the gauge pressure of the steam to 295 p.s.i. in 1 to 1¼ hr. from the time the heat is turned on. Maintain the 295 ± 10 p.s.i. pressure for 3 hr. At the end of the 3-hr. period shut off the heat supply and allow the autoclave to cool at such a rate that the pressure will be less than 10 p.s.i. at the end of 1 hr. Release slowly any small pressure remaining by opening the vent valve until atmospheric pressure is attained.

9. Open the autoclave and place the specimens immediately in water the temperature of which is above 194°F. Cool the water surrounding the bars at a uniform rate by adding cold water so that the temperature of the water will be lowered to 70°F. in 15 min. Maintain the water surrounding the bars at 70°F. for an additional 15 min., at the end of which time surface-dry the specimens and measure their lengths.

NOTE.—If it is preferred to make all measurements at 80°F., it is recommended that upon removal of the specimens from the moist closet or moist room, they be placed in water maintained at 80°F. for at least 15 min., removed, and measured for length, and then placed in the autoclave. Upon removal from the autoclave, the specimens and water shall be cooled to 80°F. in 15 min., the specimens kept in water at this temperature for an additional 15 min., and then measured for length.

10. *Calculation.*—Calculate the difference in length of the test specimen before and after autoclaving to the nearest 0.01 per cent of the effective gauge

length. Report this as the autoclave expansion of the cement. Indicate a contraction (negative expansion) by prefixing a minus sign to the percentage expansion reported.

11. *Retests.*—Cement failing to meet the test for soundness in the autoclave may be accepted if it passes a retest, using a new sample, at any time within 28 days thereafter. The provisional acceptance of the cement at the mill shall not deprive the purchaser of the right of rejection on a retest of soundness and time of setting at the time of delivery of the cement to the purchaser.

Questions

1. What is the maximum per cent expansion permitted for all types of portland cement? Is it the same for all types of air-entraining cement?
2. Is the autoclave test more severe than the pat test?

DATA RECORD—TEST 9

AUTOCLAVE EXPANSION OF PORTLAND CEMENT

1. Material		
2. Date		
3. Air temperature, F.		
4. Weight of cement used, g.		
5. Volume of water used, ml.		
6. Time of completion of molding		
7. Time of removal from mold		
8. Time of removal from moist closet		
9. Time heat turned on in autoclave		
10. Time gauge pressure reaches 295 p.s.i.		
11. Time heat is turned off in autoclave		
12. Time pressure is reduced to 10 p.s.i.		
13. Time temperature of water reaches 70°F.		
14. Time bar removed from water		
15. Length of specimen before autoclaving, in.		
16. Length of specimen after autoclaving, in.		
17. Autoclave expansion, per cent		

TEST 10

DETERMINATION OF SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

A.S.T.M. Designation: C 128-42

Purpose

1. This method of test is intended for use in making determinations of bulk and apparent specific gravity, and absorption (after 24 hr. in water at room temperature) of fine aggregate. The bulk specific gravity is the value generally desired for calculations in connection with portland-cement concrete.

2. Bulk specific gravity of solids is defined by the A.S.T.M. as "the ratio of the weight in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature."[1]

3. Apparent specific gravity of solids is defined by the A.S.T.M. as "the ratio of the weight in air of a given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature."[1]

4. Since concrete aggregates are normally used in a wet condition, the bulk specific gravity as determined for field use is based on the weight of a saturated, surface-dry sample, rather than an oven-dry sample. The weight in air, mentioned in paragraph 2 above, includes the weight of absorbed water in addition to the weight of the dry material. Such specific-gravity values are labeled "saturated, surface-dry basis."

Apparatus

Balance, 1-kg. capacity, sensitive to 0.1 g.

Flask, 500-ml. capacity, calibrated to 0.15 ml. at 20°C.

Conical mold, 1½ in. in diameter at top, 3½ in. in diameter at bottom, 2⅞ in. in height

Tamping rod, weighing 12 oz. and having a flat, circular tamping face 1 in. in diameter

Watertight pan to hold 1,000 g. of sand

Drying oven, to operate between 212 and 230°F.

Constant-temperature water bath, to operate at 68°F.

Desiccator

Method

5. *Preparation of Sample.*—Select approximately 1,000 g. of the fine aggregate from the material to be tested by the method of quartering. Dry to a constant

[1] See Standard Definitions of Terms Relating to Specific Gravity, A.S.T.M. Designation: E 12-27.

weight at a temperature between 212 and 230°F. Place the sample in a suitable pan, cover with water, and permit to stand for 24 hr. Spread the sample on a flat surface, exposed to a gently moving current of warm air, and stir frequently to insure uniform drying. Continue this operation until the fine aggregate approaches a free-flowing condition.

NOTE.—Where the absorption and specific-gravity values may be utilized as a basis for designing concrete mixtures with aggregates normally used in a moist condition, the requirement of drying to a constant weight may be eliminated.

6. *Surface-dry Condition.*—Place the fine aggregate loosely in the conical mold, tamp the surface lightly 25 times with the metal rod, and lift the mold vertically. If free moisture is present, the cone of fine aggregate will retain its shape. Continue drying with constant stirring, making tests at frequent intervals until the cone of fine aggregate slumps upon removal of the mold. This indicates that the fine aggregate has reached a surface-dry condition.

NOTE.—The procedure described in paragraph 6 above is intended to ensure that the first trial determination shall be made with some free water in the sample. If the cone of fine aggregate slumps on the first trial, the fine aggregate has been dried past the saturated and surface-dry condition. In this case a few milliliters of water shall be thoroughly mixed with the fine aggregate and the sample permitted to stand in a covered container for 30 min. The process of drying and testing the fine aggregate shall then be resumed.

7. *Testing Sample.*—Provision is made that the amount of water necessary to fill the flask to the 500-ml. mark after the sample is in the flask may be determined by weighing or by measuring the volume of the water added, using a burette accurate to 0.1 ml.

In case the determination is by weighing, weigh the empty dry flask. Weight W_a in the formula is found by adding 500 g. to this weight, it being assumed that water at 68°F. weighs 1 g. per ml. and that the flask is correctly marked for a volume of 500 ml.

In case the determination is by a volume measurement, all the water added to the flask as called for in paragraph 8 must be from a measured supply in a burette.

8. Introduce immediately into the flask a 500-g. sample of the material prepared above. Fill the flask almost to the 500-ml. mark with water at a temperature of 68°F. Roll the flask on a flat surface to eliminate all air bubbles. Place it in a constant-temperature water bath at 68°F. for approximately 1 hr. Then fill the flask with water to the 500-ml. mark and determine to the nearest 0.1 g. the weight of the flask, sample, and water. This is weight W_b.

9. Remove the fine aggregate from the flask, dry it to a constant weight at a temperature between 212 and 230°F., cool in a desiccator, and weigh. This is weight W_o.

10. *Calculations.*—Calculate the bulk specific gravity, as defined in paragraph 2 above, as follows:

$$\text{Bulk specific gravity} = \frac{W_o}{500 - (W_b - W_a)}$$

where W_o = weight of oven-dry sample in air, g.
W_a = weight of empty flask + 500 g., g.
W_b = weight of flask, sample, and water, g.
500 = weight of saturated, surface-dry sample, g.
The denominator gives the weight of the equal volume of water, mentioned in the definition.

11. In case the volume of water added to the flask is measured with the burette, then the formula becomes:

$$\text{Bulk specific gravity} = \frac{W_o}{(500 - V_w)1}$$

where V_w = volume of water added, ml.
500 = volume of the flask, ml.

12. Calculate the bulk specific gravity, saturated, surface-dry basis, as mentioned in paragraph 4 above, from the following formula:

$$\text{Bulk specific gravity, S.S.D.} = \frac{500}{500 - (W_b - W_a)}$$

where S.S.D. = saturated, surface dry
500 = weight of saturated, surface-dry sample, g.

13. In case the volume of the water added to the flask is measured with the burette, then the formula becomes:

$$\text{Bulk specific gravity, S.S.D.} = \frac{500}{(500 - V_w)1}$$

where 500 in numerator = weight of saturated, surface-dry sample, g.
500 in denominator = volume of flask, ml.

14. Calculate the apparent specific gravity as defined in paragraph 3 above, from the formula:

$$\text{Apparent specific gravity} = \frac{W_o}{W_o - (W_b - W_a)}$$

where 500 = weight of saturated, surface-dry sample, g.

15. In case the volume of water added to the flask is measured with the burette, then the formula becomes

$$\text{Apparent specific gravity} = \frac{W_o}{(500 - V_w)1 - (500 - W_o)}$$

where 500 = volume of the flask, ml., in first case
500 = weight of saturated, surface-dry sample, g. in second case

16. Calculate the percentage absorption from the formula:

$$\text{Absorption, per cent} = \frac{500 - W_o}{W_o} 100$$

SPECIFIC GRAVITIES OF VARIOUS AGGREGATES

Material	Specific gravity		
	Minimum	Maximum	Average
Sandstone	2.40	2.50	2.45
Sand	2.60	2.70	2.67
Limestone	2.60	2.70	2.65
Granite	2.65	2.75	2.70
Marble	2.50	2.90	2.70
Trap	2.80	3.00	2.90
Cinders	....	....	1.50

DATA RECORD—TEST 10

DETERMINATION OF SPECIFIC GRAVITIES AND ABSORPTION OF FINE AGGREGATE

1. Material		
2. Date		
3. Weight of empty dry flask, g.		
4. Weight of flask + 500 g., W_a, g.		
5. Weight of saturated, surface-dry sample, g.		
6. Weight of oven-dry sample, W_o, g.		
7. Volume of flask, ml.		
8. Weight of flask, sample, and water, W_b, g.		
9. In case water is added from burette, volume of water added, V_w, ml.		
10. Bulk specific gravity		
11. Bulk specific gravity, S.S.D.		
12. Apparent specific gravity		
13. Absorption, per cent		

Questions

1. Define the various kinds of specific gravity.
2. Which one is used most often in concrete calculations in the field? Why?
3. Is specific gravity ever a requirement for concrete aggregates? Why?
4. What is the range of values normal for concrete aggregates?
5. Are there actually void spaces in the aggregate particles?
6. Why would a man in the field prefer to use the alternate method as outlined?
7. What advantages does the siphon tube have over the pycnometer top? The hook gauge?

Alternate Method

17. A method quite similar to the A.S.T.M. one described above is in use in the field. Glass jars used in the home canning of fruits and vegetables or in which salad dressings, pickles, etc., are marketed are substituted for the 500-ml. flask. These are much more readily available to the man in the field and do not cost nearly as much.

18. In order to determine the amount of water necessary to fill the jar to a definite level, four devices are available:

a. A small siphon tube, which can be hung over the side of the jar to draw the water down to a fixed level.

b. A hook gauge supported on a bar of metal, which can be laid across the top of the jar. In this case, water is added until the dimple formed by the hook-gauge breaks.

c. For those jars with standard Mason jar threads, a metal cone top, known as a "pycnometer top," can be used. The top is attached to the jar, using a standard can rubber, after the jar is filled nearly full of water. Water is then added until the level is at the surface of the pycnometer top.

d. A small glass plate. See author's note in Test 12 for explanation of use.

19. Of the four devices the siphon tube is the fastest and most convenient. The tube can be filled by immersing it in water. With a finger over the lower end it can be easily hung in place on the jar. Surplus water in the jar is removed rapidly, and when the siphon breaks, it cuts off sharply. The siphon tube can be handled so that the outside of the jar is kept dry, something which is not possible with the pycnometer top.

20. *Procedure.*—Weigh the jar full of water, using one of the four devices in determining when the jar is full of water. This is weight W_a.

21. When using the quart-size jar, weigh out a sample of saturated, surface-dry sand in the amount of 1,000 g. Introduce the weighed sample into the jar, and fill the jar again with water to the same level as when weight W_a was taken. Weigh the jar, sample, and water. This is weight W_b.

22. If values other than bulk specific gravity S.S.D. are wanted, dry the sample used to a constant weight at a temperature between 212 and 230°F., and weigh. This is weight W_o.

23. *Temperature.*—In the field usually not much attention is paid to the temperature of the water and the sample. It is important in this field procedure

that the temperature of the water be the same when the two weighings are made. Calculations indicate that it does not make much difference what the temperature is for the specific-gravity value if it is the same when both the weighings are made.

24. *Calculations.*—Formulas given in paragraphs 10, 12, 14, and 16 may be used with only the modification of the weight of the saturated, surface-dry sample. It should, of course, be the value actually used.

DATA RECORD—TEST 10 ALTERNATE

DETERMINATION OF SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATE

1. Material		
2. Date		
3. Approximate size of jar, qt.		
4. Type of water-leveling device used		
5. Weight of saturated, surface-dry sample, g.		
6. Weight of oven-dry sample, W_o, g.		
7. Weight of jar full of water, W_a, g.		
8. Weight of jar, sample, and water, W_b, g.		
9. Bulk specific gravity		
10. Bulk specific gravity, S.S.D.		
11. Apparent specific gravity		
12. Absorption, per cent		

TEST 11

DETERMINATION OF SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

A.S.T.M. Designation: C 127-42

Purpose

1. This method of test is intended for use in making determinations of bulk and apparent specific gravity, and absorption (after 24 hr. in water at room temperature) of coarse aggregate. The bulk specific gravity is the value generally desired for calculations in connection with portland-cement concrete. For definitions of bulk and apparent specific gravities, and bulk specific gravity, saturated surface-dry basis, see Test 10 paragraphs 2, 3, and 4.

Apparatus

Balance, capacity 5 kg. or more and sensitive to 0.5 g. or less

Wire basket of No. 4 mesh, approximately 8 in. in diameter and 8 in. in height

Suitable container for immersing the wire basket in water and suitable apparatus for suspending the wire basket from center of scale pan of balance

Large piece of absorbent cloth for surface-drying the sample

Method

2. *Sample.*—Select approximately 5 kg. of the aggregate from the sample to be tested by the method of quartering, rejecting all material passing a ⅜-in. sieve. In the case of homogeneous aggregate, all material may be retained on a 1-in. sieve.

3. *Preparation.*—Wash thoroughly to remove dust or other coatings from the surface of the particles. Dry to a constant weight at a temperature of 212 to 230°F.

NOTE.—Where the absorption and specific-gravity values may be utilized as a basis for designing concrete mixtures with aggregates normally used in a moist condition, the requirement of drying to constant weight may be eliminated.

4. Immerse the sample in water at 59 to 77°F. for a period of 24 hr. Remove sample from water and roll in a large absorbent cloth until all visible films of water are removed, although the surface of the particles still appears to be damp. The larger fragments may be wiped individually. Care should be taken to avoid evaporation during the operation of surface drying. Determine the weight of the sample in the saturated, surface-dry condition. This weight and all subsequent weights are to be determined to the nearest 0.5 g.

5. *Testing.*—After weighing, place the saturated, surface-dry sample immediately in the wire basket and determine its weight immersed in water. Dry the sample to a constant weight at a temperature of 212 to 230°F., cool to room temperature, and weigh.

Calculations

6. *Bulk Specific Gravity.*—The bulk specific gravity shall be calculated from the following formula:

$$\text{Bulk specific gravity} = \frac{W_o}{W_1 - W_s}$$

where W_o = weight of oven-dry sample in air, g.

W_1 = weight of saturated, surface-dry sample in air, g.

W_s = weight of saturated sample suspended in water, g.

7. *Bulk Specific Gravity, Saturated, Surface-dry Basis.*—The bulk specific gravity on the basis of weight of saturated, surface-dry aggregate shall be calculated from the following formula:

$$\text{Bulk specific gravity, S.S.D.} = \frac{W_1}{W_1 - W_s}$$

8. *Apparent Specific Gravity.*—The apparent specific gravity shall be calculated from the following formula:

$$\text{Apparent specific gravity} = \frac{W_o}{W_o - W_s}$$

9. *Absorption.*—The percentage absorption shall be calculated from the following formula:

$$\text{Absorption, per cent} = \frac{W_1 - W_o}{W_o} 100$$

10. *Reproducibility of Results.*—Duplicate determinations should check to within 0.02 in the case of specific gravity and 0.05 per cent in the case of the percentage of absorption.

DATA RECORD—TEST 11

DETERMINATION OF SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE

1. Material		
2. Date		
3. Weight of material, oven dry, W_o, g.		
4. Weight of material, saturated, surface dry, W_1, g.		
5. Weight of material and basket suspended in water, g.		
6. Weight of basket suspended in water, g.		
7. Weight of material suspended in water, W_s, g.		
8. Bulk specific gravity		
9. Bulk specific gravity, saturated, surface-dry basis		
10. Apparent specific gravity		
11. Absorption, per cent		

TEST 12

DETERMINATION OF THE UNIT WEIGHT OF AGGREGATE

A.S.T.M. Designation: C 29-42

Purpose

1. To determine the unit weight of fine aggregate, coarse aggregate, or mixed aggregates.

Apparatus

2. Set of measures, 0.1, 0.5, and 1.0 cu. ft.[1]

Balance sensitive to 0.5 per cent of weight of sample

Tamping rod, 5/8 in. in diameter, 24 in. in length, tapered for a distance of 1 in. to a spherically shaped end having a radius of approximately 1/4 in.

Shovel or small scoop

Piece of plate glass for use in calibrating measure

3. *Calibration of Measure.*—Determine the volume of the measure to be used by accurately filling it with water at 62°F. and weighing the amount of water.

Author's Note.—A piece of plate glass will be found very useful in filling the measure. Weigh the measure and the piece of plate glass. Fill the measure with water until the water is about to run over the side. Cover the measure with the plate glass, sliding it on from one side. If the water does not fill all the space under the glass, add water before the glass completely covers the surface. When the piece of plate glass completely covers the surface of the measure, there should be no air pockets visible under the glass. Weigh the measure, glass plate, and water. The difference between the two weights is the weight of water in the measure.

4. The volume of the measure is found by dividing the weight of water in the measure by the unit weight of water at 62°F. This value is 62.355 lb. per cu. ft.

5. *Sample.*—Room-dry the sample, and mix thoroughly.

Author's Note.—It is suggested that the room drying be carried to the same degree as is recommended in the two tests for specific gravity, since calculations for unit weight of concrete, air-free basis, and air content of concrete by the gravimetric method involve both weights of material and specific gravity.

Compact Weight Determination

6. *Rodding Procedure.*—The rodding procedure is applicable to aggregates having a maximum size of 2 in. or less.

Fill the measure one-third full of aggregate. Level off with the fingers. Tamp the aggregate with the pointed end of the tamper 25 times evenly over the surface. Do not forcibly strike the bottom with the tamper.

Fill two-thirds full, level, and tamp this layer in the manner prescribed for the first one-third. The rod should penetrate only the second layer.

Fill the measure to overflowing. Tamp as for the second layer. Strike off the surplus with the tamping rod.

7. Determine the net weight of the aggregate in the measure. Compute the unit weight of the aggregate by dividing the net weight of aggregate in the measure by the volume of the measure.

8. *Jigging Procedure.*—The jigging procedure is applicable to aggregates hav-

[1] See A.S.T.M. specification for additional details.

ing a maximum size greater than 2 in. and not to exceed 4 in. Use the 1-cu. ft. measure.

9. Fill the measure in three approximately equal layers as described above. Compact each layer by placing the measure on a firm foundation, such as a cement-concrete floor, raising alternate sides of the measure about 2 in. from the foundation, and allowing it to drop in such a manner as to hit with a sharp slapping blow. The aggregate particles by this procedure will arrange themselves in a closely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side. Level off the surface of the aggregate with the fingers or a straightedge in such a way that projections of the larger pieces of coarse aggregate shall balance the larger voids in the surface below the top of the measure.

10. Determine the net weight of the aggregate in the measure. Compute the unit weight of the aggregate by dividing the net weight of aggregate in the measure by the volume of the measure.

Loose Weight Determination

11. *Shoveling Procedure.*—The shoveling procedure is applicable to aggregates having a maximum size of 4 in. or less.

Data Record—Test 12

Determination of Unit Weight of Aggregate

1. Material		
2. Date		
3. Maximum size of aggregate, in.		
4. Approximate size of measure, cu. ft.		
5. Weight of measure full of water, lb.		
6. Weight of empty measure, lb.		
7. Weight of water in measure, lb.		
8. Volume of measure, cu. ft.		
9. Determination used		
10. Procedure used		
11. Weight of measure full of aggregate, lb.		
12. Weight of aggregate in measure, lb.		
13. Unit weight of aggregate, lb. per cu. ft.		

12. Fill the measure to overflowing by means of a shovel or scoop, the aggregate being discharged from a height of not to exceed 2 in. above the top of the measure. Care should be taken to prevent, so far as possible, segregation of the particle sizes of which the sample is composed.

13. Level off the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate will balance the larger voids in the surface below the top of the measure.

14. Determine the net weight of the aggregate in the measure. Compute the unit weight of the aggregate by dividing the net weight of aggregate in the measure by the volume of the measure.

15. *Reproducibility of Results.*—Results with the same sample should check within 1 per cent.

Questions

1. What is meant by unit weight?
2. How does unit weight differ from specific gravity?
3. What is a normal range of values for unit weight of fine aggregate? Coarse aggregate?

TEST 13

DETERMINATION OF UNIT WEIGHTS OF COMBINATIONS OF FINE AND COARSE AGGREGATE

Purpose

1. For an interesting, educational addition to the preceding unit-weight test, prepare combinations of fine and coarse aggregate in order that a curve may be plotted showing the relationship between unit weight and percentage of fine and coarse aggregates for the range 0 to 100 per cent fine aggregate.

2. Unit-weight values for 0 and 100 per cent fine aggregate are secured from Test 12. Normally, if a series of mixes are prepared for percentages of 30, 40, 45, 50, 55, and 65 for the fine aggregate, sufficient values will be secured.

Apparatus

Same as listed for Test 12

Method

3. Start with the mixture of 30 per cent fine aggregate and 70 per cent coarse aggregate. If 44 lb. of coarse aggregate are used with the proper amount of fine aggregate, there will be sufficient mixed aggregate to fill a 0.5-cu. ft. measure with a little over.

4. By saving all the aggregate used in making the 30 per cent determination, the aggregate for the 40 per cent mixture can be secured by adding the necessary amount of fine aggregate. This procedure can be continued until the 65 per cent determination is concluded.

5. Weigh out 44 lb. of coarse aggregate, and place it in a mixing pan. If 44 lb. is the weight of 70 per cent of the mixture, the weight of 30 per cent can be calculated by dividing 44 by 70 and multiplying the result by 30. This weight is 18.85 lb. Weigh out 18.85 lb. of fine aggregate, and place it in the mixing pan with the coarse aggregate. Mix contents of pan thoroughly with square-point shovel.

6. Make unit-weight determination on the mixed aggregate as outlined in Test 12. Return aggregate to the mixing pan.

7. The weight of the coarse aggregate is to remain at 44 lb. In the second determination this is to be 60 per cent of the total, and the fine aggregate is to be 40 per cent. The total weight of fine aggregate is found by dividing 44 by 60 and multiplying the result by 40. This value is 29.35 lb. Since there are 18.85 lb. of fine aggregate in the pan, the amount to be added is 29.35 minus 18.85, or 10.50 lb. Weigh out this amount of fine aggregate, place it in the mixing pan, and mix the contents thoroughly.

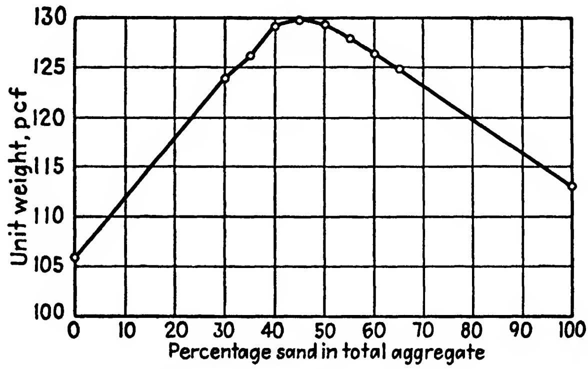

FIG. 1—test 13.—Typical curve showing the relationship between unit weight and percentage sand in the total aggregate. Values plotted are the averages of eight classes at the University of Illinois.

8. Make a unit-weight determination as previously, and return the contents of the measure to the mixing pan.

9. Repeat for remaining percentages of sand—45, 50, 55, and 65.

10. *Curve.*—Plot a curve, the unit weight of the aggregate against percentage of fine aggregate, for the range of values 0 to 100. If several classes are doing the same experiment with the same materials, it is suggested that the curve for the average values of all classes be plotted also.

11. This curve sheet should be prepared with the idea of adding curves for concrete unit weights secured in either Tests 29 or 30. With values for the aggregate and for the concrete on the same sheet, it can be seen whether the maximum values for the concrete and the combined aggregate occur at the same percentage of fine aggregate.

Questions

1. Why is it that the unit weight of a mixture of fine and coarse aggregate is greater than that of the separate materials?
2. At which percentage of fine aggregate does the maximum unit weight occur? What is the maximum unit-weight value?

DATA RECORD—TEST 13

DETERMINATION OF UNIT WEIGHTS OF COMBINATIONS OF FINE AND COARSE AGGREGATES

1. Fine aggregate ____________
2. Coarse aggregate ____________
3. Date ____________
4. Volume of measure, cu. ft. ____________
5. Weight of coarse aggregate used, lb. ____________

Percentages of aggregates		Weights of fine aggregate		Weight of aggregate in measure, lb.	Unit weight combined aggregate, lb. per cu. ft.	Average unit weights, all classes, lb. per cu. ft.
Fine	Coarse	To be used	To be added			
0	100					
30	70					
40	60					
45	55					
50	50					
55	45					
65	35					
100	0					

TEST 14

DETERMINATION OF VOIDS IN AGGREGATE FOR CONCRETE

A.S.T.M. Designation: C 30-37

Purpose

1. To determine the percentage of voids in aggregate.

Apparatus

2. No apparatus is necessary. Determinations of the specific gravity and the unit weight of the aggregate must be made first, however.

Method

3. *Calculation.*—The voids in the aggregate are calculated by the following formula:

$$\text{Voids, per cent} = \frac{\text{sp. gr.} \times 62.355 - \text{unit weight}}{\text{sp. gr.} \times 62.355} 100$$

where sp. gr. = bulk specific gravity of the aggregate (for use on construction this value should be on saturated, surface-dry basis)
62.355 = unit weight of water at 62°F., lb.
unit weight = unit weight of aggregate, lb. per cu. ft.

PERCENTAGES OF VOIDS FOR DIFFERENT WEIGHTS OF AGGREGATE PER CUBIC FOOT AND SPECIFIC GRAVITIES

Specific gravities	62.355 × specific gravity	Weights per cubic foot											
		90	95	100	105	110	115	120	125	130	135	140	145
2.50	155.89	42.3	39.1	35.9	32.6	29.4	26.2	23.0	19.8	16.6	13.4	10.2	7.0
2.55	159.00	43.4	40.3	37.1	34.0	30.8	27.7	24.5	21.4	18.2	15.1	11.9	8.8
2.60	162.12	44.5	41.4	38.3	35.2	32.1	29.1	26.0	22.9	19.8	16.7	13.6	10.6
2.65	165.24	45.5	42.5	39.5	36.5	33.4	30.4	27.4	24.5	21.3	18.3	15.3	12.2
2.70	168.36	46.5	43.6	40.6	37.6	34.6	31.7	28.7	25.8	22.8	19.8	16.8	13.9
2.75	171.48	47.5	44.6	41.7	38.8	35.9	32.9	30.0	27.1	24.2	21.3	18.4	15.4
2.80	174.59	48.5	45.6	42.7	39.8	37.0	34.1	31.3	28.4	25.5	22.7	19.8	16.9
2.85	177.71	49.4	46.5	43.7	40.9	38.1	35.3	32.5	29.7	26.8	24.0	21.2	18.4
2.90	180.83	50.2	47.5	44.7	41.9	39.2	36.4	33.6	30.9	28.1	25.3	22.6	19.8

The percentage of solids is equal to 100 minus the percentage of voids.

DATA RECORD—TEST 14

DETERMINATION OF VOIDS IN AGGREGATES FOR CONCRETE

1. Material			
2. Date			
3. Specific gravity, S.S.D.			
4. Unit weight, lb. per cu. ft.			
5. Voids, per cent			

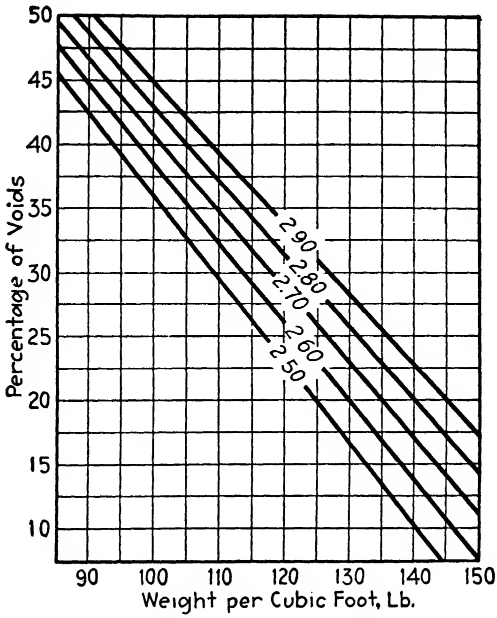

FIG. 1—test 14.—Relationship between percentage of voids and weight per cubic foot for specific gravities from 2.50 to 2.90.

TEST 15

DETERMINATION OF THE SURFACE MOISTURE IN FINE AGGREGATE

A.S.T.M. Designation: C 70-47

Purpose

1. To determine in the field the amount of surface moisture in fine aggregate by displacement in water. The accuracy of the method depends upon accurate information on the bulk specific gravity of the aggregate in a saturated, surface-dried condition. The same procedure,[1] with appropriate changes in the size of sample and size of the container, may be applied to coarse aggregate.

Apparatus

Balance, capacity 2 kg. or more and sensitive to 0.5 g. or less.

Suitable container or flask,[2] preferably of glass or noncorrosive metal. The

[1] Author's Note.—Any procedure that may be used in the determination of the specific-gravity value may be used in the determination of the surface moisture, either fine or coarse aggregate. Moist aggregate is substituted for the dried aggregate of the specific-gravity test, and the appropriate formula used.

[2] Author's Note.—See paragraphs 17 to 19 of Test 10 for a discussion of suitable containers in use.

container may be a pycnometer, a volumetric flask, a graduated flask, or other suitable measuring device. The volume of the container shall be from two to three times the loose volume of the sample. The container shall be so designed that it can be filled to mark, or the volume of its contents read, within 0.5 ml. or less.

Graduated cylinder, when the determination is to be by volume.

Method

2. *Sample.*—Select a representative sample of the fine aggregate to be tested for surface moisture. Weigh out a sample of not less than 200 g. Larger samples will yield more accurate results. This is weight W. If the determination is to be by volume, none of the surface moisture should be allowed to evaporate between this weighing and its introduction into the container, as required in paragraph 8.

3. *Method and Temperature.*—The surface-moisture content may be determined either by weight or by volume. In each case the test shall be made at a temperature in the range 65 to 85°F.

4. *Determination by Weight.*—Fill the container with water and weigh. This is weight W_a.

5. Remove a portion of the water in the container, allowing enough to remain so that the sample of aggregate will be completely immersed when it is placed in the container. Introduce the weighed sample into the container. Remove entrapped air by rolling container or stirring sample. Fill the container with water to the same level as when weight W_a was secured. Weigh the container, sample, and water. This is weight W_b.

6. *Calculation.*[1]—Calculate the surface-moisture content using the formula:

$$w\% = \frac{(G - 1)W/G - (W_b - W_a)}{W_b - W_a} 100$$

where $w\%$ = percentage surface moisture, based on the saturated, surface-dry weight of sample

W = weight of moist sample, g.

W_a = weight of container full of water, g.

W_b = weight of container, sample, and water, g.

G = specific gravity of aggregate, saturated, surface dry

[1] Author's Note.—When many determinations are to be made in the field on a construction job, a table may be prepared giving the percentages of surface moisture for the range of values that will prevail on the job. The specific-gravity value is constant for any given aggregate. The weight of the sample W can be made the same for all determinations. The weight W_a will remain the same if the temperature of the water used does not change. Small changes in temperature do not produce significant changes in W_a. The container full of water may be counterbalanced on the balance in order that when the weight, W_b, is taken, it really is the difference, $W_b - W_a$. The table that is prepared, then, shows values of surface moisture for a range of values of $W_b - W_a$ for constant values of specific gravity and weight of moist sample.

7. *Determination by Volume.*—Determine the volume of the container by filling it with water, which is measured in the graduated flask, if the container is not a flask with the capacity marked on it. This is volume V.

8. Place in the container a measured amount of water, which is sufficient to cover completely the sample when it is in the container. Place the sample in the container. Remove entrapped air by rolling container or stirring contents.

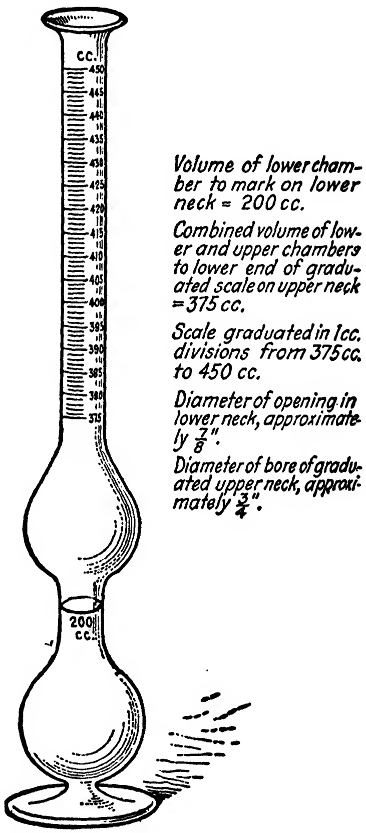

FIG. 1—test 15.—Chapman flask.

Fill the container with water from a measured supply. Determine the total amount of water added to the container. This is volume V_x.

9. *Calculation.*—Calculate the percentage of surface moisture, w%, using the formula:

$$w\% = \frac{V - V_x - (W/G)}{W + V_x - V} 100$$

where $w\%$ = percentage of surface moisture, based on the saturated, surface-dry weight of sample

V = volume of the container or flask, ml.

V_s = volume of water added to fill the container or flask, ml.

W = weight of the moist sample, g.

G = specific gravity of the aggregate, saturated, surface-dry basis

10. *Chapman Flask.*—The Chapman flask (see Fig. 1) is a special flask developed originally for the specific-gravity and surface-moisture determinations. It

Data Record—Test 15

Determination of the Surface Moisture in Fine Aggregate

Determination by Weight

1. Material		
2. Date		
3. Temperature, F.		
4. Type of container used		
5. Weight of moist sample, W, g.		
6. Weight of container full of water, W_a, g.		
7. Weight of container, sample and water, W_b, g.		
8. $W_b - W_a$		
9. Specific gravity of aggregate, S .S. D.		
10. Surface moisture, $w\%$		

Determination by Volume

1. Material		
2. Date		
3. Temperature, F.		
4. Type of container used		
5. Weight of moist sample, W, g.		
6. Volume of container, V, ml.		
7. Volume of water added to fill container with sample, V_x, ml.		
8. Specific gravity of aggregate, S.S.D.		
9. Surface moisture, $w\%$		

is no longer specified by A.S.T.M., but its use is permissible in connection with the determination by volume.

11. Place water in the flask to the 200-ml. mark. Place the weighed sample (500 g.) in the flask. Read the final volume V on the stem. The formula for surface moisture is as follows:

$$w\% = \frac{V - 200 - (W/G)}{W + 200 - V} 100$$

where $w\%$ = percentage of surface moisture, based on the saturated, surface-dry weight of the sample

V = final volume read on the flask, ml.

W = weight of the moist sample, g.

G = specific gravity of aggregate, saturated, surface-dry basis

Problems

1. Prove the formula for percentage of surface moisture. Suggestions: (1) Set up two equations, one based on a weight relationship and the other on a volume relationship; and (2) solve first for an expression for the weight of surface moisture.

2. Prepare a graph on 20-to-the-inch coordinate paper, which will give percentages of surface moisture for various values of V and for specific gravities from 2.20 to 2.80 in intervals of 0.10 specific gravity. Scales: abscissa 1 in. = 10 ml. combined volume, and ordinate 1 in. = 2 per cent surface moisture.

TEST 16

DETERMINATION OF THE SURFACE MOISTURE IN AGGREGATE WEIGHT-IN-WATER METHOD

Purpose

1. To determine the percentage of surface moisture in aggregate, either fine, coarse, or mixed. In this method the aggregate is weighed in air and then weighed suspended in water.

Apparatus

Balance, 3,000-g. capacity, sensitive to 0.1 g.

Container which can be suspended from the balance in a tank of water

Tank for water

The Dunagan apparatus shown in Fig. 1 is suitable for making this determination.

Method

2. *Selection of Sample.*—Select a representative sample of the moist aggregate and weigh immediately, or place in an airtight container to be weighed later. After the moist weight W is secured, it is not necessary to prevent evaporation

of the surface moisture. Absorbed water should not be allowed to evaporate, however.

3. *Testing.*—Suspend the container from the balance in the tank of water. The container should have an overflow outlet or have a mark on the inside in order that the level of the water may be same when the weight of the container and the weight of the container and sample are secured. Weigh or counterbalance the container suspended in water.

4. Place the sample in the container and weigh suspended in water. Subtract the weight of the suspended container to secure the weight of the sample. The weight of the sample suspended is W_s.

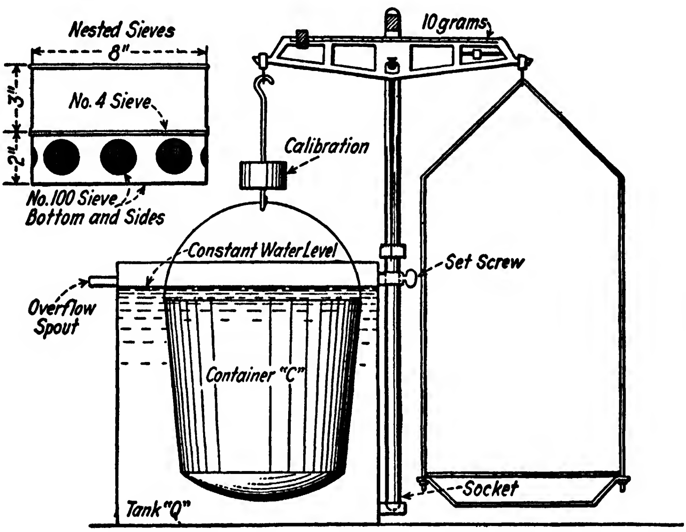

FIG. 1—test 16.—Dunagan apparatus for determining the buoyancy of materials in water.

5. *Calculation.*—Calculate the percentage of surface moisture from the formula:

$$w\% = \frac{(G - 1)W/G - W_s}{W_s} 100$$

where $w\%$ = percentage of surface moisture based on the saturated, surface-dry weight

G = specific gravity of aggregate, saturated, surface-dry basis

W = weight of the moist sample, g.

W_s = weight of the sample suspended in water, g.

Problems

1. Prove the formula for the percentage of surface moisture.
2. Prepare a series of curves on 20-to-the-inch coordinate paper, which will

give the percentages of surface moisture for a 1,000 g., moist-weight sample for a range of specific gravities from 2.20 to 2.80, in intervals of 0.10 specific gravity, and which will give percentages of surface moisture from zero to 10 per cent. Scales: abscissa 1 in. = 20 g. suspended weight, and ordinate 1 in. = 2 per cent surface moisture.

DATA RECORD—TEST 16

DETERMINATION OF THE SURFACE MOISTURE IN AGGREGATE
WEIGHT-IN-WATER METHOD

1. Material		
2. Date		
3. Weight of moist sample, W, g.		
4. Weight of sample suspended in water, W_s, g.		
5. Specific gravity of aggregate, S.S.D.		
6. Surface moisture, $w\%$		

TEST 17

DETERMINATION OF SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES

A.S.T.M. Designation: C 136-46

Purpose

1. To determine the particle-size distribution of fine and coarse aggregates, using sieves with square openings. The method is also applicable to the use of laboratory screens with round openings. It is not intended for use in the sieve analysis of aggregates recovered from bituminous mixtures or for the sieve analysis of mineral fillers.

Apparatus

Balance, sensitive to within 0.1 per cent of the weight of the sample

Set of sieves as may be necessary to check the specification requirements. The woven, wire-cloth sieves shall conform to the Standard Specifications for Sieves for Testing Purposes (A.S.T.M. Designation: E 11).

Drying oven to operate between 212 and 230°F.

Method

2. *Samples.*—Obtain samples for sieve analysis by quartering or by use of a sample splitter from a representative sample selected from the material to be tested. Fine aggregate sampled by the quartering method shall be thoroughly mixed and in a moist condition. The sample for test shall be approximately of the weight desired and shall be the end result of the sampling method. The selection of samples of an exact, predetermined weight shall not be attempted.

3. Samples of fine aggregate for sieve analysis shall weigh after drying approximately the amount indicated in the following table:

Material with at least 95 per cent finer than a No. 10 sieve.......... 100 g.
Material with at least 90 per cent finer than a No. 4 sieve and more than 5 per cent coarser than a No. 10 sieve...................... 500 g.

In no case, however, shall the fraction retained on any sieve at the completion of the sieving operation weigh more than 4 g. per sq. in. of sieving surface. This amounts to 200 g. for the usual 8-in. diameter sieve. The amount of material retained on the critical sieve may be regulated by: (1) the introduction of a sieve having larger openings than the critical sieve or (2) by the proper selection of the size of the sample.

4. Samples of coarse aggregate for sieve analysis shall weigh, after drying, not less than an amount indicated in the following table:

Maximum size of particle, in	*Minimum weight of sample, g.*
⅜	1,000
½	2,500
¾	5,000
1	10,000
1½	15,000
2	20,000
2½	25,000
3	30,000
3½	35,000

TABLE 1—NOMINAL SIEVE OPENINGS OF CERTAIN STANDARD SIEVES

Values given are taken from A.S.T.M. Standard Specifications for Sieves for Testing Purposes (Designation E 11). For additional information and values for other sieves, see A.S.T.M. Specification E 11.

Sieve designation	Sieve opening		Sieve designation, in.	Sieve opening	
	mm.	in.		mm.	in.
No. 200	0.074	0.0029	⅜	9.52	0.375
No. 100	0.149	0.0059	½	12.7	0.500
No. 50	0.297	0.0117	¾	19.1	0.750
No. 30	0.59	0.0232	1	25.4	1.000
No. 20	0.84	0.0331	1½	38.1	1.50
No. 16	1.19	0.0469	2	50.8	2.00
No. 10	2.00	0.0787	2½	63.5	2.50
No. 8	2.38	0.0937	3	76.2	3.00
No. 4	4.76	0.187	3½	88.9	3.50
No. 3	6.35	0.25	4	101.6	4.00

5. In the case of mixtures of fine and coarse aggregate separate the material into two sizes on the No. 4 sieve. Prepare the samples of fine and coarse aggregate as outlined above.

6. In the case of fine aggregate determine the amount of the material finer than the No. 200 sieve in accordance with Test 18.

7. *Preparation of Samples.*—Dry the samples to substantially constant weight at a temperature not exceeding 230°F.

8. *Testing.*—Separate the sample into a series of sizes, using such sieves as are necessary to determine compliance with the specifications for the material under test.

9. Conduct the sieving operation by means of a lateral and vertical motion, accompanied by jarring action so as to keep the sample moving continuously over the surface of the sieve. In no case shall fragments in the sample be turned or manipulated through the sieve by hand. Continue sieving until not more than 1 per cent by weight of the residue passes any sieve during 1 min.

10. On that portion of the sample retained on the No. 4 sieve, the above-described procedure for determining thoroughness of sieving shall be carried out with a single layer of material. When mechanical sieving is used, the thoroughness of sieving shall be tested by using the hand method of sieving as described above.

11. Determine the weight of each size on a scale or balance conforming to the requirement mentioned under apparatus.

12. *Reporting Results.*—Report percentages to the nearest whole number. Calculate percentages on the basis of the weight of the test sample, including any material finer than the No. 200 sieve.

13. Report the results of the sieve analysis as (1) total percentages passing each sieve or (2) total percentages retained on each sieve or (3) percentages retained between consecutive sieves, depending upon the form of the specifications for the use of the material under test.

14. *Curves.*—Plot sieve-analysis curves for all the samples tested showing the relationship between total per cent passing and the diameter of opening. Use the same axes and scales for all curves. Scale: ordinate 1 in. = 20 per cent passing; abscissa 1 in. = 0.2 in. diameter of opening. If average values for a number of classes are available, it is suggested that the average values be plotted rather than the ones from the different classes.

Questions

1. Are the sieves for this test to have round or square openings?

2. For the numbered sieves what does the number indicate? What is meant by the diameter of opening of a sieve?

3. Should the sample be weighed to a predetermined weight? Why?

4. What is the maximum weight of sample allowed on any sieve at the end of sieving? Why should there be a limit?

5. How are test results expressed? Which method is more commonly used?

6. What kind of a graph is often drawn, using the test results?

Data Record—Test 17

Sieve Analysis of Fine and Coarse Aggregates

1. Material ______________
2. Date ______________
3. Shaker used ______________
4. Time of shaking ______________
5. Weight of sample used ______________

Sieve designation	Total weight retained	Total per cent retained	Total per cent passing	Fractional values		
				Sieves		Per cent
				Passing	Retained	
						100

Data Record—Test 17

Sieve Analysis of Fine and Coarse Aggregates

1. Material ______________
2. Date ______________
3. Shaker used ______________
4. Time of shaking ______________
5. Weight of sample used ______________

Sieve designation	Total weight retained	Total per cent retained	Total per cent passing	Fractional values		
				Sieves		Per cent
				Passing	Retained	
						100

TEST 18

DETERMINATION OF THE AMOUNT OF MATERIAL FINER THAN No. 200 SIEVE IN AGGREGATES

A.S.T.M. Designation: C 117-37

Purpose

1. To determine the total quantity of material finer than a standard No. 200 sieve in aggregates.

Apparatus

No. 200 sieve
No. 16 sieve
Pan for washing sample
Balance, sensitive to 0.02 per cent of weight of test sample
Drying oven (to operate between 212 and 230°F.)

Method

2. *Test Sample.*—Select the sample from the thoroughly mixed material, which contains sufficient moisture to prevent segregation. Select a representative sample, sufficient to yield not less than the appropriate weight of dried material, as shown in the following table:

Nominal diameter of largest particle, in.	*Approximate minimum weight of sample, g.*
¼	500
¾	2,500
1½	5,000

3. *Testing.*—Dry the sample to a constant weight at a temperature not exceeding 230°F. Weigh sample to the nearest 0.02 per cent.

4. Place the sample in the container, and add sufficient water to cover it. Agitate the container vigorously, and pour wash water immediately over the nested sieves, arranged with the coarser sieve on top. The agitation should be sufficiently vigorous to result in the complete separation from coarse particles of all particles finer than the No. 200 sieve and to bring the fine material into suspension in order that it will be removed by decantation of the wash water. Avoid, as much as possible, the decantation of the coarse particles of the sample.

5. Repeat until the wash water is clear. Return all material on the nested sieves to the washed sample. Dry the washed aggregate to a constant weight at a temperature not to exceed 230°F. Weigh to the nearest 0.02 per cent.

6. *Calculation.*—Calculate the results from the following formula:

$$\text{Percentage of material finer than No. 200 seive} = \frac{\text{original dry weight} - \text{dry weight after washing}}{\text{original dry weight}}\ 100$$

7. *Check Determinations.*—When check determinations are desired, evaporate the wash water to dryness, or filter it through tared filter paper, which shall

subsequently be dried. Weigh the residue and calculate the percentage as follows:

$$\text{Percentage of material finer than No. 200 seive} = \frac{\text{weight of residue}}{\text{original dry weight}}\, 100$$

Questions

1. Why is it necessary to select the sample while it is still damp? What determines the weight of the sample to be used?
2. Why is it necessary to use water in connection with this sieving operation? What is the purpose of the No. 16 sieve?
3. How is the test-result value expressed?

DATA RECORD—TEST 18

AMOUNT OF MATERIAL FINER THAN NO. 200 SIEVE IN AGGREGATES

1. Material		
2. Date		
3. Nominal diameter of largest particle, in.		
4. Weight of dry sample, g.		
5. Weight of material after washing, g.		
6. Material finer than No. 200 sieve, g.		
7. Weight of residue from wash water, g.		
8. Material finer than No. 200 sieve, per cent		

TEST 19

DETERMINATION OF ORGANIC IMPURITIES IN SANDS FOR CONCRETE

A.S.T.M. Designation: C 40-33

Purpose

1. To determine the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sands are necessary before they are approved for use.

Apparatus

Two 12-oz., clear-glass graduated bottles (only one necessary when color chart is available.

Chemicals

120 ml. of 3 per cent solution of sodium hydroxide (NaOH) in water. Where chemically pure sodium hydroxide is not available, commercial soda lye may be used.

2.5 ml. of 2 per cent solution of tannic acid in 10 per cent alcohol (not necessary when color chart is available)

Method

2. Select a representative sample of 1 lb. by quartering or by use of a sample splitter. Fill one 12-oz. bottle to the 4½-oz. mark with sand. Add 3 per cent solution of sodium hydroxide until the volume of the sand and solution after shaking amounts to 7 oz. Shake thoroughly. Allow to stand 24 hr. Compare color of clear liquid above the sand with the standard color solution or with the color chart.

3. *Preparation of a Standard Color Solution.*—When a color chart is not available, a standard color solution may be made as follows: Add 2.5 ml. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 97.5 ml. of a 3 per cent solution of sodium hydroxide in water. Place the solution in the other 12-oz. bottle, stopper, and allow to stand for 24 hr.

4. Color charts or colored glasses are available and may be used in place of the solution. Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

Questions

1. What is the purpose of this test?
2. What should be done with an aggregate that shows a color darker than the standard color?

DATA RECORD—TEST 19

ORGANIC IMPURITIES IN SANDS FOR CONCRETE

1. Material		
2. Date		
3. Time sand is immersed in sodium hydroxide solution		
4. Comparison with standard color at end of 24 hr.		

TEST 20

DETERMINATION OF COAL AND LIGNITE IN SAND

A.S.T.M. Designation: C 123-44

Purpose

1. This method of test covers a procedure for the approximate determination of coal and lignite in the routine laboratory examination of sands. This method

separates along with the coal and lignite other particles of low specific gravity, such as small pieces of wood, vegetable matter, etc.

Apparatus

Balance, having a capacity of at least 200 g. and sensitive to 0.01 g.
Container suitable for drying the sand sample
Two, 400-ml. tall-form, lipped beakers
Wire gauze or a small piece of sieve, having about 30 openings per in.
Hot plate or oven to operate at 221°F.

Chemicals

250 ml. liquid having a specific gravity of 2.0. Such a liquid can be prepared from an appropriate mixture of carbon tetrachloride and acetylene tetrabromide or bromoform and monobromo-benzene.

Carbon tetrachloride

Method

2. Select a sample of moist sand, which will yield 200 g. of oven-dry sand. Dry to a constant weight at a temperature of approximately 221°F. Weigh out a 200-g. sample, to the nearest 0.01 g.

3. Place 250 ml. of the liquid having a specific gravity of 2.0 in one of the beakers. Pour the sand sample slowly into the liquid. Pour the liquid into the second beaker, passing it through the gauze or sieve. Take care that only the floating particles are poured off with the liquid and that none of the sand is decanted onto the gauze or sieve.

4. Return the liquid collected in the second beaker to the beaker containing the sand. Agitate the sample by stirring. Repeat the decanting process until the sample is free of floating particles.

5. Wash the decanted particles on the gauze or sieve in carbon tetrachloride until the flotation liquid is removed, and then dry. The particles will dry very quickly but may be placed in the oven at 221°F. for a few minutes if desired. Brush the particles from the gauze or sieve onto the balance pan, and weigh accurately to the nearest 0.01 g.

6. *Calculation.*—Calculate the approximate percentage of coal and lignite from the following formula:

$$\text{Coal and lignite, per cent} = \frac{\text{wt. of decanted particles}}{\text{wt. of dry sample (200 g.)}} 100$$

Questions

1. Is the specific gravity of coal and lignite lower or higher than that of the sand particles?
2. How are the coal and lignite particles separated from the sand particles?
3. How is the result of this test expressed?

DATA RECORD—TEST 20

DETERMINATION OF COAL AND LIGNITE IN SAND

1. Material		
2. Date		
3. Weight of original sample, dry, g.		
4. Weight of decanted material, dry, g.		
5. Coal and lignite, per cent		

TEST 21

DETERMINATION OF CLAY LUMPS IN AGGREGATE

A.S.T.M. Designation: C 142-39

Purpose

1. To determine approximately the clay lumps in aggregate.

Apparatus

Balance, sensitive to within 0.1 per cent of the weight of sample to be weighed

Containers of a size and shape that will permit the spreading of the sample on the bottom in a thin layer

Sieves as may be necessary

Sample splitter

Method

2. *Samples.*—Obtain samples by quartering or by the use of the sample splitter from a representative sample selected from the material to be tested. Handle samples in such a manner as to avoid breaking the clay lumps which may be present.

3. Dry samples to substantially constant weight at a temperature not exceeding 230°F.

4. Samples of fine aggregate shall consist of particles coarser than a No. 16 sieve and shall weigh not less than 100 g.

5. Samples of coarse aggregate shall be separated into different sizes using the following sieves: No. 4, 3/8 in., 3/4 in., and 1 1/2 in. The weight of sample for the different sizes shall be not less than indicated in the following table:

Size of particles making up sample, in.	*Weight of sample, minimum, g.*
No. 4 to 3/8 in.	1,000
3/8 in. to 3/4 in.	2,000
3/4 in. to 1 1/2 in.	3,000
Over 1 1/2 in.	5,000

6. In case of mixtures of fine and coarse aggregates, separate the material into two sizes on the No. 4 sieve. Prepare the samples of fine and coarse aggregates in accordance with paragraphs 4 and 5.

7. *Testing.*—Spread the sample in a thin layer on the bottom of the container, and examine for clay lumps. Any particles which can be broken into finely divided particles with the fingers shall be classed as clay lumps. After all discernible clay lumps have been broken, remove the residue from the clay lumps by use of the sieves indicated in the following table:

Size of particles making up the sample	*Size of sieve for sieving residue of clay lumps*
Fine aggregate	No. 20
No. 4 to 3/8 in	8
3/8 in. to 3/4 in	4
3/4 in. to 1 1/2 in	4
Over 1 1/2 in	4

8. *Calculation.*—Calculate the percentage of clay lumps to the nearest 0.1 per cent in accordance with the following formula:

$$\text{Percentage clay lumps} = \frac{W - W_r}{W} 100$$

where W = weight of sample, g.
W_r = weight of sample after removal of clay lumps, g.

DATA RECORD—TEST 21

DETERMINATION OF CLAY LUMPS IN AGGREGATE

1. Material	
2. Date	
3. Weight of fine-aggregate sample, W, g.	
4. Weight of residue, W_r, g.	
5. Clay lumps, per cent	
6. Material	
7. Coarse aggregate sample, No. 4 to 3/8 in., g.	
8. Coarse aggregate sample, 3/8 to 3/4 in., g.	
9. Coarse aggregate sample 3/4 to 1 1/2 in., g.	
10. Coarse aggregate sample over 1 1/2 in., g.	
11. Total coarse aggregate sample, W, g.	
12. Total weight of residue, W_r, g.	
13. Clay lumps, per cent	

Questions

1. What is the size of the sample for fine aggregate? What are the size restrictions on the particles?
2. What determines the amount of coarse aggregate in the test sample?
3. How is the amount of the clay lumps determined?
4. How is the test value given?

TEST 22

MEASURING THE MORTAR-MAKING PROPERTIES OF FINE AGGREGATE

A.S.T.M. Designation: C 87-47

Purpose

1. To measure the mortar-making properties of fine aggregate for concrete by means of a compression test on specimens made from a mortar of plastic consistency and gauged to a definite water-cement ratio. Its principal use is intended for the determination of the effect of organic impurities revealed by the colorimetric test.

2. The fine aggregate under test is compared, in mortar as described in this test method, with graded standard sand having a fineness modulus of 2.40 ± 0.10. The graded sand consists of a mixture of approximately equal parts by weight of standard Ottawa sand (see Test 6) and graded Ottawa sand (see Test 7).

3. The procedure outlined in the A.S.T.M. specification indicates only how to prepare the batches of mortar and how to make and test the specimens. No mention is made of the number of test specimens to be made nor the age or ages at testing. Either 2-in. cubes or 2- by 4-in. cylinders may be made. It is suggested that six specimens be made using the fine aggregate under consideration and six specimens using the graded standard sand and that half be tested at 7 days and half at 28 days.

Apparatus

Graduate or burette
Large iron kitchen spoon
Mixing pan, 4-qt. capacity, 9½ in. in diameter at the top and 4½ in. in height
⅜-in. tamping rod
2- by 4-in. cylinder molds or 2-in. cube molds
Moist closet
Water storage tank
Testing machine

Flow table, consisting of a circular bronze plate 10 in. in diameter, so mounted that the surface is level, and equipped with a mechanism for raising the plate ½ in. and allowing it to fall without cushioning. A right truncated cone, 2¾ in. in diameter at the top, 4 in. in diameter at the bottom, and 2 in. in height, shall be used to measure the volume of the mortar for the test. The flow table with the attached shaft shall weigh 9 ± 1 lb. The frame of the table shall be attached rigidly to a concrete pedestal, which in turn shall be attached rigidly to the floor. The concrete pedestal shall be at least 8 in. in diameter, 25 in. in height, and shall weigh at least 100 lb.

Method

4. *Preparation of Graded Standard Sand.*—If six cubical specimens are to be made, prepare 2,000 g. of graded standard sand. If six cylindrical specimens are to be made, the amount should be 3,000 g. Weigh out equal amounts of standard Ottawa sand and graded Ottawa sand. Mix thoroughly and make a sieve analysis, as outlined in Test 17, using sieves Nos. 100, 50, 30, 16, 8, and 4. Compute the fineness modulus. If the value does not lie within the range 2.3 to 2.5, adjust the mixture until the desired fineness modulus is secured.

5. *Preparation of Aggregate in Saturated, Surface-Dry Condition.*—Both the fine aggregate under consideration and the graded standard sand must be in a saturated, surface-dry condition, as required for the specific-gravity determination (see Test 10) when they are mixed into the mortar. After soaking the samples for 24 hr., remove from the water, and dry as outlined in Test 10, paragraph 6. When the samples have just reached the surface-dry stage, they are ready to be made into mortar under paragraph 10.

6. *Temperature.*—The temperature of the mixing water, moist closet, and storage tank shall be maintained between 65 and 75°F.

7. *Preparation of Mortar.*—Both batches of mortar are prepared in the same manner. It is suggested that the one using graded standard sand be made first.

8. The weight of water used is always 0.6 of the weight of the cement. Cement weighing 600 g., and 360 g. of water will normally be sufficient to produce six 2-in. cubes. These amounts should be increased 50 per cent if the specimens are to be 2- by 4-in. cylinders.

9. Place the cement and water in the mixing pan and permit the cement to absorb the water for 1 min. Mix the materials into a smooth paste with the spoon.

10. Weigh the quantity of saturated, surface-dry sand which has been prepared. Add sand from this weighed supply to the cement paste in the mixing pan, beating it into the mixture until the mortar appears to be of the desired consistency (flow 100 ± 5). Continue the mixing for 30 sec. and determine the flow as outlined in paragraph 11.

11. *Flow Test.*—Center the cone on the flow table, and fill immediately with mortar. Rod the mortar 25 times with the ⅜-in. rod, strike off the surplus, wipe the top clean, remove the cone, and give the table 10 drops in 10 sec. Measure the diameter of the pat on two diameters at right angles to each other. The increase in diameter, expressed as a percentage of the original diameter, is the flow value. The desired flow value is 100 ± 5.

12. Should the flow value be too great, return the mortar to the mixing pan, add sand, mix thoroughly, and determine the flow value. If too dry, discard the batch. If the second flow value is not within the range desired, discard the batch.

13. Determine the quantity of sand used by weighing portion remaining and subtracting that value from the original weight.

14. *Molding Specimens.*—Mold the test specimens immediately following the securing of a satisfactory flow value. Fill the cylinder molds in three increments and the cubes in 2 increments, rodding each increment with 25 strokes of the $\frac{3}{8}$-in. rod. Fill the molds to overflowing.

15. Place the specimens in the moist closet for curing. Three to four hours after molding strike off the specimens to a smooth surface. Remove the specimens from the molds 20 to 24 hr. after molding, and store in water until tested.

16. *Capping Specimens.*—If the specimens are cylindrical, cap before testing

TEST 22

MEASURING THE MORTAR-MAKING PROPERTIES OF FINE AGGREGATE

1. Material						
2. Date						
3. Air temperature						
4. Brand of cement						
5. Weight of cement used						
6. Weight of water used						
7. Type of specimen made						
			Graded standard sand batch		Test sand batch	
8. Weight of sand used						
9. Flow-test value						
	Age	Specimen number	Total load, lb.	Unit load, lb. per sq. in.	Total load, lb.	Unit load, lb. per sq. in.
10. Test results	7 days	1				
		2				
		3				
		Average				
	28 days	1				
		2				
		3				
		Average				

in such a manner that the ends are perfectly plane and at right angles to the axis of the cylinder. The material used for capping and the thickness of the cap shall be such that it will not flow or fracture under the load. Cubes made in suitable molds need not be capped and shall be tested at right angles to the direction of molding.

17. *Testing Specimens.*—Test three specimens of each kind at 7 days and three more at 28 days, in accordance with provisions for the test for hydraulic-cement mortars (A.S.T.M. Designation: C 109), Test 7 in this book.

Questions

1. What is the principal use for this test?
2. How are the mortar-making properties of fine aggregate determined? (Answer in a single sentence.)
3. What is meant by a graded standard sand? What shape test specimens may be made?
4. What is the required condition concerning the aggregate as far as dryness is concerned?
5. What is the requirement concerning amounts of cement and water? How is the amount of the aggregate determined?
6. Describe the flow test. What flow value is required for the mortar?
7. What are the requirements concerning (*a*) molding the specimens? (*b*) storing the specimens? (*c*) capping the specimens? (*d*) curing the specimens? (*e*) testing the specimens?

TEST 23

DETERMINATION OF THE SOUNDNESS OF AGGREGATES BY USE OF SODIUM SULFATE OR MAGNESIUM SULFATE

A.S.T.M. Designation: C 88-46*T*

Purpose

1. This method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of sodium sulfate or magnesium sulfate. It furnishes information helpful in judging the soundness of aggregates subject to weathering action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions. Attention is called to the fact that test results by the use of the two salts differ considerably, and care must be exercised in fixing proper limits in any specifications which may include requirements for these tests.

Apparatus

Sieves as may be needed from the following list: Nos. 100, 50, 30, 16, 8, 4, ⅜-in., ¾-in., 1½-in., 2½-in.

Containers for immersing samples [1]

[1] See A.S.T.M. specification for further details.

Balances: for fine aggregate capacity not less than 500 g. and sensitive to 0.1 g.; for coarse aggregate capacity not less than 5,000 g. and sensitive to 1.0 g.

Drying oven maintaining temperature between 221 and 230°F.

Hydrometers for use in the ranges 1.151 to 1.174 and 1.295 to 1.308

Special Solutions

2. *Sodium Sulfate Solution.*—Prepare the saturated, sodium sulfate solution by dissolving a chemically pure, U.S.P., or equal grade of the salt in water, at a temperature of 77 to 86°F. Sufficient salt of either the anhydrous (Na_2SO_4) or the crystalline ($Na_2SO_4 \cdot 10H_2O$) form shall be added to ensure not only saturation but also the presence of excess crystals when the solution is ready for use in the tests.

3. Experience with the test method indicates that a grade of sodium sulfate designated by the trade as dried powder, which may be considered as approximately anhydrous, is the most practical to use. That grade is more economically available than the anhydrous form. The decahydrate sodium sulfate presents difficulties in compounding the required solution on account of its cooling effect on the solution.

4. For the solution, 215 g. of anhydrous salt or 700 g. of the decahydrate per liter of water are sufficient for saturation at 72°F. However, since the salts are not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 350 g. of the anhydrous salt or 750 g. of the decahydrate salt per liter of water is recommended.

5. Stir the mixture thoroughly during the addition of the salt and at frequent intervals until used. Cool the solution to a temperature of 70 ± 2°F., and maintain it at that temperature for at least 48 hr. before use. Stir thoroughly immediately before use. Check the specific gravity of the solution with a hydrometer. The solution must have a specific-gravity value between 1.151 and 1.174.

6. *Magnesium Sulfate Solution.*—Prepare the saturated magnesium sulfate solution by dissolving a chemically pure, U.S.P., or equal grade of the salt in water at a temperature of 77 to 86°F. Sufficient salt of either the anhydrous ($MgSO_4$) form or the crystalline ($MgSO_4 \cdot 7H_2O$) (Epsom Salt) form shall be added to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests.

7. For the solution, 350 g. of anhydrous salt or 1,230 g. of the heptahydrate per liter of water are sufficient for saturation at 73°F. However, since these salts are not completely stable, with the hydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1,400 g. per l. of water.

8. Stir the mixture thoroughly during the addition of the salt, and stir at frequent intervals until used. Cool the solution to a temperature of 70 ± 2°F., and maintain it at that temperature for at least 48 hr. before use. Stir thoroughly immediately before using. Check the specific gravity of the solution

with a hydrometer. The solution must have a specific-gravity value between 1.295 and 1.308.

Method

9. *Fine-aggregate Sample.*—Fine aggregate for the test shall be passed through a 3/8-in. sieve. The sample shall be of such size that it will yield not less than 100 g. of each of the following sizes, which shall be available in amounts of 5 per cent or more, expressed in terms of the following sieves:

Passing No. 30, retained No. 50
Passing No. 16, retained No. 30
Passing No. 8, retained No. 16
Passing No. 4, retained No. 8
Passing 3/8-in., retained No. 4

10. *Coarse-aggregate Sample.*—Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 sieve have been removed. Such sizes shall be tested in accordance with the procedure for fine aggregate. The sample shall be of such size that it will yield not less than the following amounts of the different sizes, which shall be available in amounts of 5 per cent or more:

Size	
No. 4 to 3/8 in.	300 g.
3/8 to 3/4 in.	1,000 g.
3/8 to 1/2 in. material	33 per cent
1/2 to 3/4 in. material	67 per cent
3/4 to 1 1/2 in.	1,500 g.
3/4 to 1 in. material	33 per cent
1 to 1 1/2 in. material	67 per cent
1 1/2 to 2 1/2 in.	3,000 g.
1 1/2 to 2 in. material	50 per cent
2 to 2 1/2 in. material	50 per cent
Larger sizes by 1-in. spread in sieve size, each fraction	3,000 g.

11. *Alternate A.*—If the grading of the sample makes the following sizes more appropriate, they may be used:

Size	
No. 4 to 1/2 in.	300 g.
1/2 to 1 in.	1,500 g.
1/2 to 3/4 in. material	33 per cent
3/4 to 1 in. material	67 per cent
1 to 2 in.	3,000 g.
1 to 1 1/2 in. material	50 per cent
1 1/2 to 2 in. material	50 per cent
Larger sizes by 1-in. spread in sieve size, each fraction	3,000 g.

12. *Alternate B.*—When it is desired to test coarse aggregate in narrower size ranges than provided above, the following sizes may be used:

Size	
No. 4 to 3/8 in	300 g.
3/8 to 1/2 in	500 g.
1/2 to 3/4 in	750 g.
3/4 to 1 in	1,000 g.
1 to 1 1/2 in	1,500 g.
1 1/2 to 2 in	2,000 g.
Larger sizes by 1-in. spread in sieve size, each fraction	3,000 g.

13. It should be noted that testing closely sized aggregates such as these constitutes a more severe test than testing a graded aggregate, and this fact should be taken into account in establishing limits in writing specifications.

14. *Samples Deficient in Sizes.*—Should samples contain less than 5 per cent of any of the sizes specified, that size shall not be tested; but for the purpose of calculating the test results, it shall be considered to have the same loss in sodium sulfate or magnesium sulfate treatment as the average of the next smaller and the next larger size; or if one of these sizes is absent, it shall be considered to have the same loss as the next larger or next smaller size, whichever is present.

15. *Preparation of Test Sample. Fine Aggregate.*—Wash the sample of fine aggregate on a No. 50 sieve, dry to a constant weight at 221 to 230°F., and separate into the different sizes by sieving, as follows:

16. Make a rough separation of the graded sample by means of a nest of the standard sieves listed in paragraph 9 above. From the fractions obtained in this manner select samples of sufficient size to yield 100 g. after sieving to refusal. In general a 110-g. sample will be sufficient. Fine aggregate sticking in the meshes of the sieves shall not be used in preparing the samples.

17. Weigh out samples consisting of 100 g. of each of the separated fractions after final sieving, and place in separate containers for the test.

18. *Coarse Aggregate.*—Wash thoroughly the sample of coarse aggregate, dry to a constant weight at 221 to 230°F., and separate into the different sizes shown in paragraph 10 by sieving to refusal. Weigh out the proper weight of sample for each fraction and place in separate containers for the test. In the case of fractions coarser than the 3/4-in. sieve, count the number of particles.

19. *Ledge Rock.*—For testing ledge rock, prepare the same by breaking it into fragments reasonably uniform in size and shape and weighing approximately 100 g. each. The test sample shall weigh 5,000 g. ± 2 per cent. Wash the sample thoroughly and dry previous to test as described in paragraph 18.

20. *Storage of Samples in Solution.*—Immerse the samples in the prepared solution of sodium sulfate or magnesium sulfate for not less than 16 nor more than 18 hr. in such a manner that the solution covers them to a depth of at least 1/2 in. Suitably weighted wire grids placed over the sample in the containers will permit this coverage to be achieved with very lightweight aggregates.

Cover the containers to reduce evaporation and to prevent the accidental addition of extraneous substances. The samples immersed in the solution shall be maintained at a temperature of 70 ± 2°F. for the immersion period.

21. *Drying Samples after Immersion.*—After the immersion period remove the aggregate sample from the solution, permit it to drain, and place in drying oven which has been previously brought to a temperature of 221 to 230°F. Exercise care to avoid loss of any of the aggregate particles or, in the case of fine aggregate, of any detritus coarser than a No. 100 sieve. In the case of coarse aggregate the detritus should also be saved if the complete analysis suggested in paragraph 26 is made.

22. Dry the samples to a constant weight at the specified temperature. After drying, cool the samples to room temperature and then immerse again in the prepared solution.

23. *Number of Cycles.*—The process of alternate immersion and drying shall be repeated until the required number of cycles is obtained.

24. *Quantitative Examination.*—Make the quantitative examination as follows: After the completion of the final cycle and after the sample has cooled, wash the sample free from the sodium sulfate or magnesium sulfate, as determined by the reaction of the wash water with barium chloride.

25. After the sodium sulfate or magnesium sulfate solution has been removed, dry each fraction of the sample to a constant weight at 221 to 230°F. and weigh. Except in the case of ledge rock, sieve each sample over the same sieve on which it was retained before the test. Weigh the particles retained on this sieve and record weight.

26. *Note.*—In addition to the procedure described in paragraphs 24 and 25, it is suggested that additional information of value will be obtained by examining each fraction visually in order to determine whether there is any evidence of excessive splitting of the grains. It is suggested also that additional information of value will be obtained if, after treating each separate fraction of the sample as described in paragraph 25, all sizes, including detritus, are combined and a sieve analysis made using a complete set of sieves for the determination of the fineness modulus. The results of the sieve analysis should be recorded as cumulative percentages retained on each sieve.

27. *Alternative Procedure.*—After the sodium sulfate or magnesium sulfate solution has been removed, dry each fraction to a constant weight at 221 to 230°F. and weigh. Except in the case of ledge rock, sieve each fraction over a sieve having square openings one-half the size of the sieve on which the material was originally retained. Weigh the particles retained on these sieves and record the weight.

28. *Ledge Rock.*—In the case of ledge rock determine the loss in weight by subtracting from the original weight of the sample the final weight of all fragments which have not broken into three or more pieces.

29. *Qualitative Examination.*—Examine fractions of samples coarser than ¾ in. qualitatively after each immersion and quantitatively at the completion of the test.

30. The qualitative examination and record shall consist of two parts: (1) observing the effect of the action by the sodium sulfate or magnesium sulfate solution and the nature of the action and (2) counting the number of particles affected.

31. NOTE.—Many types of action may be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc. While only particles larger than ¾ in. in size are required to be examined qualitatively, it is recommended that examination of the smaller sizes be made in order to determine whether there is any evidence of excessive splitting.

32. *Report.*—The report shall include the following:

a. Weight of each fraction of each sample before test.

b. Except in the case of ledge rock, material from each fraction of the sample,

DATA RECORD—TEST 23

SOUNDNESS OF AGGREGATE BY USE OF SODIUM OR MAGNESIUM SULFATE

Sieve size		Grading of original sample, per cent	Weight of test fractions before test, g.	Weight of test fractions after test, g.	Percentage passing finer sieve after test (actual percentage loss)	Weighted average (corrected percentage loss)
Passing	Retained					
No. 100						
No. 50	No. 100					
No. 30	No. 50					
No. 16	No. 30					
No. 8	No. 16					
No. 4	No. 8					
⅜-in.	No. 4					
Totals		100.0				

Soundness Test for Coarse Aggregate

2½ in.	1½ in.					
1½ in.	¾ in.					
¾ in.	⅜ in.					
⅜ in.	No. 4					
Totals		100.0				

finer than the sieve on which the fraction was retained before test, expressed as percentage by weight of the fraction.

c. Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative. In these calculations sizes finer than the No. 50 sieve shall be assumed to have 0 per cent loss.

d. In the case of the particles coarser than ¾ in. before test: (1) the number of particles in each fraction before test, and (2) the number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

e. In the case of ledge rock: (1) the percentage of loss calculated as described in paragraph 28 and (2) the number of pieces affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc.

f. Character of solution (sodium or magnesium sulfate).

Questions

1. What differences are there in the solubility characteristics of the two salts? Might different, soundness-test results be expected with the two salts on the same aggregate?
2. What is meant by a cycle? In which part of the cycle does the disintegration take place?
3. How are the soundness-test results expressed?

TEST 24

DETERMINATION OF THE AIR CONTENT OF PORTLAND-CEMENT MORTAR

A.S.T.M. Designation: C 185-47T

Purpose

1. To determine the air content of portland-cement mortar, for use in controlling the amount of air-entraining agent added to portland cement to produce air-entraining portland cement.

Apparatus

Cylindrical measure, 500-ml. capacity[1]
Tamping rod, ¼ in. in diameter, 10 in. in length[1]
Steel straightedge, not over ¼ in. in thickness
6-in. metal spatula with straight edges
Scales, capacity 2 kg., accurate to 1 g.
Mixing bowl, 5- to 7-qt. capacity, flat bottom[1]
Sieves, Nos. 20 and 30
Glass graduate, 250-ml. capacity[1]
Burmister flow trough[1]
Snug-fitting rubber glove for one hand

[1] See A.S.T.M. specification for greater detail.

Method

2. *Temperature.*—The temperature of the room and dry materials shall be maintained between 68 and 81.5°F. The temperature of the mixing water shall not vary from 70° ± 3°F.

3. *Standard Sand.*—The sand used for making the standard mortar shall be natural silica sand from Ottawa, Ill., graded to pass a No. 20 sieve and be retained on a No. 30 sieve. This sand shall be considered standard when not more than 15 g. are retained on the No. 20 sieve and not more than 5 g. pass the No. 30 sieve after 5 min. of continuous sieving of a 100-g. sample in the manner specified for sieving cement, Test 2.

4. *Calibration of Measure.*—Clean, dry, and weigh the measure together with a piece of plate glass large enough to cover the open end of the measure. Fill the measure with distilled water at 70°F. to a point where the meniscus extends appreciably above the top of the measure. Place the glass plate on the top of the measure, allowing excess water to be squeezed out. The absence of air bubbles as seen through the glass plate ensures that the measure is completely full. Wipe the excess water from the sides of the measure, and weigh. Divide the weight of water in the measure, in grams, by 0.998 to secure the volume in milliliters.

5. *Batch.*—The amounts of cement and standard sand to be used in making the standard mortar are 300 g. and 1,200 g., respectively. The amount of water is determined by the Burmister flow trough. The flow value must be between 2.4 and 2.9 in. The amount of water must be a multiple of 4 ml. For the first trial the amount of water must be estimated.

6. *Mixing.*—The mixing is to be done in a bowl by vigorous and continuous stirring, squeezing, and kneading with one hand, which is protected by a snug-fitting rubber glove.

7. Wipe the inside of the mixing bowl with a damp cloth or damp sponge. Place the water in the bowl. Add the cement to the water and mix for 30 sec.

8. Add approximately one-half the sand and mix for 30 sec. Add the remainder of the sand and mix for 1 min. Allow the mortar to stand for 1½ min., covered with a damp cloth. Mix for 1 min. more.

9. *Flow Determination.*—If the flow trough is not dry, dry it. Put the gate in place and support in a horizontal position. Fill the trough between the gate and the closed end with mortar in two layers, puddling each layer 15 times with the gloved forefinger of one hand. Cover the remaining mortar of the batch in the bowl with a damp cloth. Exercise care in placing the mortar under the sloping gate and at the back end of the trough.

10. Immediately after completion of puddling the last layer and before smoothing off the surface, tap lightly the closed end of the trough twice on each side with the handle of the spatula to prevent the mortar from sliding and breaking away from the closed end during the flow determination. Place the flat side of the spatula blade across the trough just behind the gate, with the length of the blade at right angles to the length of the trough. Smooth off the mortar

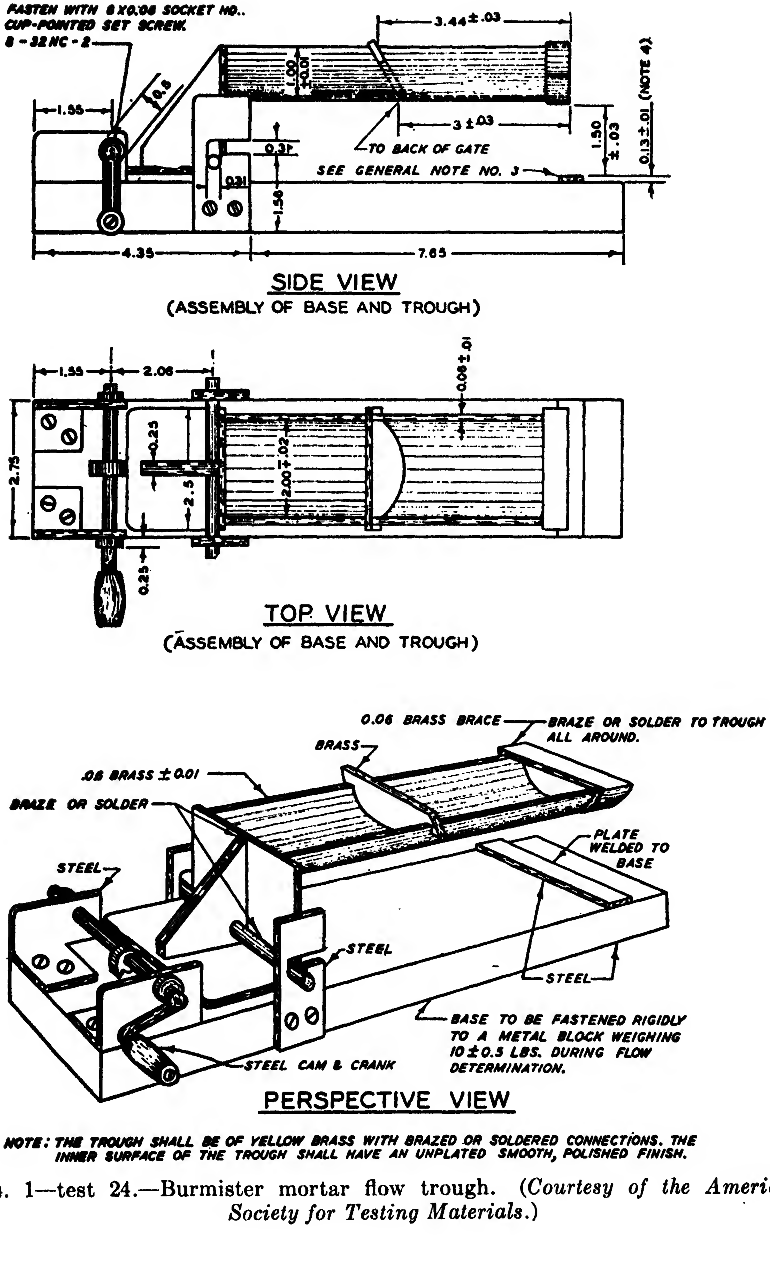

FIG. 1—test 24.—Burmister mortar flow trough. (*Courtesy of the American Society for Testing Materials.*)

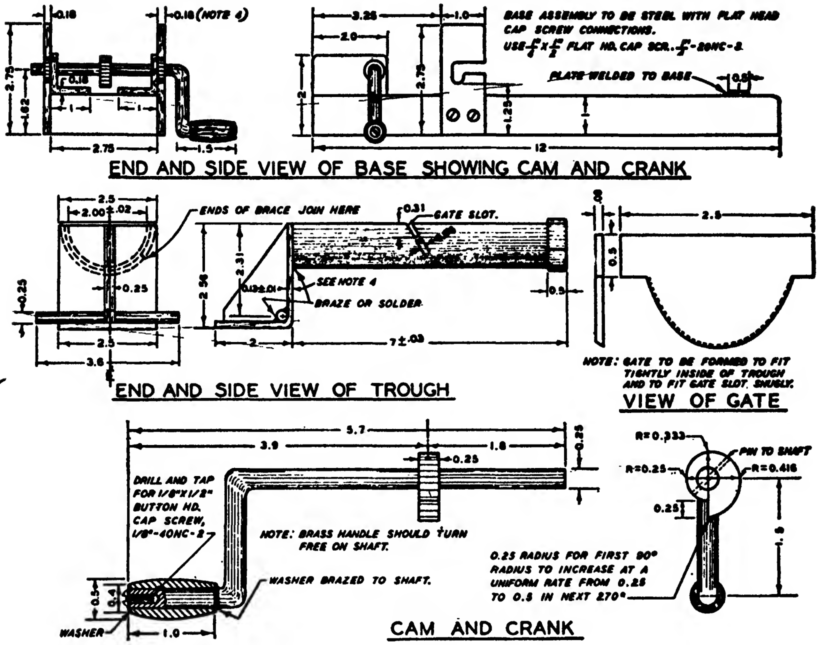

FIG. 1 (*Cont.*)—Burmister mortar flow trough. (*Courtesy of the American Society for Testing Materials.*)

by drawing the spatula blade with its leading edge slightly raised to the closed end of the trough in a single stroke. Cut off the mortar to a level surface flush with the top of the trough by drawing the straight edge of the spatula with a sawing motion over the trough from the gate to the back end.

11. Care shall be taken that the surface of the trough from the gate to the open end is clean and dry. If seepage under the gate has occurred, it shall be removed with a dry, absorbent cloth.

12. NOTE.—It is essential to the smooth operation of the trough and height of drop that the contact surface of the cam and heel plate of the trough, and the pivotal shaft and its side seats be kept clean and free of grit. Contamination of these surfaces due to striking off excess mortar and other operations shall be prevented by suitable, removable covers of metal or cloth.

13. Remove the gate by lifting one side in a hinge motion, using the other side as a pivot. Allow the free end of the trough to drop under its own weight. Raise again the free end until the trough is horizontal, and allow trough to drop. Make ten drops at the rate of 1 drop per sec. Measure the flow to the nearest 0.1 in. by means of a suitable scale. The flow value is the difference between 3 in. and the distance from the toe of the slope of the mortar to the open end of the trough.

14. The operation of raising and dropping the free end of the flow trough shall be started immediately after removing the gate and not more than 45 sec. after the completion of mixing. Each determination of flow shall be made on a fresh portion of material from the same or a new batch. When the flow is not within the required range, a new batch shall be made with an adjusted water content.

15. *Weight per 500 ml. of Mortar.*—Clean, dry, and weigh the empty 500-ml. measure.

16. When the quantity of mixing water has been found that produces a flow between 2.4 and 2.9 in., the weight of 500 ml. of mortar shall be determined immediately, using the mortar remaining in the mixing bowl after the flow has been determined. The portion of the mortar used in the flow determination shall not be used in the determination of the weight per 500 ml.

17. Place the mortar in the 500-ml. measure in three, equal layers, rodding each layer 15 times with the tamping rod, taking care to penetrate only the surface of the layer previously placed. Spade thoroughly each layer with the spatula around the inner surface of the measure to remove all rod holes and to consolidate the mortar adhering to the inner surface of the measure. Care shall be taken that no rod holes are left in the mortar and that no additional holes are introduced by the spading operation.

18. Strike off the excess mortar with a steel straightedge flush with the top of the measure, making two passes over the entire surface. Make the second pass at right angles to the first. Take care in the striking-off operation that no loose sand grains cause the straightedge to ride above the top surface of the measure.

19. The entire operation of filling and striking off the measure shall be accomplished in 1½ min. Wipe off all mortar and water adhering to the outside of the measure. Weigh the measure and contents. The weight of the contents of the measure is the weight W in the formula.

20. *Calculations.*—Calculate the air content of the mortar from the following formula, which is based on the batch proportions given in paragraph 5, a specific-gravity value of 3.15 for the cement and 2.65 for the standard sand:

$$\text{Air content, per cent} = 100 - 2W\frac{(182.7 + P)}{5{,}000 + 10P}$$

where W = weight of 500 ml. of mortar, g.

P = percentage of mixing water, based on the weight of the cement

21. *Reproducibility.*—Make duplicate determinations of the air content by this method on separate batches. The average value obtained shall be reported. Values for percentage of air content obtained in the test should not differ from the average by more than 1 per cent.

Questions

1. What is the purpose of the test?
2. What is meant by standard sand? Why use it rather than any sand that might be available locally?

3. Which of these materials have their quantities fixed by the specification: cement, water, or standard sand? How is the quantity of the other material determined?

4. Why is use of the mortar in the flow test prohibited when making the air-content measurement?

5. How is the test value expressed?

DATA RECORD—TEST 24

AIR CONTENT OF PORTLAND-CEMENT MORTAR

1. Material		
2. Date		
3. Weight of measure, glass plate, and water, g.		
4. Weight of measure and glass plate, g.		
5. Weight of water to fill measure, g.		
6. Volume of measure, ml.		
7. Weight of cement used in batch, g.		
8. Weight of standard sand used in batch, g.		
9. Weight of water used in batch, g.		
10. Percentage of water used, *P*		
11. Flow value, in.		
12. Weight of measure full of mortar, g.		
13. Weight of measure, g.		
14. Weight of mortar in measure, *W*, g.		
15. Per cent air in mortar		
16. Average of two determinations		

TEST 25

DETERMINATION OF AIR CONTENT OF CONCRETE—PRESSURE METHOD

Purpose

1. To determine the air content of freshly made concrete, expressed as a percentage of the volume of the concrete.

Apparatus

Pressure-type apparatus (to be called air meter)
Shovel or scoop

Method

2. *Correction for Air Held in Aggregates.*—Air in the pores of the aggregates does not count as entrained air in concrete. The air in the aggregates is included in the air content of the concrete as measured by the air meter. It is customary to make tests on the aggregates individually first to determine the correction factor to be applied.

3. The amounts of fine and coarse aggregates to be used in making the correction-factor determination for each should be the same as will be in the concrete in the bowl of the air meter when the air content of the concrete is determined. Estimate the amount of each material that will be in a cubic yard of

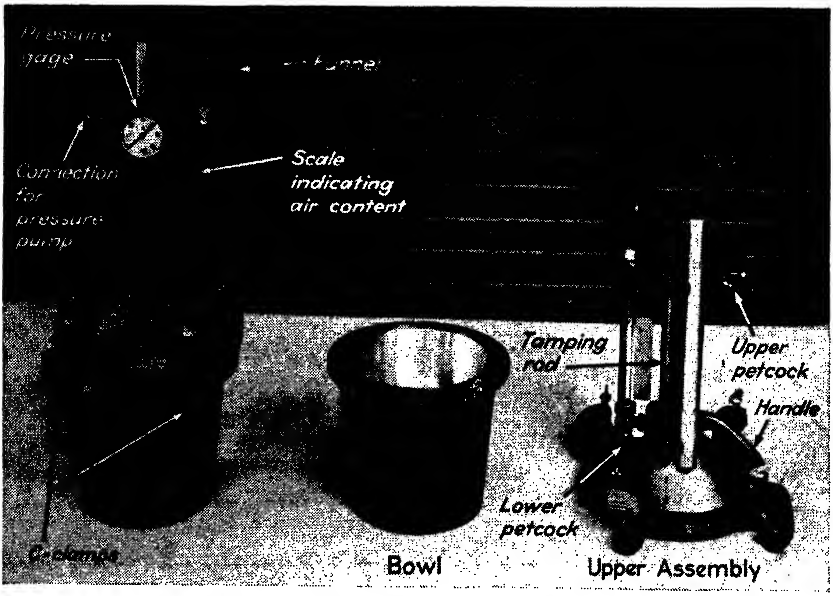

Fig. 1—test 25.—The Klein pressure-type air meter as designed and built by the Illinois Division of Highways. (*Courtesy of Illinois Division of Highways.*)

concrete, and compute the corresponding amounts for a volume equal to the volume of the bowl of the air meter. If it is found later that these amounts are in error, a second determination can be made or the original values corrected on a proportional basis.

4. Weigh out the amount of fine aggregate figured above. Fill the bowl about half full of water. Place the fine aggregate in the bowl and stir vigorously by hand to remove air around and between the particles. Fill the bowl with water. Clean contact surfaces between bowl and upper assembly. Clamp upper assembly to bowl, fill with water to arrow (or zero) mark, apply the pressure for which the air meter is calibrated. Read on the scale the per cent air in the sand.

5. Repeat for the coarse aggregate. The correction factor for the total aggregate is the sum of the two factors.

6. *Determination on Concrete.*—Fill the bowl with concrete in three equal increments, rodding each increment 25 times with the ⅝-in. rod. Strike off the concrete even with the top of the bowl. Clean the contact surfaces between the bowl and upper assembly. Clamp upper assembly tightly to the bowl.

7. Close the lower pet cock and open upper pet cock and funnel valve. Pour water through the funnel until the water stands at a level slightly above the arrow (zero) mark on the graduated scale. Close the funnel valve and adjust the water level to the arrow (zero) mark by means of the lower pet cock.

8. Close the upper pet cock, and apply pressure with the air pump until the gauge reads exactly the pressure for which the air-meter scale is graduated. Read the air content of the concrete on the graduated scale, as indicated by the new water level. Subtract the correction factor for the aggregate to secure the entrained-air content of the concrete.

DATA RECORD—TEST 25

AIR CONTENT OF CONCRETE—PRESSURE METHOD

1. Material	
2. Date	

Correction Factor for Aggregate

3. Volume of air meter bowl, cu. ft.	
4. Assumed weight of fine aggregate per cu. yd. of concrete, lb.	
5. Assumed weight of coarse aggregate per cu. yd. of concrete, lb.	
6. Weight of fine aggregate for use in factor determination, lb.	
7. Weight of coarse aggregate for use in factor determination, lb.	
8. Air content of fine aggregate, per cent	
9. Air content of coarse aggregate, per cent	
10. Correction factor for total aggregate, per cent	

Air Content of Concrete

11. Air-meter reading, per cent	
12. Entrained-air content of concrete, per cent	

9. Release the air pressure by opening the upper pet cock. The water level now should rise to the zero mark of the scale, or to some mark below the zero if there is no arrow mark above the zero. For most of the outfits there is a small difference in the water levels before and after the pressure has been applied. This is assumed to be an adjustment in the equipment under pressure. The air content is taken to be the difference between this final reading and the value secured when the air pressure is applied. If no arrow mark is placed above the zero, there will always be a slight, additional correction to be applied. It can be combined with the factor for the aggregate for simplicity of application.

10. *Calculation.*—No calculation is necessary other than the application of the correction factor mentioned above.

Questions

1. Explain briefly the general idea of determining air content of concrete with this type of apparatus. Is water considered to be incompressible?
2. Does air inside the particles of aggregate count as entrained air in the concrete? How is the air content of the concrete determined? How is the value expressed?
3. Why is it that the level of the water above the concrete does not return to the same level after the application of the pressure as it was before the application of the pressure? Which one is used in arriving at the air content?
4. How is the air content of concrete expressed?

TEST 26
DETERMINATION OF AIR CONTENT OF CONCRETE—INDIANA METHOD

Purpose

1. To determine the air content of freshly made concrete, expressed as a percentage of the volume of the concrete.

Apparatus

Balance
Unit-weight measure, ½-cu. ft. capacity
Tamping rod
Hook gauge attached to bar to lie across top of container
Thermometer

Method

2. *Calibration of Measure.*—Calibrate the measure as described in paragraphs 3 and 4 of Test 12.

3. Repeat the calibration using the hook gauge. The surface of the water should be at the point of the hook gauge. It is advisable to add water very slowly at the end and until the dimple caused by the point of the gauge breaks.

4. *Testing.*—Make a unit-weight determination on the concrete as outlined in Chap. 14 on testing.

5. Remove concrete from the measure until about 30 lb. remain. Weigh to

DATA RECORD—TEST 26

AIR CONTENT OF CONCRETE—INDIANA METHOD

Calibrations of Measure

Without Hook Gauge

1. Weight of measure full of water, lb.	
2. Weight of empty measure, lb.	
3. Weight of water in measure, lb.	
4. Volume of the measure, cu. ft.	

With Hook Gauge

5. Weight of measure filled with water to hook gauge, lb.	
2. Weight of empty measure, lb.	
6. Weight of water in measure to hook gauge, lb.	
7. Volume of measure to hook gauge, cu. ft.	

Unit Weight (Actual) of Concrete

8. Weight of measure full of concrete, lb.	
2. Weight of empty measure, lb.	
9. Weight of concrete in measure, lb.	
10. Unit weight (actual) of concrete, lb. per cu. ft.	

Unit Weight (Air-free) of Concrete

11. Weight of measure and concrete, lb.	
2. Weight of empty measure, lb.	
12. Weight of concrete in measure, lb.	
13. Weight of measure, concrete, and water to hook gauge, lb.	
14. Weight of water to fill measure to the hook gauge, lb.	
15. Volume of water to fill measure to the hook gauge, lb.	
16. Volume of air-free concrete, cu. ft.	
17. Unit weight of concrete, air-free basis, lb. per cu. ft.	

Air Content

18. Air content, per cent	

determine the exact amount. Add sufficient water to inundate sample. Stir until all the air is removed. A piece of flat steel is more effective than the standard tamping rod. The end of the standard rod not used for tamping can be flattened.

6. Add water to the point on the hook gauge, as was done in calibrating the measure. Remove the gauge and determine the weight of the contents of the measure.

7. Calculate the unit weights of the concrete, on both the actual and air-free bases. Calculate the per cent of entrained air. Typical calculations are given in Chap. 6.

Questions

1. Describe briefly the basic idea involved in making the air-content determination this way.
2. What is the formula for calculation of air content?
3. How does the Indiana method differ from the gravimetric method? (Tie answer into formula.)
4. What advantages does the Indiana method have over the pressure method? Over the gravimetric method? Over the rolling method? Where is it at a disadvantage in comparison with other methods?
5. Does the air content of the aggregates have any effect on the value secured for the concrete in this method?
6. Assume the unit weights as determined come out 150.2 and 145.3 lb. per cu. ft. What is the air content of the concrete? Assume then that errors of manipulation and calculation increase the first value 0.5 lb. per cu. ft. and decrease the second value 0.5 lb. per cu. ft. What is the air content based on these values? What is the difference between these air contents?

TEST 27

DETERMINATION OF THE AIR CONTENT OF CONCRETE—OHIO METHOD

Purpose

1. To determine the air content of freshly made concrete, expressed as a percentage of the volume of the concrete.

Apparatus

Balance
Unit-weight measure, ½-cu. ft. capacity
Tamping rod, one end flattened for stirring concrete
Hook gauge attached to bar to lie across top of measure
Graduated glass cylinder

Method

2. *Calibration of Measure.*—Calibrate the measure as described in paragraphs 3 and 4 of Test 12.

3. *Testing.*—Make a unit-weight determination on the concrete as outlined in Chap. 14 on testing.

4. Remove all the concrete from the measure, and clean the measure. Calculate the weight of ⅛ cu. ft. of concrete, based on the unit weight secured above. Weigh this amount of concrete into the measure. Compact the concrete exactly as was done in making the unit-weight test.

5. Fill the measure to the hook-gauge point, adding water until the dimple breaks.

6. Remove some of the water from the measure. Be careful not to lose any during removal and handling, and save for later use. Stir the remaining contents in the measure with the stirring rod to remove the entrained air.

7. Return carefully the water that was removed from the measure before stirring began. The water now should not be at the height of the hook-gauge point. Add water from a measured supply in the graduated glass cylinder until the dimple breaks over the hook-gauge point. The amount of water added from the cylinder is a measure of the amount of entrained air.

DATA RECORD—TEST 27

AIR CONTENT OF CONCRETE—OHIO METHOD

Calibration of Measure

1. Weight of measure (without hook gauge) full of water, lb.	
2. Weight of empty measure, lb.	
3. Weight of water in the measure, lb.	
4. Volume of measure, cu. ft.	

Unit Weight of Concrete (Actual)

5. Weight of measure full of concrete, lb.	
2. Weight of empty measure, lb.	
6. Weight of concrete in measure, lb.	
7. Unit weight of concrete, lb. per cu. ft.	

Air Content of Concrete

8. Calculated weight of ⅛ cu. ft. of concrete, lb.	
2. Weight of empty measure, lb.	
9. Weight of measure and concrete, lb.	
10. Volume of water added from graduated glass cylinder, ml.	
11. Air content of concrete, per cent	

8. *Calculation.*—The percentage of entrained air is found by dividing the volume of water added from the graduated cylinder in cubic feet by ⅛ cu. ft. and multiplying by 100. Since the volume of water added will be in milliliters, it is necessary to change the value to cubic feet. This may be done by dividing by 28,322 or multiplying by 0.00003531.

Author's Modification

9. Since the actual volume of the concrete is about 20 to 25 times the volume of the entrained air, the determination of the exact, actual volume in this method is not highly essential. The purpose of the unit-weight determination in paragraph 3 above is for the calculation of the weight of ⅛ cu. ft. of concrete. This unit-weight determination may be omitted.

10. Instead of weighing out ⅛ cu. ft. based on the unit-weight test, weigh out 25 or 30 lb. Compact this concrete in the measure in the standard manner as would be done for any air-content determination.

11. Follow instructions given in paragraphs 5, 6, and 7 above.

12. If a 30-lb. sample of concrete was used, read the air content of the concrete from the curve shown in Fig. 14-13. If another weight of sample is chosen for use and/or it is found that the unit-weight of air-free concrete is much different than 150 lb. per cu. ft., it will be necessary to prepare another chart.

Questions

1. How does the Ohio method differ from the Indiana method? Is there a reduction in the number of weighings and calculations in the field?

2. Is the volumetric determination of the amount of water that replaces the air in the concrete more accurate than the weighing of this water along with the sample, measure, and the water above the concrete?

3. Why is it that small variations in the actual unit weight of the concrete have small effects on the air content of the concrete in this method? Set up the formula for the air-content calculation, showing how the actual unit weight enters in.

4. How much difference would it make in the air content of the concrete, as calculated, if the unit weight of air-free concrete were 145 lb. per cu. ft. instead of the 150 lb. per cu. ft. used in preparing Fig. 14–13? Figure for a volume of water of 300 ml.

DATA RECORD—TEST 27

AIR CONTENT OF CONCRETE—MODIFIED OHIO METHOD

1. Weight of measure and concrete, lb.	
2. Weight of empty measure, lb.	
3. Weight of concrete, lb.	
4. Volume of water added from graduated glass cylinder, ml.	
5. Air content of concrete, per cent	

TEST 28

MORTAR-VOIDS DETERMINATION

Purpose

1. To secure data to plot the mortar-voids curves for use in connection with the Talbot-Richart method of proportioning.

Apparatus

Balance (1,000-g. capacity, sensitive to 1 g.)
Solid-bottom rigid cylindrical container of 200- to 250-ml. capacity
Tamper
2 mixing pans
Small trowel for mixing
Burette for measuring water

Method

2. Before attempting to do this experiment, the material in Chap. 5 should be read. A set of typical numerical results will be given here along with the instructions in order that the reader can follow more readily.

3. *Volume of Mold.*—Determine the volume of the mold by filling with water and weighing, or by running in water from the burette. Illustration: 207 ml.

4. *Specific Gravities of Materials.*—Determine the specific gravities of the cement and sand to be used in the tests. Illustration: cement 3.14, sand 2.66.

5. *Quantities of Materials.*—Figure the quantities of materials per batch for each of the proportions to be used. Values of a_m/c_m of 1, 2, 3.5, and 5 are recommended. A small surplus of mortar is necessary in order to be sure that there is enough for all batches.

Illustration. A sample computation will be given for a value of a_m/c_m of 3.0 only, in which the volume of the particles of sand is three times the volume of the particles of cement. For a 207-ml. container it is sufficient to make the value of $A_m + C_m = 200$ ml. Solving for A_m and C_m, we get $A_m = 150$ ml. and $C_m = 50$ ml. Next multiply the specific gravity of the sand by A_m and the specific gravity of the cement by C_m.

$$\text{Weight of cement } 50 \times 3.14 = 157.0 \text{ g.}$$

$$\text{Weight of sand } 150 \times 2.66 = 399.0 \text{ g.}$$

6. *Mixing.*—Weigh out cement and sand for the first determination. Mix the dry materials thoroughly in the mixing pan. Add water from burette, and mix thoroughly. The amount of water for the first trial should give a rather dry consistency. If too much water is added, start over again with another batch of dry materials and a smaller amount of water. Illustration: 50 ml. of water a_m/c_m of 3.0.

7. *Molding.*—Since the same mold is used in all determinations, it is desirable to balance the weight of the mold first with a counterpoise in order that the readings taken will be the weights of the mortar. After mixing, place mortar

in the container in four increments, rodding each increment with a suitable tamper. A flat-end tamper is more suitable since a pointed rod will leave holes in the drier batches. The number of blows struck should be uniform for all layers of all batches. Ten to fifteen blows are suggested. When the mold is filled, strike off neatly with a trowel, clean surplus mortar from outside, and weigh. Illustration: weight = 400 g.

8. *Continuation.*—Empty mortar into pan, and add 10 ml. more of water from the burette. Remix, refill mold, and weigh as before. Illustration: weight = 445 g. Repeat above operation with increased amounts of mixing water. The amount of mixing water producing the least volume of mortar is being sought. When this apparently has been accomplished, the following computations are made.

9. *Computations.*—Compute the volumes of the batches, assuming that the part of the batch placed in the mold is representative of the entire batch.

$$\text{Volume of batch} = \text{volume of mold} \times \frac{\text{weight of batch}}{\text{weight placed in mold}}.$$

Illustration (for first case using 50 ml. of water):

$$\text{Volume of batch} = 207 \text{ ml.} \frac{606 \text{ g.}}{400 \text{ g.}} = 314 \text{ ml.}$$

Continue computations for other amounts of mixing water. See table for values. Examination of the results of the computations indicates that the amount of water necessary to produce minimum volume of mortar is in the neighborhood of 70 ml.

10. *Check Tests.*—Using a fresh batch of cement and sand, run a check test to determine more exactly the amount of mixing water to produce a minimum amount of mortar and to secure data for larger amounts of mixing water. It will be unnecessary to repeat with 50 g. of water, but we should start with 60 ml. Use 65, 70, 80, and 100 ml. The greatest amount of water used should be about 50 per cent greater than that required for basic water content.

11. Repeat all of the above for the other values of a_m/c_m given in paragraph 5 above.

12. *Final Calculations.*—With the data obtained above, compute values of a_m, c_m, v_m, w_m and $(v + c)$. Illustration (using first determination of the original run, with 50 ml. of water):

TYPICAL DATA RECORD—MORTAR-VOIDS TEST

$a_m/c_m = 3.0$

Specific gravities	cement	3.14
	sand	2.66
Volume of mold		207 ml.
Dry materials used per batch	cement	157 g.
	sand	399 g.
Solid or absolute volumes	cement	50 ml.
	sand	150 ml.

Initial Run

Water, g.	Total weight batch, g.	Weight placed in container, g.	Volume of batch, ml.	a_m	c_m	w_m	v_m	$\frac{c}{c+v}$
50	606	400	314	0.478	0.159	0.159	0.363	0.304
60	616	445	287	0.522	0.174	0.209	0.304	0.364
70	626	472	275	0.545	0.182	0.254	0.273	0.400
80	636	470	280	0.535	0.178	0.287	0.287	0.383

Check Run

60	616	450	284	0.528	0.176	0.212	0.296	0.374
65	621	460	280	0.535	0.178	0.232	0.287	0.383
70	626	460	282	0.531	0.177	0.248	0.292	0.378
80	636	459	287	0.522	0.174	0.279	0.304	0.364
100	656	457	297	0.500	0.167	0.333	0.333	0.333

$$a_m = \frac{150}{314} = 0.478$$

$$c_m = \frac{50}{314} = 0.159$$

$$v_m = 1 - a_m - c_m = 0.363$$

$$w_m = \frac{50}{314} = 0.159$$

$$\frac{c}{v+c} = \frac{c_m}{v_m + c_m} = \frac{0.159}{0.363 + 0.159} = 0.304$$

13. *Curves.*—Plot curves as shown in Fig. 5-11 or for any water content desired.

DATA RECORD—TEST 28

MORTAR-VOIDS DETERMINATION

Identification	cement	__________
	sand	__________
Specific gravities	cement	__________
	sand	__________
Volume of mold		__________ ml.
$\frac{a_m}{c_m}$ =		__________
Dry materials per batch	cement	__________
	sand	__________
Solid or absolute volumes	cement	__________
	sand	__________

Initial Run

Water, g.	Total weight batch, g.	Weight put in container, g.	Vol. of batch, ml.	a_m	c_m	w_m	v_m	$\frac{c}{v+c}$

Check Run

Concrete Projects

A number of concrete projects have been planned as Tests 29 to 35 to give the student (1) ideas concerning the interrelationship of the many items involved in concrete proportioning; (2) some experience in making the tests on concrete; (3) an idea of the care necessary to secure consistent results; and (4) to furnish data that can be used in making the many standard calculations in connection with concrete mixes. Not all the projects can be done in one school term, but certain ones can be chosen to give variety from year to year.

Projects on time of mixing, method of curing, and age of concrete are not included since it is felt that the ones on proportioning are much more important to the student. If it is desired to make flexure tests in place of the compression test, that can easily be done, or if it is desired to make a few flexure tests in addition to the compression tests outlined, the size of several batches can be increased and the specimens made at the same time as the compression specimens.

Tests 29 and 30 are a pair involving percentage of fine aggregate in the total aggregate as the main variable. In Test 29 the water-cement ratio is held constant while the aggregate-cement ratio is varied to hold the slump constant. In Test 30 the two ratios are reversed.

Test 31 is designed to show the effect of the amount of mixing water while holding the proportions of the dry materials constant.

In Test 32 water-cement ratio is varied while the slump is held constant, requiring that the aggregate-cement ratio be varied. In this project the percentage of sand should be varied over a small range, using less sand in the richer mixes.

In Test 33 the main purpose is to show how to vary the consistency of the concrete when the water-cement ratio is held constant. This is done by varying the aggregate-cement ratio.

Tests 34 and 35 are a pair in which the maximum size of the aggregate is the main variable. In Test 34 water-cement ratio is held constant while the aggregate-cement ratio is varied to hold the slump constant. In Test 35 the ratios are reversed.

In connection with the two pairs, 29–30 and 34–35, it is worth while to compute the sieve analyses of the combined aggregates for all the batches and to plot the sieve-analysis curves. It is also advantageous to determine the unit weights of the combined aggregate and to make graphs showing the relationship between unit weight of the aggregate and the main variable. Unit weights of the concrete can then be plotted on the same sheets.

It is worth while also for the student to calculate the unit weights of air-free concrete for all batches as the projects are done. These values are the maximum ones that should ever prevail, and when a test value is higher than the air-free value, it is immediately known that something is not right.

Along with the air-free unit weights the student should plot the test results that his class secured. For use in student calculations, however, it is advisable for the instructor to average the values from all the classes that may be doing the same project and possibly smooth up the curve, or if only one class is involved, he should decide on the curve to be drawn as representative of the values secured. These values go in column 10 of calculation sheet No. 1. This is an important detail since most of the calculations to be made depend upon the unit-weight value. The three unit-weight curves should be drawn to the same pair of axes.

The author feels that it is worth while to have the students prepare some graph sheets for the plotting of strengths from all the projects. One sheet should have the strengths plotted against water-cement ratio, another against cement-space ratio, a third against cement content of the concrete, and a fourth against density of the concrete. The original

Abrams and Talbot-Richart curves can be put on the proper sheets if desired.

In plotting graphs the independent variable should always be the abscissa and the dependent variable the ordinate. The dependent variable values are plotted against the independent variable values.

Entrainment of air in concrete is a relatively new feature, which can be included or omitted as may be desired. Air-entraining cements and admixtures are both available. It might be well to omit this feature in Test 31 since some of the batches are very wet or very dry. It would be well also to omit air entrainment from Test 28—the mortar-voids test—since in figuring the relative water contents of the various batches of Test 31, the basic water content of the mortar from Test 28 is used. If air entrainment is a feature and the amount is to be determined by any method that requires stirring or rolling the sample in an excess of water, the size of the batch must be increased by the amount used in the test. Concrete from the Klein air-meter determination can apparently be used in the making of cylinders but should be returned to the concrete pan and mixed with the remainder of the concrete before beginning to mold cylinders.

The amount of the air may be determined by the gravimetric method, which provides that the unit weight of air-free concrete shall be calculated and the actual unit weight determined by test. If a Klein air meter is available or the equipment for the Indiana method (including modifications), it is worth while to make such a test in addition to the gravimetric calculation.

Inclusion of air in the concrete modifies certain of the relationships in proportioning. Normally, concrete with entrained air has a greater slump than concrete without, all other items being the same. On the other hand, concrete with entrained air can be made with a slightly smaller percentage of fine aggregate.

TEST 29

EFFECT OF VARYING THE PERCENTAGE OF SAND IN THE TOTAL AGGREGATE FOR A CONSTANT SLUMP AND WATER-CEMENT RATIO

Purpose

1. To show the effect of varying the percentage of sand in the total aggregate, holding the slump and water-cement ratio constant. In order to hold the slump constant, the aggregate-cement ratio must be varied.

Apparatus

2. Scales, 200-lb. capacity (with scale arm graduated in decimals of a pound)
Pans for weighing dry materials

Bucket for weighing water
Pans for the mixed concrete
Small concrete mixer (tilting-drum type)
Tamping rods
Unit-weight measure
Air meter for measuring air content of concrete
Slump cone
Cylinder molds and plates (at least 3 molds and 6 plates for each batch of concrete)
Finishing trowels
Pointing trowels
Shovels
Moist room for storing test specimens
Compression testing machine

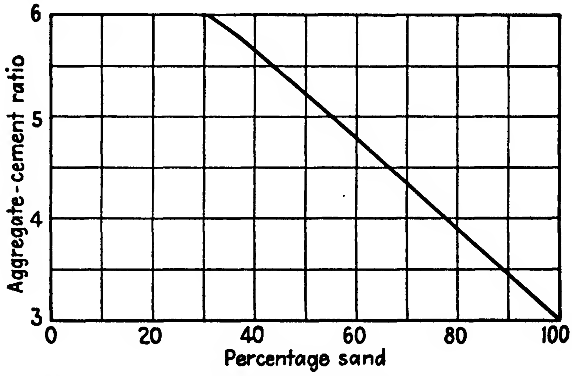

FIG. 1.—test 29.—Typical curve showing the relationship between aggregate-cement ratio and percentage of sand. This one is for a water-cement ratio of 6 gal. per sack and air-entrained concrete.

Method

3. *Quantities of Materials per Batch.*—Select first the percentages of sand to be used. Suggested values for an 8-batch series are 100, 80, 60, 50, 40, 35, 30, and 25.

4. Select the water-cement ratio to use in all batches, such as 6, 6½, 6¾, 7, or 7½ gal. per bag of cement.

5. Select a slump range, such as 2 to 4 in., 3 to 5 in., 4 to 6 in., or 5 to 7 in. It may be difficult to secure slumps within the range selected the first time the test is run.

6. Select the aggregate-cement ratio for each batch. A typical curve from the author's file is given in Fig. 1. In planning the project for class work, it may be necessary to make a few trial batches the first time the project is undertaken, to get the exact relationship between the aggregate-cement ratio and the percentage of sand for the materials and conditions to be used.

7. Using the values selected in paragraphs 3 to 6, compute the weights of cement, fine aggregate, coarse aggregate, and water necessary to make enough concrete for the estimated requirements. Actual unit weights of concrete will vary from approximately 130 lb. per cu. ft. for 100 per cent sand to 145 to 150 lb. per cu. ft. for 25 per cent sand.

8. Weigh out all the materials for a batch, and mix in the mixer. After discharging the batch from the mixer, it may be necessary to remove small amounts sticking at various spots in the drum.

9. Make unit-weight test as described in Chap. 14.

10. Make air-content determination with the air meter as described in Test 25. If the Indiana or Ohio method is used, as described in Tests 26 or 27, return to the concrete pan the portion of the unit-weight sample that is removed before washing out the air.

11. Make slump test as described in Chap. 14.

12. Mold the cylinders, and store until tested as described in Chap. 14.

13. Test cylinders at the age selected as described in Chap. 14.

14. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

15. Calculate the sieve analysis of the combined aggregate used in each batch from the sieve analyses of the individual materials, as determined in Test 12.

16. *Curves.*—Plot the sieve-analyses curves for the combined aggregates, using the values calculated in paragraph 15 above, putting all the curves on one sheet with one pair of axes. Identify each curve.

17. Average the strength of all workable batches. Plot this strength on a curve sheet showing the relationship between compressive strength and water-cement ratio. Results of other student projects will be put on the same sheet.

18. Plot the strength of each batch against the corresponding cement-space ratio, and connect the points with a series of straight lines. Prepare the sheet in order that the results of other student projects can be placed on the same sheet.

19. Plot the strength of each batch against the corresponding cement-content value, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

20. Plot the strength of each batch against the corresponding density value, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

21. Plot the calculated unit weight of air-free concrete against the percentage of sand, using the sheet prepared for the aggregates in Test 13. Use the same axes and the same scales.

22. Plot the actual unit weight of concrete against percentage of sand, using values secured by your class. Use same axes as for the preceding curve.

23. Plot the actual unit weight of concrete against percentage of sand, using average values of all classes. These are the values that will be used in the cal-

culations outlined in Chap. 6. For convenience all the students should have the same values.

24. Plot aggregate-cement-ratio values against percentage of sand.
25. Plot cement content of concrete values against percentage of sand.
26. Plot cement-space-ratio values against percentage of sand.
27. Plot fineness-modulus values against percentage of sand.
28. Plot b/b_0 values against percentage of sand.
29. Plot mortar factor values against percentage of sand.

Summary

30. Prepare a table summarizing the important items such as:

a. Percentages of sand
b. Aggregate-cement ratios
c. Slumps
d. Air contents
e. Fineness modulus values of combined aggregate
f. b/b_0 ratios
g. Mortar factors
h. Cement-space ratios
i. a/c ratios
j. Densities of the batches
k. Cement contents
l. Water contents
m. Strengths
n. Unit weights of the concrete

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item then had to be varied in order to hold the slump constant?

2. How well was the slump held constant? What was the range of actual slump values?

3. If air-entraining portland cement was used, was the air content relatively constant? If not, was air entrainment greater with the higher percentages of sand?

4. If air-entraining admixture was used, was the rate per pound of cement held constant? If it was, was the air content of the concrete relatively constant? If the amount of the admixture was varied, how did it vary with the percentage of sand?

5. How did the aggregate-cement ratio vary with the percentage of sand?

6. According to Abrams, the strength of all the batches should be the same since the water-cement ratio is the same for all batches. Are they the same? What is the maximum variation of any one batch from the average? Give the variation as a percentage based on the average of all workable batches. In averaging concrete

strengths, which should be the same, what is the permissible variation usually permitted?

7. How do the fineness modulus, b/b_0 ratio, and mortar-factor values vary with the percentage of sand?

8. How does the cement content of the concrete vary with the percentage of sand? How does the density of the concrete vary with the percentage of sand?

9. Since the concrete strengths do not vary appreciably with changes in the percentage of sand, should it be concluded that any percentage of sand is permissible? What other factor is varying, however, which has a bearing on the percentage of sand to use?

10. What is the range of values of cement-space ratio? Is this large or small?

11. Does the maximum unit weight of the concrete occur at the same percentage of sand as does the maximum unit weight of the combined aggregate?

12. In some respect this project is patterned after the work of Fuller and Thompson. In what respect does it vary?

DATA RECORD—TEST 29

EFFECT OF VARYING THE PERCENTAGE OF SAND IN THE TOTAL AGGREGATE FOR A CONSTANT SLUMP AND WATER-CEMENT RATIO

1. Brand of cement ________ Water-cement ratio ________
2. Mixer used ________ Time of mixing, min. ________
3. Size of cylinders: diameter ________ in.; length ________ in.
4. Date cylinders made: ________ To be tested ________
5. Clock time: making ________ capping ________
6. Kind of cap used ________
7. Date and clock time cylinders placed in moist room ________
8. Curing conditions: ________ day in molds; ________ days in moist room

Batch Number (1)	Per cent sand (2)	Aggregate cement ratio (3)	Batch weights, lb. Cement (4)	Sand (5)	Pebbles (6)	Water (7)	Slump, in. (8)	Unit weight concrete, lb. per cu. ft. (9)	Air content, % (10)
1									
2									
3									
4									
5									
6									
7									
8									

Cylinder Strengths

1. Date cylinders tested ____________
2. Age at testing, days ____________
3. Testing machine used ____________
4. Average diameter of cylinders, in. ____________
5. Cross-sectional area, sq. in. ____________

Batch number (1)	Aggregate-cement ratio (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Sand, lb. (13)	Pebbles, lb. (14)	Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, percent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

$b_0 =$ ____________

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

TEST 30

EFFECT OF VARYING THE PERCENTAGE OF SAND IN THE TOTAL AGGREGATE FOR A CONSTANT SLUMP AND AGGREGATE-CEMENT RATIO

Purpose

1. To show the effect of varying the percentage of sand in the total aggregate, holding the slump and aggregate-cement ratio constant. In order to hold the slump constant, the water-cement ratio must be varied also.

Apparatus

2. See list for Test 29.

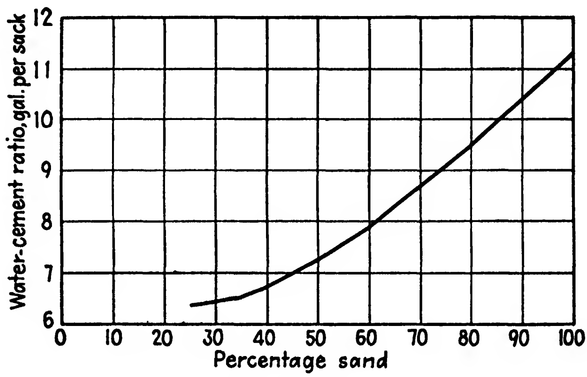

FIG. 1—test 30.—Typical curve showing the relationship between water-cement ratio and percentage of sand. This one is for an aggregate-cement ratio of 6 and air-entrained concrete.

Method

3. *Quantities of Materials per Batch.*—Select first the percentages of sand to use. Suggested values for an 8-batch series are 100, 80, 60, 50, 40, 35, 30, and 25.

4. Select the aggregate-cement ratio to use in all the batches, such as 5½, 6, 6½, or 7.

5. Select a slump range, such as 2 to 4 in., 3 to 5 in., 4 to 6 in., or 5 to 7 in. It may be difficult to secure slumps within the range selected the first time the test is run.

6. Select the water-cement ratio for each batch. A typical curve from the author's file is given in Fig. 1. In planning the project for class work, it may be necessary to make a few trial batches the first time the project is undertaken to get the exact relationship between the two cement ratios for the materials and conditions to be used.

7. Using the values selected in paragraphs 3 to 6, compute the weights of cement, fine aggregate, coarse aggregate, and water necessary to make enough

concrete for the estimated requirements. Actual unit weights of concrete will vary from approximately 130 lb. per cu. ft. for 100 per cent sand to 145 to 150 lb. per cu. ft. for 25 per cent sand.

8. Weigh out all the materials for a batch, and mix in the mixer. After discharging the batch from the mixer, it may be necessary to remove small amounts sticking at various spots in the drum.

9. Make unit-weight test as described in Chap. 14.

10. Make air-content determination with the air meter as described in Test 25. If the Indiana method is used, as described in Tests 26 or 27, return to the concrete pan the portion of the unit-weight sample that is removed before washing out the air.

11. Make slump test as described in Chap. 14.

12. Mold the cylinders, and store until tested as described in Chap. 14.

13. Test cylinders at the age selected as described in Chap. 14.

14. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

15. Calculate the sieve analysis of the combined aggregate used in each batch from the sieve analyses of the individual materials, as determined in Test 12.

16. *Curves.*—Plot the sieve-analyses curves for the combined aggregates, using the values calculated in paragraph 15 above, putting all the curves on one sheet with one pair of axes. Identify each curve.

17. Plot the strength of each batch against the corresponding water-cement ratio, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

18. Plot the strength of each batch against the corresponding cement-space ratio, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

19. Plot the strength of each batch against the corresponding cement-content value, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

20. Plot the strength of each batch against the corresponding density value, and connect the points with a series of straight lines. Prepare the sheet in such a way that the results of other student projects can be placed on the same sheet.

21. Plot the calculated unit weights of air-free concrete against the percentage of sand, using the sheet prepared for the aggregates in Test 13. Use the same axes and the same scales.

22. Plot the actual unit weight of the concrete against percentage of sand, using values secured by your class. Use same axes as for the preceding curve.

23. Plot the actual unit weight of the concrete against the percentage of sand, using average values of all classes. These are the values that will be used in the calculations outlined in Chap. 6. For convenience all the students should have the same values.

24. Plot water-cement-ratio values against percentage of sand.

25. Plot cement-content values for concrete against percentage of sand.
26. Plot cement-space-ratio values against percentage of sand.
27. Plot fineness-modulus values against percentage of sand.
28. Plot mortar-factor values against percentage of sand.

Summary

29. Prepare a table summarizing the important items such as:

a. Percentages of sand
b. Water-cement ratios
c. Slumps
d. Air contents
e. Fineness-modulus values of combined aggregate
f. b/b_0 ratios
g. Mortar factors
h. Cement-space ratios
i. a/c ratios
j. Densities of the batches
k. Cement contents
l. Water contents
m. Strengths
n. Unit weights of the concrete

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item then had to be varied in order to hold the slump constant?

2. How well was the slump held constant? What was the range of actual slump values?

3. If air-entraining portland cement was used, was the air content relatively constant? If not, was air entrainment greater with the higher percentages of sand?

4. If air-entraining admixture was used, was the rate per pound of cement held constant? If it was, was the air content relatively constant? If the amount of the admixture was varied, how did it vary with the percentage of sand?

5. How did the water-cement ratio vary with the percentage of sand?

6. How did the strength vary with the water-cement ratio? with the cement space ratio? with the cement content? with the density of the concrete? Do the results check with the results of Fuller and Thompson? Abrams? Talbot and Richart?

7. How do the fineness modulus, b/b_0 ratio, and mortar factor vary with the percentage of sand?

8. How does the cement content of the concrete vary with the percentage of sand? How does the density of the concrete vary with the percentage of sand?

9. Does the maximum unit weight of the concrete occur at the same percentage of sand as does the maximum unit weight of the combined aggregate?

10. This project is patterned after the work done by Fuller and Thompson. Are the results in line with theirs?

DATA RECORD—TEST 30

EFFECT OF VARYING THE PERCENTAGE OF SAND IN THE TOTAL AGGREGATE FOR A CONSTANT SLUMP AND AGGREGATE-CEMENT RATIO

1. Brand of cement ________ Aggregate-cement ratio ________
2. Mixer used ________ Time of Mixing, min. ________
3. Size of cylinders: diameter ________ in.; length ________ in.
4. Date cylinders made: ________ To be tested ________
5. Clock time: making ________ capping ________
6. Kind of cap used ________
7. Date and clock time cylinders placed in moist room ________
8. Curing conditions: ________ day in molds; ________ days in moist room

Batch	Per cent sand	Water cement ratio, gal. per bag	Batch weights, lb.				Slump, in.	Unit weight concrete, lb. per cu. ft.	Air content, %
			Cement	Sand	Pebbles	Water			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1									
2									
3									
4									
5									
6									
7									
8									

Cylinder Strengths

1. Date cylinders tested ________
2. Age at testing, days ________
3. Testing machine used ________
4. Average diameter of cylinders, in. ________
5. Cross-sectional area, sq. in. ________

Batch number (1)	Water-cement ratio (2)	Total loads, lb.		Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
		Individual (3)	Average (4)		
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Sand, cu. ft. (3)	Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Sand, lb. (13)	Pebbles, lb. (14)	Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\,(v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

b_0 = ______________

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

TEST 31

EFFECT OF VARYING THE WATER-CEMENT RATIO FOR A GIVEN AGGREGATE-CEMENT RATIO AND PERCENTAGE OF SAND

Purpose

1. To show the effect of varying the water-cement ratio while holding the aggregate-cement ratio and percentage of sand constant. Important effects to note are those on slump and compressive strength.

2. For this project it is suggested that no air-entrainment feature be attempted. The drier batches have a large air content anyway, and the wetter batches may not have much air entrained due to the large amount of mixing water, which tends to wash the air out of the concrete.

3. It is proposed also to (1) calculate the Abrams relative-consistency value for each batch, which can be done without additional testing and (2) calculate the Talbot-Richart relative water content of each batch, which requires the determination of basic water content in the mortar-voids test.

Apparatus

4. See list for Test 29.

Method

5. *Quantities of Materials per Batch.*—Select the percentage of sand and aggregate-cement ratio. Suggested percentages of sand are 35, 36, 37, 38, 39, or 40; suggested aggregate-cement ratios are 5.5, 6.0, 6.5, or 7.0.

6. Select the water-cement ratio for each batch. The range of consistency covered should extend from very dry to very wet. This will give a peak on the strength-water-cement-ratio curve. It will also furnish the data necessary for the determination of the water-cement ratio giving normal consistency as defined by Abrams and for computing the relative consistency of each batch. An interval of about 0.4 gal. per bag will give the necessary range for an eight-batch series.

7. Using the values selected in paragraphs 5 and 6 above, compute the weights of cement, fine aggregate, coarse aggregate, and water necessary to make enough concrete for the estimated requirements. Weights of cement and aggregates can be the same for all batches since the variation in the amount of mixing water used will not affect greatly the volume of concrete produced.

8. Weigh the materials, mix the concrete, make the unit-weight and slump tests, mold, store, and test the specimens as outlined in Chap. 14. Air-content determinations can be made on the workable batches—those that are not too dry or too wet. If the air-entrainment feature is omitted, the test can still be made and thus give the students more experience with it.

9. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

10. *Determination of Relative Consistencies.*—Plot a curve showing the relationship between slump and water-cement ratio. Connect the points with a series of straight lines. Since Abrams defines concrete of normal consistency as having a slump of ½ to 1 in., it will be necessary to use the average of this

range in scaling off the water-cement ratio for normal consistency. Concrete of normal consistency has a relative consistency of 1.00. To secure the relative consistency of each batch, divide the water-cement ratio of each batch by the water-cement ratio for normal consistency. Plot a second curve showing the relationship between slump and relative consistency.

11. *Determination of Relative Water Contents.*—Secure from the data of Test 28 the w_m value at basic water content for the a/c ratio of this project. Use this value in calculating the relative water content of each batch as explained in Chap 6. Plot a curve showing the relationship between slump and relative water content.

12. *Curves.*—On the curve sheet, which was prepared from the data secured in Test 17 (see paragraph 14), plot the curve representing the sieve analysis of the combined aggregate used in this project.

13. On the curve sheets, which have been prepared for plotting strength results from all projects, plot the strengths of all workable batches. Connect points with a series of straight lines. These sheets have as the X axis water-cement ratio, cement-space ratio, cement content, and density.

14. Plot three curves using one set of axes, showing the relationship between unit weight of the concrete and water-cement ratio. First plot the unit weight of air-free concrete. These are calculated values. Then plot the unit weights as secured by your class. Finally plot average, smooth curve to be used in all calculations. All students should have the same curve in the third case in order to facilitate checking and comparison with others. The instructor should decide on the values for this curve.

15. Plot strength against relative consistency.

16. Plot strength against relative water content.

Summary

17. Prepare a table summarizing the important items such as:

a. Water-cement ratios
b. Slumps
c. Relative consistencies
d. Relative water contents
e. Cement-space ratios
f. Cement contents
g. Water contents
h. Unit weights of the concrete
i. Strengths
j. b/b_0 ratios
k. Mortar factors

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item varied as a result of the major variable?

2. What was the water-cement ratio at normal consistency? Would you expect that the water-cement ratio at normal consistency would vary for other mixes and combinations of materials?

3. Did maximum strength occur essentially at a relative consistency of 1.0? At what relative water content did maximum strength occur?

4. Were the batches with water-cement ratios lower than the one producing maximum strength suitable for construction work? Were the batches at the wet end of the series suitable for construction work?

5. Do the strengths for the workable batches fit the Abrams pattern curve? Do they fit the Talbot-Richart curve?

6. What is the range of values of cement content between relative consistencies of 1.0 and 1.3? Is this a large or a small variation?

7. What is the range of values of b/b_0 and mortar factor between relative consistencies of 1.0 and 1.3? Are these ranges large or small?

DATA RECORD—TEST 31

EFFECT OF VARYING THE WATER-CEMENT RATIO FOR A GIVEN AGGREGATE-CEMENT RATIO AND PERCENTAGE OF SAND

1. Brand of cement ____________ Aggregate-cement ratio ____________
2. Percentage of fine aggregate ____________
3. Proportions: by volume ____________ by weight ____________
4. Batch weights, lb.: cement ____________ fine aggregate ____________ coarse aggregate ____________
5. Size of cylinders: diameter ________ in.; ________ length ________ in.
6. Mixer used ____________ Time of mixing, min. ____________
7. Date cylinders made ____________ To be tested ____________
8. Clock time: making ____________ capping ____________
9. Kind of cap used ____________
10. Date and clock time cylinders placed in moist room ____________
11. Curing conditions: ________ day in molds; ________ days in moist room

Batch number (1)	Water-cement ratio, gal. per bag (2)	Weight mixing water, lb. (3)	Slump, in. (4)	Unit weight concrete, lb. per cu. ft. (5)	Air content, % (6)
1					
2					
3					
4					
5					
6					
7					
8					

Cylinder Strengths

1. Date cylinders tested ____________
2. Age at testing, days ____________
3. Testing machine used ____________
4. Average diameter of cylinders, in. ____________
5. Cross-sectional area, sq. in. ____________

Batch number (1)	Water-cement ratio (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd of concrete: Cement bags (12)	Sand, lb. (13)	Pebbles, lb. (14)	Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

b_0 = ————————

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

Special Calculation Sheet

Calculation of Relative Water Contents and Relative Consistencies

1. *a/c* ratio ______________
2. Value of w_m at basic water content from Test 28 (average value of all students' results) ______________
3. Water-cement ratio for normal consistency (taken from curve plotted as instructed in paragraph 10) ______________

Batch number (1)	Volume mortar in batch, cu. ft. (2)	Volume mortar per cu. ft. of concrete, cu. ft. (3)	Volume water per cu. ft. of concrete (w) cu. ft. (4)	Volume water per cu. ft. of mortar (w_m) cu. ft. (5)	Relative water content (6)	Abrams's relative consis-tency (7)
1						
2						
3						
4						
5						
6						
7						
8						

Column 2—Secure values from column 14, calculation sheet 2.
Column 3—Divide column 2 by column 11, calculation sheet 1.
Column 4—Secure values from column 5, calculation sheet 2.
Column 5—Divide column 4 by column 3.
Column 6—Divide column 5 by line 2.
Column 7—Divide water-cement ratios by line 3.

TEST 32

EFFECT OF VARYING THE WATER-CEMENT RATIO AND AGGREGATE-CEMENT RATIO, HOLDING THE SLUMP CONSTANT

Purpose

1. To show the effect of varying both the water-cement ratio and the aggregate-cement ratio while holding the slump constant. The percentage of sand can be held constant, or the percentages can be increased as the two ratios are increased. Values shown in Fig. 2 were used for the ratios shown in Fig. 1 to produce a b/b_0 ratio of approximately 0.73. Less sand can be used for the lower ratios than for the higher ratios.

Apparatus

2. See list for Test 29.

Method

3. *Quantities of Materials per Batch.*—Select first the water-cement ratios to be used. Suggested values for an 8-batch series are 4.5, 5.25, 6.0, 6.75, 7.5, 8.25, 9.0, and 9.75.

4. Select the aggregate-cement ratio for each batch. A typical curve from

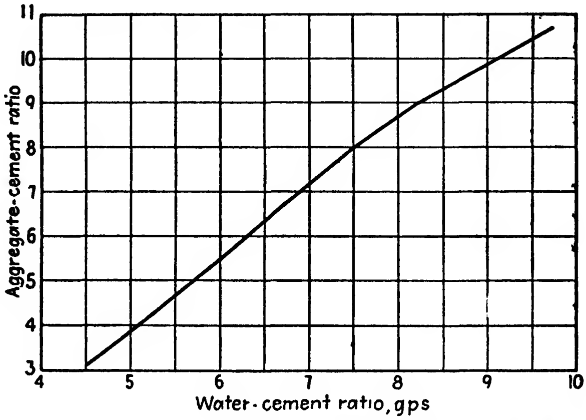

FIG. 1—test 32.—Typical curve showing relationship between aggregate-cement ratio and water-cement ratio, holding the slump constant. This curve was for air-entrained concrete. The percentage of sand was increased as the water-cement ratio increased.

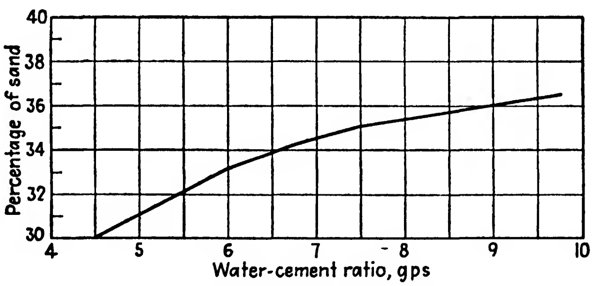

FIG. 2—test 32.—Typical curve showing the relationship between percentage of sand in total aggregate and water-cement ratio, for the curve shown in Fig. 1, to hold the b/b_0 ratio constant (at about 0.73 in this case).

the author's file is given in Fig. 1. If no curve is available for the materials and conditions, the aggregate-cement ratios might be selected arbitrarily. Water for each batch could be added from a weighed supply as mixing progresses until the desired consistency is secured, based on observation of the concrete in the mixer. The water-cement ratios could then be figured from the amounts of water used.

5. Select the percentage of sand to be used. If this item is to be kept con-

stant, a value between 35 and 40 per cent is suggested. If the percentage of sand is to be varied, the smaller percentages should be used with the smaller water-cement ratios. See Fig. 2 for a typical curve.

6. Using the values selected in paragraphs 3 to 5, compute the weights of cement, aggregates, and water necessary to make enough concrete for the estimated requirements. Actual unit weights may vary from 140 to 150 lb. per cu. ft. The smaller values in this range are secured from the larger water-cement ratios. Use of air-entraining cement or admixture will lower the unit weights.

7. Weigh the materials, mix the concrete as suggested in Chap. 14, and make the unit-weight test. Make air-content determination as outlined in one of tests—25, 26, or 27. Make slump test, mold, store, and test cylinders as outlined in Chap. 14.

8. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

9. *Curves.*—On the curve sheets, which have been prepared for plotting strength results from all projects, plot the strengths of all batches. Connect the points with a series of straight lines. These sheets have as the X axis water-cement ratio, cement-space ratio, cement content, and density.

10. Plot three curves using one set of axes, showing the relationship between unit weight of the concrete and water-cement ratio. First plot the unit weight of air-free concrete. These are calculated values. Then plot the unit weights as secured by your class. Finally plot the average smooth curve to be used in all calculations. These are the values to go in column 10 of calculation sheet No. 1. All students should have the same curve in the third case in order to facilitate checking and comparison with others. The instructor should decide on the values for this curve.

11. Plot aggregate-cement ratio values against water-cement ratio values.

12. Plot percentages of sand against water-cement ratio values, if the percentage of sand is varied.

13. Plot cement contents against water-cement ratio values.

14. Plot water contents against water-cement ratio values.

15. Plot cement-space-ratio values against water-cement-ratio values.

Summary

16. Prepare a table summarizing the important items such as:

a. Water-cement ratios
b. Aggregate-cement ratios
c. Percentages of sand
d. Slumps
e. Cement-space ratios
f. Cement contents
g. Water contents
h. Unit weights of concrete
i. b/b_0 ratios

j. Mortar factors

k. Densities

l. Fineness-modulus values

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item had to be varied to hold the slump constant? What was the purpose of varying the percentage of sand, if it was varied?

2. How well was the slump held constant? What was the range of actual slump values?

3. How uniform were b/b_0 values? the mortar factor values? If values were not uniform, what changes might be made to secure greater uniformity?

4. If air-entraining portland cement was used, was the air content relatively constant? If not, was there a consistent variation with water-cement ratio? If there was a consistent variation, how did it go?

5. If air-entraining admixture was used, was the rate per pound of cement held constant? If it was, was the air content relatively constant? If the amount of the admixture was varied, how did it vary with water-cement ratio?

6. How did the strength vary with the water-cement ratio? with the cement-space ratio? with the cement content? with the density?

7. For what range of water-cement ratios is the water content of the concrete practically the same? This uniformity of water content is sometimes used in designing a concrete mix; therefore, it is important to know the range of water-cement ratios for which it is fairly constant.

8. How does cement-space ratio vary with water-cement ratio?

9. Do the smaller ranges of water-cement ratios permit relatively low percentages of sand? Why?

10. How do the cement contents of the concrete vary with water-cement ratio? What is the range of cement contents for the range of water-cement ratios of this project?

Data Record—Test 32

Effect of Varying the Water-cement Ratio and Aggregate-cement Ratio, Holding the Slump Constant

1. Brand of cement ______
2. Percentage fine aggregate (if held constant) ______
3. Size of cylinders: diameter ______ in.; length ______ in.
4. Mixer used ______ Time of Mixing ______ min.
5. Date cylinders made ______ To be tested ______
6. Clock time: making ______ capping ______
7. Kind of cap ______
8. Date and clock time cylinders placed in moist room ______
9. Curing conditions: ______ day in molds; ______ days in moist room

Batch number	Water-cement ratio	Aggregate-cement ratio	Fine aggregate, per cent	Batch weights, lb.				Slump, in.	Unit weight concrete, lb. per cu. ft.	Air content concrete, per cent
				Cement	Sand	Pebbles	Water			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1										
2										
3										
4										
5										
6										
7										
8										

Cylinder Strengths

1. Date cylinders tested ______________
2. Age at testing, days ______________
3. Testing machine used ______________
4. Average diameter of cylinders, in. ______________
5. Cross-sectional area, sq. in. ______________

Batch number (1)	Water-cement ratio (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strength, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Quantities of materials per cu. yd. of concrete: Sand, lb. (13)	Quantities of materials per cu. yd. of concrete: Pebbles, lb. (14)	Quantities of materials per cu. yd. of concrete: Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

$b_0 =$ ______________

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

TEST 33

EFFECT OF VARYING THE AGGREGATE-CEMENT RATIO FOR A CONSTANT WATER-CEMENT RATIO

Purpose

1. To show the effect of varying the aggregate-cement ratio while holding the water-cement ratio constant. The percentage of sand should be held constand in this project. By proper selection of aggregate-cement ratios the consistency can be varied from very dry to very wet, as was done in Test 31.

Apparatus

2. See list for Test 29.

Method

3. *Quantities of Materials per Batch.*—Select the water-cement ratio to use, such as 6, 6½, 6¾, 7, or 7½ gal. per bag of cement. Select the percentage of sand to use within the range of 35 to 40 per cent.

4. Select the aggregate-cement ratio for each batch. The consistency range should extend from very dry to very wet. For a water-cement ratio of 6½ gal. per bag, 35 per cent sand, and air-entrained concrete, the author has found that a range of aggregate-cement ratios of 8.0 to 4.5 produces slumps ranging from about 0 to 9 in. For the first time through, it might be well to be prepared to make additional batches at the wet end and drop off some at the dry end.

5. Using the values selected above, compute the weights of material necessary to make enough concrete for the estimated requirements.

6. Weigh the materials, mix the concrete, and make the unit-weight determination, as outlined in Chap. 14. Make air-content determination as outlined in one of Tests 25, 26, or 27. Make the slump test, mold, store, and test cylinders as outlined in Chap. 14.

7. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

8. *Curves.*—Average the strengths of all workable batches. Plot this strength on the curve sheet showing the relationship between strength and water-cement ratio.

9. Plot the strengths of all workable batches against cement-space ratio on the sheet prepared for plotting results of all student concrete projects. Plot the strengths also on the sheets prepared with cement content and with density as the X axis.

10. Plot three curves using one set of axes, showing the relationship between unit weight of the concrete and aggregate-cement ratio. First plot the unit weight of air-free concrete. These are calculated values. Then plot the unit weights as secured by your class. Finally plot the average, smooth curve to be used in all calculations. These are the values to go in column 10 of calculation sheet No. 1. All students should have the same curve in the third case in order

to facilitate checking and comparison with others. The instructor should decide on the values for this curve.

11. Plot the slump values against aggregate-cement ratio.

12. Plot the cement content of the concrete against the slump values.

13. Plot the cement content of the concrete against the aggregate-cement-ratio values.

Summary

14. Prepare a table summarizing the important items such as:

a. Aggregate-cement ratios
b. Slumps
c. Cement-space ratios
d. Cement contents
e. Water contents
f. Unit weights of concrete
g. b/b_0 ratios
h. Mortar factors
i. Densities
j. Strengths

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? How did the consistency of the concrete vary with the major variable?

2. According to Abrams, the strength of all workable batches should be the same. Are they? How much of a spread is there?

3. Talbot and Richart indicate that for the same cement-space ratio the wetter consistencies should produce lower strengths. How much of a spread in cement-space ratio is there? If the cement-space ratio spread is quite small, the average value might be used for all workable batches. If this is done, are the wetter batches consistently weaker than the drier ones?

4. What is the relationship between cement content and slump? What is the change in cement content for a reduction in slump from 6 to 3 in.? From 4 to 1 in.?

5. If a contractor were working under a specification providing for a fixed water-cement ratio, would it be to the contractor's advantage to use as dry a consistency as conditions will permit? What is the important item affected as far as the contractor is concerned?

DATA RECORD—TEST 33

EFFECT OF VARYING THE AGGREGATE-CEMENT RATIO FOR A CONSTANT WATER-CEMENT RATIO

1. Brand of cement ____________ Water-cement ratio ____________
2. Percentage of fine aggregate ____________
3. Size of cylinders: diameter ____________ in.; length ____________ in.
4. Mixer used ____________ Time of mixing ____________ min.
5. Date cylinders made ____________ To be tested ____________
6. Clock time: making ____________ capping ____________
7. Kind of cap used ____________
8. Date and clock time cylinders placed in moist room ____________
9. Curing conditions: ____________ day in molds; ____________ days in moist room

Batch number	Aggregate-cement ratio	Batch weights, lb.				Slump, in.	Unit weight concrete, lb. per cu. ft.	Air content, per cent
		Cement	Sand	Pebbles	Water			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1								
2								
3								
4								
5								
6								
7								
8								

Cylinder Strengths

1. Date cylinders tested ____________
2. Age at testing, days ____________
3. Testing machine used ____________
4. Average diameter of cylinders, in. ____________
5. Cross-sectional area, sq. in. ____________

Batch number (1)	Aggregate-cement ratio (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Sand, lb. (13)	Pebbles, lb. (14)	Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

$b_0 =$ ____________

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

TEST 34

EFFECT OF VARYING THE MAXIMUM SIZE OF THE AGGREGATE FOR A CONSTANT SLUMP AND WATER-CEMENT RATIO

Purpose

1. To show the effect of varying the maximum size of the aggregate, holding the slump and water-cement ratio constant. In order to hold the slump constant, the aggregate-cement ratio must be varied also.

Apparatus

2. See the list for Test 29.

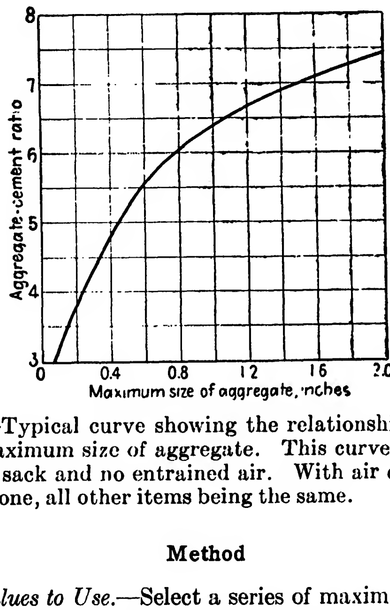

FIG. 1—test 34.—Typical curve showing the relationship between aggregate-cement ratio and maximum size of aggregate. This curve is for a water-cement ratio of 6¾ gal. per sack and no entrained air. With air entrainment the curve would be above this one, all other items being the same.

Method

3. *Selection of Values to Use.*—Select a series of maximum sizes of aggregate, which will cover a fairly wide range. Possible values for an eight-batch series are No. 10 sieve, No. 4 sieve, ⅜ in., ¾ in., 1 in., 1½ in., 2 in., and 2½ in.

4. Select the water-cement ratio to use in all the batches, such as 6, 6½, 6¾, 7 or 7½ gal. per bag of cement.

5. Select the slump range, such as 2 to 4 in., 3 to 5 in., 4 to 6 in., or 5 to 7 in. It may be difficult to secure slumps within the range selected the first time the test is run.

6. Select the aggregate-cement ratio to use with each maximum size of aggregate. A typical curve from the author's file is shown in Fig. 1. A few trial batches may need to be run before attempting the project with a class.

7. *Selection of Gradation for Each Batch.*—For the batches containing only fine aggregate, a commercial plastering sand and a commercial concrete sand are suggested. For the batches with coarse aggregate in them, it is suggested that

the percentage of sand be the value taken from the proper curve in Fig. 6-4. For the coarse-aggregate portion of the combined aggregate, it is suggested that the gradation follow a straight line from the No. 4 sieve up to the maximum size.

8. *Quantities of Materials per Batch.*—Using the values selected above, compute the weights of materials necessary to make enough concrete for the estimated requirements.

9. *Making and Testing Specimens.*—Weigh the materials, mix the concrete, and make the unit-weight determinations as outlined in Chap. 14. Make air-content determinations as outlined in one of Tests 25, 26, or 27. Make the slump test, mold, store, and test the cylinders as outlined in Chap. 14.

10. *Sieve Analyses and Unit-weights of Combined Aggregate.*—It is suggested that the sieve analysis of the combined aggregate in each batch be calculated and the results plotted on a single sheet of coordinate paper, as was done in Tests 29 and 30.

11. It is also suggested that the unit weight of the combined aggregate of each batch be determined and the results plotted, unit weight against maximum size of aggregate. The curves for the unit weights of the concrete can then be added to the same sheet, as was done in Tests 29 and 30.

12. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

13. *Curves.*—Average the strengths of all the batches. Plot this value on the curve sheet, showing the relationship between strength and water-cement ratio.

14. Plot the strength of each batch against cement-space ratio, cement content, and density on the proper graph sheets, which have been prepared for plotting the results of all concrete projects.

15. Plot three curves, showing the relationship between unit weight of the concrete and the maximum size of the aggregate, on the graph sheet that has been prepared for the unit weights of the combined aggregate as suggested above in paragraph 11. First plot the unit weight of the air-free concrete. These are calculated values. Then plot the unit weights as secured by your class. Finally plot the average, smooth curve for the unit weights to be used in all calculations. All students should have the same curve in the third case in order to facilitate checking and comparison with others. The instructor should decide on the values for this curve. Values will be recorded in column 10 of calculation sheet No. 1.

16. Plot a curve showing the relationship between aggregate-cement ratio and maximum size of aggregate.

17. Plot a curve showing the relationship between cement content of the concrete and maximum size of aggregate.

18. Plot a curve showing the relationship between cement-space ratio and the maximum size of the aggregate.

19. Plot a curve showing the relationship between fineness modulus of the combined aggregate and maximum size of the aggregate.

20. Plot a curve showing the relationship between b/b_0 values and the maximum size of the aggregate.

21. Plot a curve showing the relationship between mortar factor and the maximum size of the aggregate.

Summary

22. Prepare a table summarizing the important items such as:
a. Maximum size of the aggregate
b. Aggregate-cement ratios
c. Slumps
d. Unit weights of the concrete
e. Unit weights of the combined aggregate
f. Fineness modulus of the combined aggregate
g. Strengths
h. b/b_0 ratios
i. Mortar factors
j. Cement contents
k. Densities
l. Percentages of fine aggregate
m. Air contents if air entrainment is a feature

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item had to be varied in order to hold slump constant?

2. How well was the slump held constant? What was the range of actual values?

3. If air-entraining portland cement was used, was the air content relatively constant? If not, how did it vary with maximum size of the aggregate?

4. If an air-entraining admixture was used, was the rate per pound of cement held constant? If it was, was the air content of the concrete fairly constant? If the amount of the admixture was varied, how did it vary with the maximum size of the aggregate?

5. How did the aggregate-cement ratio vary with the maximum size of the aggregate?

6. Was the strength of all batches essentially the same? What was the average value? How much of a range was there?

7. How did strength vary with cement-space ratio? with cement content? with density? Were the variations large or small?

8. How did the cement content of the concrete vary with the maximum size of the aggregate?

9. How did the fineness modulus, b/b_0 ratio, and mortar factor vary with maximum size of the aggregate?

10. How did cement-space ratio vary with maximum size of the aggregate?

DATA RECORD—TEST 34

EFFECT OF VARYING THE MAXIMUM SIZE OF THE AGGREGATE FOR A CONSTANT SLUMP AND WATER-CEMENT RATIO

1. Brand of cement ______________ Water-cement ratio ______________
2. Size of cylinders: diameter ____________ in.; length ____________ in.
3. Mixer used ______________ Time of mixing ______________ min.
4. Date cylinders made ______________ To be tested ______________
5. Clock time: making ______________ capping ______________
6. Kind of cap used ______________
7. Date and clock time cylinders placed in moist room ______________
8. Curing conditions: ________ day in molds; ________ days in moist room

Batch number (1)	Maximum size of aggregate, in. (2)	Aggregate-cement ratio (3)	Fine aggregate, per cent (4)	Batch weights, lb.				Slump, in. (9)	Unit weight concrete, lb. per cu. ft. (10)	Air content concrete, per cent (11)
				Cement (5)	Sand (6)	Pebbles (7)	Water (8)			
1										
2										
3										
4										
5										
6										
7										
8										

Cylinder Strengths

1. Date cylinders tested ______________
2. Age at testing, days ______________
3. Testing machine used ______________
4. Average diameter of cylinders, in. ______________
5. Cross-sectional area, sq. in. ______________

Batch number (1)	Maximum size of aggregate, in. (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb. (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Sand, lb. (13)	Pebbles, lb. (14)	Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

$b_0 =$ ————————

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume Pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

TEST 35

EFFECT OF VARYING THE MAXIMUM SIZE OF THE AGGREGATE FOR A CONSTANT SLUMP AND AGGREGATE-CEMENT RATIO

Purpose

1. To show the effect of varying the maximum size of the aggregate, holding the slump and aggregate-cement ratio constant. In order to hold the slump constant, the water-cement ratio must be varied also.

Apparatus

2. See the list for Test 29.

Method

3. *Selection of Values to Use.*—Select a series of maximum sizes of aggregate, which will cover a fairly wide range. Possible values for an eight-batch series are No. 10 sieve, No. 4 sieve, 3/8 in., 3/4 in., 1 in., 1 1/2 in., 2 in., and 2 1/2 in.

4. Select the aggregate-cement ratio to use in all the batches, such as 5 1/2, 6, 6 1/2, or 7.

5. Select a slump range, such as 2 to 4 in., 3 to 5 in., 4 to 6 in., or 5 to 7 in. It may be difficult to secure slumps within the range selected the first time the test is run.

6. Select the water-cement ratio for each batch. If no data is at hand from which to make an estimate, water can be added to the batch during the mixing operation from a weighed supply until the consistency of the concrete appears satisfactory.

7. *Selection of Gradation for Each Batch.*—For the batches containing only fine aggregate, a commercial plastering sand and a commercial concrete sand are suggested. For the batches with coarse aggregate in them, it is suggested that the percentage of sand be the value taken from the proper curve in Fig. 6-4. For the coarse-aggregate portion of the combined aggregate, it is suggested that the gradation follow a straight line from the No. 4 sieve up to the maximum size.

8. *Quantities of Materials per Batch.*—Using the values selected above, compute the weights of materials necessary to make enough concrete for the estimated requirements.

9. *Making and Testing Specimens.*—Weigh the materials, mix the concrete, and make the unit-weight determinations as outlined in Chap. 14. Make air-content determinations as outlined in one of Tests 25, 26, or 27. Make the slump test, mold, store, and test the cylinders as outlined in Chap. 14.

10. *Sieve Analyses and Unit Weights of Combined Aggregate.*—It is suggested that the sieve analysis of the combined aggregate in each batch be calculated and the results plotted on a single sheet of coordinate paper, as was done in Tests 29 and 30.

11. It is also suggested that the unit weight of the combined aggregate of each batch be determined and the results plotted, unit weight against maximum

size of aggregate. The curves for the unit weights of the concrete can then be added to the same sheet, as was done in Tests 29 and 30.

12. *Calculations.*—Calculate the values for each batch as explained in Chap. 6 under calculations.

13. *Curves.*—On the curve sheets, which have been prepared for plotting strength results from all concrete projects, plot the strengths of all batches. Connect the points with a series of straight lines. These sheets have as the X axis water-cement ratio, cement-space ratio, cement content, and density.

14. Plot three curves showing the relationship between unit weight of the concrete and the maximum size of the aggregate, on the graph sheet that has been prepared for the unit weights of the combined aggregate as suggested above in paragraph 11. First plot the unit weight of the air-free concrete. These are calculated values. Then plot the unit weights as secured by your class. Finally plot the average smooth curve for the unit weights to be used in all calculations. All students should have the same curve in the third case in order to facilitate checking and comparison with others. The instructor should decide on the values for this curve. Values will be recorded in column 10 of calculation sheet No. 1.

15. Plot a curve showing the relationship between water-cement ratio and maximum size of the aggregate.

16. Plot a curve showing the relationship between cement content of the concrete and maximum size of the aggregate.

17. Plot a curve showing the relationship between cement-space ratio and the maximum size of the aggregate.

18. Plot a curve showing the relationship between fineness modulus of the combined aggregate and the maximum size of the aggregate.

19. Plot a curve showing the relationship between b/b_0 ratio and the maximum size of the aggregate.

20. Plot a curve showing the relationship between mortar factor and the maximum size of the aggregate.

Summary

21. Prepare a table summarizing the important items such as.

a. Maximum size of the aggregate
b. Water-cement ratios
c. Slumps
d. Unit weights of the concrete
e. Unit weights of the combined aggregates
f. Fineness modulus of the combined aggregates
g. Strengths
h. b/b_0 ratios
i. Mortar factors
j. Cement contents
k. Densities

l. Percentages of fine aggregate

m. Air contents if air entrainment is a feature

Study this table and the curves to secure ideas about the interrelationships between the various items, keeping in mind all the time the items that were varied and the ones that were held constant.

Study Questions

1. What was the major variable? What items were held constant? What item then had to be varied in order to hold the slump constant?

2. How well was the slump held constant? What was the range of actual slumps?

3. If air-entraining portland cement was used, was the air content relatively constant? If not, how did it vary with maximum size of aggregate?

4. If an air-entraining admixture was used, was rate per pound of cement held constant? If it was, was the air content of the concrete relatively constant? If the amount of the admixture was varied, how did it vary with the maximum size of the aggregate?

5. How did the water-cement ratio vary with the maximum size of the aggregate?

6. How did the strength vary with the water-cement ratio? With the cement-space ratio? With the cement content? With the density of the concrete?

7. How did the fineness modulus, b/b_0 ratio, and mortar factor vary with maximum size of the aggregate?

8. How did the cement content of the concrete vary with the maximum size of the aggregate? How does the density of the concrete vary?

Data Record—Test 35

Effect of Varying the Maximum Size of the Aggregate for a Constant Slump and Aggregate-cement Ratio

1. Brand of cement ______________ Aggregate-cement ratio ______________
2. Size of cylinders: diameter ______________ in.; length ______________ in.
3. Mixer used ______________ Time of mixing ______________ min.
4. Date cylinders made ______________ To be tested ______________
5. Clock time: making ______________ capping ______________
6. Kind of cap used ______________
7. Date and clock time cylinders placed in moist room ______________
8. Curing conditions: __________ day in molds; __________ days in moist room

Batch number	Maximum size of aggregate, in.	Water-cement ratio	Fine aggregate, per cent	Batch weights, lb.				Slump, in.	Unit weight concrete, lb. per cu. ft.	Air content concrete, per cent
				Cement	Sand	Pebbles	Water			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1										
2										
3										
4										
5										
6										
7										
8										

Cylinder Strengths

1. Date cylinders tested ______________
2. Age at testing, days ______________
3. Testing machine used ______________
4. Average diameter of cylinders, in. ______________
5. Cross-sectional area, sq. in. ______________

Batch number (1)	Aggregate cement ratio (2)	Total loads, lb. Individual (3)	Total loads, lb. Average (4)	Compressive strengths, p.s.i. (5)	Max. variation any cylinder from average, per cent (6)
1					
2					
3					
4					
5					
6					
7					
8					

Calculation Sheet No. 1

Batch number (1)	Solid volumes: Cement, cu. ft. (2)	Solid volumes: Sand, cu. ft. (3)	Solid volumes: Pebbles, cu. ft. (4)	Volume water, cu. ft. (5)	Volume batch, air-free basis, cu. ft. (6)	Weight batch concrete, lb. (7)	Unit weight concrete, air-free basis, lb (8)
1							
2							
3							
4							
5							
6							
7							
8							

Batch number (9)	Actual unit weight concrete, lb. per cu. ft. (10)	Actual volume batch concrete, cu. ft. (11)	Quantities of materials per cu. yd. of concrete: Cement bags (12)	Quantities of materials per cu. yd. of concrete: Sand, lb. (13)	Quantities of materials per cu. yd. of concrete: Pebbles, lb. (14)	Quantities of materials per cu. yd. of concrete: Water, gal. (15)	Yield, concrete per bag cement, cu. ft. (16)
1							
2							
3							
4							
5							
6							
7							
8							

Calculation Sheet No. 2

Batch number (1)	c (2)	a (3)	b (4)	w (5)	Density, $a+b+c$ (6)	$v=1-(a+b+c)$ (7)	Air voids $100\ (v-w)$, per cent (8)	$\frac{c}{v+c}$ (9)
1								
2								
3								
4								
5								
6								
7								
8								

b_0 = ____________

Batch number (10)	$\frac{a}{c}$ (11)	$\frac{b}{b_0}$ (12)	Fineness modulus (13)	Volume of mortar, cu. ft. (14)	Volume pebbles, cu. ft. (15)	Mortar factor (16)
1						
2						
3						
4						
5						
6						
7						
8						

APPENDIX A

Conversion Factors

Relation between Temperatures Centigrade and Fahrenheit.

$$\text{Temperature degrees Fahrenheit} = {}^9/_5{}^\circ\text{C.} + 32$$

$$\text{Temperature degrees Centigrade} = \frac{5(^\circ\text{F.} - 32)}{9}$$

English Metric Conversion Factors.

453.6 grams	=	1 pound
2.205 pounds	=	1 kilogram
28.35 grams	=	1 ounce
0.03527 ounce	=	1 gram
25.4 millimeters	=	1 inch
2.54 centimeters	=	1 inch
0.03937 inch	=	1 millimeter
0.3937 inch	=	1 centimeter
3.281 feet	=	1 meter
2.113 pints	=	1 liter
3.785 liters	=	1 gallon
16.39 cubic centimeters	=	1 cubic inch
28320 cubic centimeters	=	1 cubic foot
0.061 cubic inch	=	1 cubic centimeter
0.00003351 cubic foot	=	1 cubic centimeter

APPENDIX B

List of A.S.T.M. Specifications for Concrete Materials and for Concrete and for Methods of Testing Concrete and Concrete Materials

Serial Designation	
C 10-37	Specifications for Natural Cement
C 14-41	Specifications for Concrete Sewer Pipe
C 29-42	Test for Unit Weight of Aggregate
C 30-37	Test for Voids in Aggregate
C 31-44	Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field
C 33-46	Specifications for Concrete Aggregates
C 39-44	Test for Compressive Strength of Molded Concrete Cylinders
C 40-33	Test for Organic Impurities in Sands for Concrete
C 42-44	Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexure Strengths
C 55-37	Specifications for Concrete Building Brick
C 58-28	Definition of Term Sand
C 58-28T	Definition of Term Aggregate
C 70-47	Test for Surface Moisture in Fine Aggregate
C 75-41	Specifications for Reinforced-concrete Sewer Pipe
C 76-41	Specifications for Reinforced-concrete Culvert Pipe
C 78-44	Test for Flexural Strength of Concrete (Using Simple Beam with Third-point Loading)
C 85-42	Test for Cement Content of Hardened, Portland-cement Concrete
C 87-47	Test for Measuring Mortar-making Properties of Fine Aggregate
C 88-46T	Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C 90-44	Specifications for Hollow Load-bearing Concrete-masonry Units
C 94-48	Specifications for Ready-mixed Concrete
C 109-47	Test for Compressive Strength of Hydraulic-cement Mortars
C 111-36	Specifications for Sodium Silicate for Curing Concrete
C 114-47	Chemical Analysis of Portland Cement
C 114-48T	Chemical Analysis of Portland Cement
C 115-42	Test for Fineness of Portland Cement by the Turbidimeter
C 116-44	Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method)
C 117-37	Test for Amount of Material Finer than No. 200 Sieve in Aggregates
C 118-39	Specifications for Concrete Irrigation Pipe
C 123-44	Test for Coal and Lignite in Sand

Serial Designation	
C 124-39	Test for Flow of Portland-cement Concrete by Use of the Flow Table
C 125-46T	Definitions of Terms Relating to Concrete and Concrete Aggregates
C 127-42	Test for Specific Gravity and Absorption of Coarse Aggregate
C 128-42	Test for Specific Gravity and Absorption of Fine Aggregate
C 129-39	Specifications for Hollow Nonload-bearing Concrete Masonry Units
C 130-42	Specifications for Lightweight Aggregates for Concrete
C 131-47	Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine
C 136-46	Test for Sieve Analysis of Fine and Coarse Aggregates
C 138-44	Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete
C 139-39	Specifications for Concrete Masonry Units for Construction of Catch Basins and Manholes
C 140-39	Methods of Sampling and Testing Concrete Masonry Units
C 142-39	Test for Clay Lumps in Aggregates
C 143-39	Slump Test for Consistency of Portland-cement Concrete
C 145-40	Specifications for Solid Load-bearing Concrete Masonry Units
C 150-47	Specifications for Portland Cement
C 151-43	Test for Autoclave Expansion of Portland Cement
C 156-44T	Test for Water-retention Efficiency of Methods for Curing Concrete
C 157-43	Test for Volume Change of Cement Mortar and Concrete
C 171-42T	Specifications for Waterproof Paper for Curing Concrete
C 172-44	Method of Sampling Fresh Concrete
C 173-42T	Test for Air Content (Volumetric) of Freshly Mixed Concrete
C 174-44	Method of Measuring Length of Drilled Concrete Cores
C 175-48T	Specifications for Air-entraining Portland Cement
C 183-46	Methods of Sampling Hydraulic Cement
C 184-44	Test for Fineness of Hydraulic Cement by the No. 200 Sieve
C 185-47T	Test for Air Content of Portland-cement Mortar
C 186-47	Test for Heat of Hydration of Portland Cement
C 187-44	Test for Normal Consistency of Hydraulic Cement
C 188-44	Test for Specific Gravity of Hydraulic Cement
C 189-44	Test for Soundness of Hydraulic Cement over Boiling Water (Pat Test)
C 190-44	Test for Tensile Strength of Hydraulic-cement Mortars
C 191-44	Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles
C 192-47T	Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory
C 204-46T	Test for Fineness of Portland Cement by Air-permeability Apparatus
C 205-47T	Specifications for Portland, Blast-furnace Slag Cement
D 98-46T	Specifications for Calcium Chloride
E 11-39	Specifications for Sieves for Testing Purposes

APPENDIX C

Proof is given here of some of the formulas used in connection with a number of the tests.

Specific Gravity Formula—Pycnometer Method

Let W_a = weight of pycnometer full of water, g.
W_b = weight of pycnometer, sand and water, g.
W_f = weight of empty pycnometer, g.
W_1 = weight of water to fill empty pycnometer, g.
W_2 = weight of water to fill pycnometer with sand in the pycnometer, g.
W_o = weight of sample of sand, saturated, surface-dry basis, g.
G = specific gravity of sand

Formula:

$$G = \frac{W_o}{W_o - (W_b - W_a)}$$

Proof:

$$W_1 - W_2 = \text{weight of equal volume of water}$$

$$W_1 = W_a - W_f$$

$$W_2 = W_b - W_f - W_o$$

$$W_1 - W_2 = W_a - W_f - W_b + W_f + W_o$$

$$= W_o - (W_b - W_a)$$

Surface-moisture Formula—Chapman Flask Method

Let W = weight of moist sample, g.
W_o = weight of sample, saturated, surface-dry basis, g.
W_x = weight of surface moisture,
G = specific gravity, saturated, surface-dry basis
V = combined volume of sample and water, ml.
$w\%$ = percentage surface moisture based on saturated, surface-dry weight of sample

Formula:

$$w\% = \frac{V - 200 - (W/G)}{W + 200 - V} 100$$

Proof:

$$W = W_o + W_x$$

$$V = 200 + \frac{W_o}{G} + \frac{W_x}{1}$$

$$W_o = W - W_x$$

$$V = 200 + \frac{W - W_y}{G} + W_x$$

Multiply both sides by G

$$GV = 200G + W - W_x + GW_x$$

$$GW_x - W_x = GV - 200G - W$$

$$(G - 1)W_x = GV - 200G - W$$

$$W_x = \frac{GV - 200G - W}{G - 1}$$

The percentage of surface moisture is the weight of surface moisture, divided by the weight of aggregate on saturated, surface-dry basis, times 100.

$$w\% = \frac{W_x}{W - W_x} 100$$

$$w\% = \frac{\dfrac{GV - 200G - W}{G - 1}}{W - \dfrac{GV - 200G - W}{G - 1}} 100$$

Multiply both numerator and denominator by $G - 1$

$$w\% = \frac{GV - 200G - W}{GW - W - GV + 200G + W} 100$$

Divide both numerator and denominator by G

$$w\% = \frac{V - 200 - (W/G)}{W + 200 - V} 100$$

Surface-moisture Formula—Volumetric Method

This method is quite similar to the Chapman flask method, except that water will be taken from a measured supply in order to fill a flask or container to a given volume.

Let W = weight of moist sample, g.
W_o = weight of sample on a saturated, surface-dry basis, g.
W_x = weight of surface moisture, g.

G = specific gravity on a saturated, surface-dry basis
V = volume of the container or flask, ml.
V_x = volume of water added to fill the container or flask, ml.
$w\%$ = percentage of surface moisture based on saturated, surface-dry weight of sample

Formula:

$$w\% = \frac{V - V_x - (W/G)}{W + V_x - V} 100$$

Proof: The percentage of surface moisture is the weight of surface moisture, divided by the weight of aggregate on a saturated, surface-dry basis, times 100. Therefore:

$$w\% = \frac{W - W_o}{W_o} 100$$

To derive an expression for W_o, begin with

$$W = W_o + W_x$$

$$V = \frac{W_o}{G} + \frac{W_x}{1} + V_x$$

$$W_x = W - W_o$$

$$W_x = V - V_x - \frac{W_o}{G}$$

$$W - W_o = V - V_x - \frac{W_o}{G}$$

$$W_o - \frac{W_o}{G} = W + V_x - V$$

$$\frac{G-1}{G} W_o = W + V_x - V$$

$$W_o = \frac{G}{G-1}(W + V_x - V)$$

$$w\% = \frac{W - [G/(G-1)](W + V_x - V)}{[G/(G-1)](W + V_x - V)} 100$$

$$= \frac{W - (W/G) - W - V_x + V}{W + V_x - V} 100$$

$$= \frac{V - V_x - (W/G)}{W + V_x - V} 100$$

Surface Moisture Formula—Pycnometer Method

Let W = weight of moist sample, g.
W_o = weight of sample, saturated, surface-dry basis, g.

W_a = weight of pycnometer full of water, g.
W_b = weight of pycnometer, sample, and water, g.
G = specific gravity of particles of sample, saturated, surface-dry basis
$w\%$ = percentage of surface moisture based on saturated, surface-dry weight of sample

Formula:

$$w\% = \frac{(G - 1)W/G - (W_b - W_a)}{(W_b - W_a)} 100$$

Proof: The percentage of surface moisture is the weight of surface moisture divided by the weight of aggregate on a saturated, surface-dry basis, times 100. Therefore

$$w\% = \frac{W - W_o}{W_o} 100$$

To secure an expression for W_o, start with the formula for specific gravity, pycnometer method:

$$G = \frac{W_o}{W_o - (W_b - W_a)}$$

from which

$$W_o = \frac{G}{G - 1} (W_b - W_a)$$

Substituting this value of W_o in the above equation for $w\%$

$$w\% = \frac{W - [G/(G - 1)](W_b - W_a)}{[G/(G - 1)](W_b - W_a)} 100$$

Divide through by $\frac{G}{G - 1}$

$$w\% = \frac{(G - 1)W/G - (W_b - W_a)}{(W_b - W_a)} 100$$

Surface Moisture Formula—Weight-in-water Method

Let W = weight of moist sample, g.
W_o = weight of sample on saturated, surface-dry basis, g.
W_s = weight of sample suspended in water, g.
G = specific gravity of aggregate particles, saturated, surface-dry basis
$w\%$ = percentage surface moisture based on saturated, surface-dry weight of sample

Formula:

$$w\% = \frac{(G - 1)W/G - W_s}{W_s} 100$$

Proof: The percentage of surface moisture is the weight of surface moisture, divided by the weight of aggregate on a saturated, surface-dry basis, times 100. Therefore:

$$w\% = \frac{W - W_o}{W_o} 100$$

To secure an expression for W_o start with the formula for specific gravity, weight-in-water method:

$$G = \frac{W_o}{W_o - W_s}$$

from which

$$W_o = \frac{G}{G - 1} W_s$$

Substituting this value of W_o in the above equation for $w\%$

$$w\% = \frac{W - GW_s/(G - 1)}{GW_s/(G - 1)} 100$$

Divide both numerator and denominator by $\frac{G}{G - 1}$

$$w\% = \frac{(G - 1)W/G - W_s}{W_s} 100$$

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