BIRLA CENTRAL LIBRARY
PILANI (RAJASTHAN)
Call No. 624.15 S47F
Accession No. 55070

THE GLASGOW TEXT BOOKS OF CIVIL ENGINEERING. Edited by G. MONCUR, B.Sc., M.I.C.E., M.Am.Soc.C.E. *Professor of Civil Engineering in the Royal Technical College, Glasgow.*

FOUNDATIONS

Other Volumes in the Series.

ROAD ENGINEERING
E. L. Leeming, M.Sc., A.M.Inst.C.E

RAILWAY SIGNAL ENGINEERING (MECHANICAL)
Leonard P. Lewis, of the Caledonian Railway; Lecturer on Railway Signalling at the Royal Technical College, Glasgow.

MODERN SANITARY ENGINEERING
Gilbert Thomson, M.A., F.R.S.E., M.Inst.C.E.

REINFORCED CONCRETE RAILWAY STRUCTURES
J. D. W. Ball, A.M.Inst.C.E.

HYDRAULICS OF PIPE LINES
W. F. Durand, Professor of Mechanical Engineering, Leland Stanford University, California.

EARTHWORK IN RAILWAY ENGINEERING
J. W. P. Gardner, M.Inst.C.E.

DOCK AND LOCK MACHINERY
William Hunter, M.Inst.C.E.

SURVEYING AND FIELD WORK
J. Williamson, A.M.Inst.C.E.

PLANE AND GEODETIC SURVEYING
David Clark, B.Sc. In 2 volumes.

PRACTICAL DESIGN OF SIMPLE STEEL STRUCTURES
David Stewart, B.Sc.

THE GLASGOW TEXT BOOKS.
EDITED BY G. MONCUR.

FOUNDATIONS

THE EXAMINATION AND TESTING OF THE GROUND PRELIMINARY TO THE CONSTRUCTION OF WORKS

METHODS AND APPLIANCES

BY
WILLIAM SIMPSON O.B.E. (MIL.)
M.INST.C.E., M.INST.MECH.E., M.INST.STRUCT.E.
PAST PRESIDENT NEWCASTLE-UPON-TYNE
ASSOCIATION OF THE INSTITUTION OF CIVIL ENGINEERS,
FORMERLY CHIEF ENGINEER, PORT OF SUNDERLAND,
CONSULTING ENGINEER

LONDON
CONSTABLE & COMPANY LTD
10—12 ORANGE STREET W.C. 2
1928

PRINTED IN GREAT BRITAIN BY THE WHITEFRIARS PRESS, LTD.,
LONDON AND TONBRIDGE.

PREFACE

THE subject of Foundations generally covers so large a field that the space devoted in treatises to the matter of the preliminary investigation and testing of the ground, prior to the designing and construction of works, is necessarily brief. The need for a close examination of the natural conditions of ground which is to be utilised for works of construction is becoming more clearly recognised by engineers, and in many cases the necessary investigations have to be carried out by the engineer himself, or under his personal direction. It is desirable, therefore, that he should be familiar with the methods and appliances used in such exploratory work, and their proper application in practice, and that he should be able to interpret correctly the results obtained from investigations of the ground under varied conditions, and to apply them with intelligence to constructional problems.

The following chapters attempt to show at some length the intimate relationship which exists between Structural Geology and Civil Engineering generally, and to describe in detail the methods and appliances used under varied conditions to obtain the data necessary to disclose the structural and lithological properties of the ground, and the capabilities of soils as regards bearing and compression, in connection with works of construction.

The author desires to acknowledge his indebtedness to the Sullivan Machinery Company, London, for the photographs of "Sullivan" diamond drills reproduced in Chapter IV. of this book.

WM. SIMPSON.

SUNDERLAND,
July, 1927.

CONTENTS

CHAPTER I

GEOLOGICAL CONDITIONS IN RELATION TO WORKS OF CONSTRUCTION

CHAPTER II

METHODS OF EXAMINATION—PROBING ON LAND, AND UNDER WATER

CHAPTER III

METHODS OF EXAMINATION—BORING ON LAND, WASH BORING, AND PERCUSSIVE BORING

CHAPTER IV

METHODS OF EXAMINATION—BORING ON LAND, ROTARY BORING

CHAPTER V

METHODS OF EXAMINATION—BORING UNDER WATER, WASH, PERCUSSIVE, AND ROTARY BORING

CHAPTER VI

METHODS OF EXAMINATION—SINKING OF BORE HOLES

CHAPTER VII

METHODS OF EXAMINATION—TEST PITS AND SHAFTS

CHAPTER VIII

TESTING GROUND FOR BEARING AND COMPRESSION

LIST OF ILLUSTRATIONS

FOUNDATIONS

CHAPTER I

GEOLOGICAL CONDITIONS IN RELATION TO WORKS OF CONSTRUCTION

It is essential that the engineer should have the fullest knowledge possible of the strata through which works of construction are to be carried, from the important bearing it has on their design, execution, and cost. The greater the magnitude and importance of the projected works, the more accurate and searching should be the examination of the ground. Delays in completion, increased costs, and failures of engineering works are, in many instances, traceable to inadequate or misleading information regarding the strata at the beginning.

Geological Surveys for Engineering Purposes

A survey of the geological structure of an area within which important engineering works are to be executed, is a necessary preliminary to the detailed examination of the ground which engineers usually make by means of test borings, test pits, and other direct means of investigation for the purpose of obtaining local information.

Object of the Geological Survey.—The general object of a geological survey for engineering purposes is to determine :—

(1) The structure of the area.
(2) The lithology of the area.

(1) Structure.—By structure is meant the extent, arrangement, and thickness of the solid rocks and of the superficial deposits, or unconsolidated rocks, under which the former frequently lie.

The question of structure concerns the rocks as in two main divisions :—

(*a*) The Solid Rocks.
(*b*) The Superficial Deposits.

(*a*) *The Solid Rocks.*—The solid rocks comprise the great igneous, sedimentary, and metamorphic classes. The igneous rocks have been solidified from molten materials, and are usually met with in large masses, or as bosses, cills, and dykes, which have pierced through or become intercalated with the other rocks. Granites, diorites, dolerites, and syenites are typical of this class. The sedimentary rocks have been derived from pre-existing rocks, and stratification is their great characteristic feature. Sandstones, limestones, marls, and shales are typical of this class. The metamorphic rocks have been formed from the original igneous and sedimentary rocks by alteration, chiefly due to pressure, heat, and water. Schists, gneisses, quartzes, and marbles are typical of this class.

(*b*) *The Superficial Deposits.*—The majority of engineering works is intimately associated with the superficial deposits, which nearly everywhere overlie the solid rocks as a comparatively thick covering. They consist mostly of sands, gravels, clays, loams, and boulder clays, summed up under the comprehensive term of "drift." As compared with the solid rocks, they are highly variable and inconstant, and subject to rapid changes in thickness and disposition over short distances. For this reason they must be investigated more closely than solid rocks by using the most positive and direct tests, as afforded by test borings and pits.

(2) LITHOLOGY.—By lithology is meant the study of the rocks as they exist in the field, having regard to their characteristic appearance and composition. The solid rocks are divisible into distinct groups, differing from each other in lithological character, and distinguished by specific names. In so far as general characteristics are concerned, the chief points of difference are :—

(*a*) Composition.
(*b*) Appearance of weathering.
(*c*) Structure and texture.
(*d*) Fracture.
(*e*) Feel.
(*f*) Specific gravity.
(*g*) Colour.

The lithological character of the superficial deposits is generally apparent to the eye. Thus the unconsolidated sand-rocks are typically represented by sands, gravels, and shingles, differing in mineral composition, due to their varied sources of origin, and often in colour, and with a strong tendency to stratification. The clay-rocks are generally met with as beds of plastic clays of sedimentary origin, differing greatly in composition and colour, white, grey, green, brown, red, and bluish clays being common colours. Loam is principally an admixture of clay and sand, of varying composition and colour. Boulder clay is a stiff, gritty, and tenacious clay, usually unstratified, with a proportion of worn stones in it, which may vary in size from pebbles up to large boulders. The colour of the clay varies according to its source of derivation, red, grey, yellow-grey, and blue-grey being typical colours.

The differences in the lithological character of rocks are of great importance in tracing them in the field, and identifying them from test borings and pits.

Geological Survey Maps.—Much valuable information is given in the geological maps published in this and other countries with regard to regional topography and geology. The Geological Survey Departments of Great Britain and Ireland use the Ordnance Survey maps for geological mapping purposes, the areas occupied by groups of rocks being defined by distinctive colouring. The usual map scales are 1 in. to a mile, and 6 in. to a mile. In addition, horizontal sections, to a scale of 6 in. to a mile, showing the general geological structure, and vertical sections, usually to a scale of 40 ft. to an inch, showing further details are published. Most of the geological maps have accompanying memoirs giving a description of the geology of the map to which they refer, and other valuable information for which there is no room on the maps. Further detailed information is to be found in the district memoirs and numerous pamphlets dealing with special matters, such as water supply.

Before commencing a geological survey, the foregoing sources of information should be freely consulted where applicable to the case, as well as any other reliable publications on the subject by accredited societies.

Method of Procedure.—The methods employed in geological surveying are too comprehensive to be dealt with here, and special treatises on the subject should be consulted for information as to its principles and practice, but its general relationship to engineering problems will be pointed out briefly.

A geological survey may be made by the engineer himself, provided that he has a practical knowledge of geological field work, or, and preferably, in collaboration with an expert who has specialised in the practical application of geology to engineering. So far as engineering requirements are concerned, the geological survey may be of a preliminary nature, in which the broad structural and lithological features only of an area are necessary for the purpose in hand, as in running trial lines of communication, or prospecting for a suitable site for an impounding reservoir ; or it may be of a full and complete character, in which the structure and lithology of a fixed route or site are worked out in detail, with a view to the execution of engineering works within the selected limits.

Geological surveys for engineering purposes may therefore be divided into :—

(1) A preliminary survey.
(2) A detailed survey.

(1) PRELIMINARY SURVEY.—The object of a preliminary survey is to ascertain the broad geological structure and the general lithological character of an area sufficiently well to disclose its

suitability, or otherwise, for the execution of projected engineering works. As several surveys of this kind may have to be made before a definite decision can be arrived at as to the best route or site, the necessary data should be got together in the readiest way by largely using existing information. The general structure of the area may be visualised by a careful study of the geological maps and sections relating to it, together with the supplementary information to be found in memoirs and other publications. Sections should be constructed from the maps showing as far as possible the geological structure, and if the area is limited it will be found necessary as a rule to embrace a much wider field before this can be done satisfactorily. The sections should be made in the direction of dip, and to a natural scale, so as to convey a true conception of structure. It will then be seen what further data, if any, are necessary to complete the survey map and sections to the extent required, and which must be sought for in the field.

As the preliminary survey partakes of the nature of a reconnaisance, the main features of structure only need be followed out, and in this respect the general topography should be carefully studied on the ground, as it generally is the key to the geological structure. All outcrops and natural and artificial exposures should be examined and marked on the contoured map, together with the dip and strike of the beds. Persistent beds should be followed out fully, as they form a kind of structural base or datum, and make a good check on the correctness of the improvised sections. The general lithological character of the strata should also be noted. In an area occupied by surface deposits, with only occasional or partial exposures, while the boundaries may be traced, the thickness and character of the materials making up the deposits remain hidden. If thought necessary in such cases to obtain further information regarding them, a few test borings or pits, placed in well chosen positions, will probably meet the want.

From the supplementary information collected in the field, the geological plan and sections can be completed sufficiently well to be of service in studying the physical conditions with reference to the projected works. In this respect the sections will be found to be of particular value in disclosing the geological structure of which the surface perhaps gives no clear indication, and of suggesting better alternative schemes for alignment or site, should it be apparent that the one chosen is not satisfactory.

(2) DETAILED SURVEY.—The detailed survey has for its object the recording of all geological information likely to affect the designing and construction of the works, and detail and accuracy are therefore required. The undertaking of this survey presupposes that the route or site of the works has been practically fixed, and special attention must be given to acquiring the fullest information regarding the structure and lithology of the area. If a preliminary survey has already been made, it will facilitate the work of the detailed survey, as the general structure of the area is known to begin with. The basis of this survey will be a large scale contoured map or plan, accurately constructed, as from this plan the true dip and thickness of the beds will be calculated, and graphically projected. The outcrops and boundaries of the various rock beds and rock groups will require to be accurately marked upon the plan, and dip and strike taken and noted whenever opportunity occurs, as a check upon the calculated figures derived from the plan. The lithological character of the beds should be recorded, and their degrees of resistance to weathering carefully noted. In general, no physical feature should be passed over which is likely to bear upon or affect the construction of the works.

It will hardly be possible to complete a survey of this kind without having recourse to test borings and pits, which will be found necessary where the surface evidence is insufficient or doubtful, as, for instance, in the vicinity of a concealed fault. They should be put down intelligently with reference to the geological structure, and at the most advantageous points so as to give the most reliable and comprehensive information without multiplying their number. The true dip, strike, and thickness of concealed beds can always be found, in the absence of reliable data, from three such test borings or pits properly placed to form a triangle and sufficiently deep, the positions and levels of which are known. Where igneous rocks occupy an area, they are usually so irregular and variable that search has to be made for them in this way, and faults and highly folded strata should be proved in a similar manner. The same remarks apply to superficial deposits, the structure and composition of which are concealed, and about which no reliable information can be got except by test borings and pits. From the engineer's point of view, it is desirable in a survey of this kind that doubtful inferences as to geological structure should be avoided, when direct evidence can be had by boring at reasonable cost.

From all the data at disposal, the geological plan can now be completed, and natural scale sections constructed in any required direction. In many cases it will be found advantageous to plot some of the sections to a large scale, and include upon them all the details of geological structure and lithology for convenience of study. With the detailed plans and sections before him, the engineer is in a position to prepare the necessary preliminary designs and estimates of the cost of the proposed works with a reasonable approach to accuracy.

When the final drawings are in course of preparation for the construction of the works, further detailed information as to the nature of the ground is obtained from test borings and pits, put down, as directed by the engineer, at points where an exact record of the strata is required for foundations and other constructional work. The data available from the detailed geological survey, together with that from these local borings and pits, form the basis on which the works are finally designed, and quantities and cost arrived at.

Identification of Rocks.—It is of great practical importance that the engineer should be able to recognise rocks in the field, both solid and superficial, as the success of engineering work depends so much on the correct interpretation of geological evidence. An unfamiliar acquaintance with rocks frequently leads to the confounding of one kind with another, and serious results may follow. From long experience, safe bearing loads have been assigned to certain rocks carrying foundations of structures, and it is obviously a matter of grave error to apply this data to the wrong rocks when designing and estimating the cost of engineering works. One of the most evident requirements, and most intimately connected with foundations, is that the engineer should be able to identify and describe correctly the rocks obtained in the form of samples from test borings and pits, as, apart from the question of design and cost, a schedule of borings usually forms an integral part of a contract for important engineering works, and if this is misleading heavy claims may be made by the contractor, and become the subject of costly litigation.

A sound grasp of structural geology is the basis on which all practical knowledge gained in the field is built up and applied. An intimate working acquaintance with rocks can only be got by long and careful observation of their appearance and behaviour as seen in natural exposures, and in cuttings, quarries, pits, and other artificial openings. The specific names of rocks can be learned, if necessary, by examining a district of which a good map and memoir are published by H.M. Geological Survey, and by comparison of hand specimens taken in the field with museum specimens. Engineers who are engaged in constructional works have unique opportunities, which should be studiously courted, of becoming thoroughly familiar with the appearance and behaviour of rocks as exposed in the works of railways, docks, water supply, and drainage whilst under construction. The experience thus acquired is invaluable in the successful solution of engineering problems, and gives the engineer confidence in dealing with the many difficult questions which arise in connection with foundations.

Dip and Strike in Relation to Works.—The general relationship of dip and strike to engineering works is a very important one. It affects their design and execution in a marked manner, and should be fully appreciated in all examinations of the ground. This relationship may be made clear by the following simple illustration, in which Fig. 1 shows in plan part of an area occupied by solid bedded rocks, the extent, sequence, thickness, dip and strike of which have been determined. It is proposed to carry a railway in cutting through this area, and preliminary sections or trial lines are made in three directions :—

(1) In the direction of the dip, *AA*.
(2) In the direction of the strike, *BB*.
(3) In a direction between the dip and the strike, *CC*.

(1) Cutting in Direction of Dip.—From the geological data a section along the line of dip, *AA*, can be plotted, as shown on Fig. 2. This section shows the true dip, sequence, and thickness of the strata, and is a correct representation of the general geological structure of the area.

The cross section of the proposed cutting, *AA*, is shown on Fig. 3, and it is to be noted that the edges of the beds where cut by a section line at right angles to the cutting are horizontal on both sides of it, as they follow the line of strike. The slopes of the cutting will thus be approximately the same on each side, and stand at a high angle if the rocks are reasonably durable. No exceptional difficulties may be expected either in executing or maintaining the works of this cutting under ordinary conditions.

(2) Cutting in the Direction of Strike.—The geological section along the line of strike, *BB*, is shown on Fig. 3. This section shows the beds in proper sequence, where cut through, but their thickness is exaggerated owing to their not being cut at right angles to their dip, and the general geological structure is not fully disclosed. The cross section of the proposed cutting, *BB*, is shown on Fig. 2, and here it is to be observed that the strata plunge steeply across the cutting, as they follow the line of dip. The slopes of the cutting will therefore be unequal, that

on the side where the beds dip into the cutting requiring to be formed at a much flatter angle than the side where they dip away from it. The amount of excavation from this cutting will, therefore, be much greater than that from the cutting which follows the line of dip (Fig. 2). The slopes will require special treatment

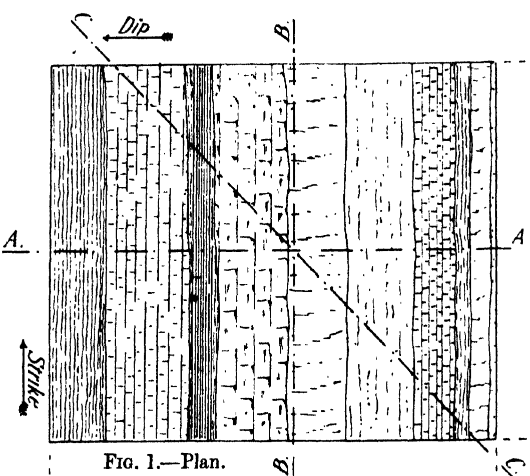


FIG. 1.—Plan.

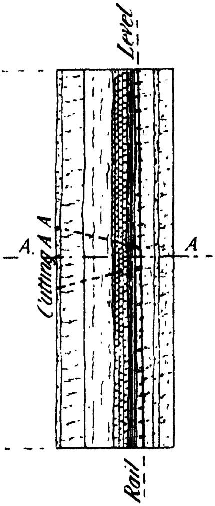


FIG. 3.—Section *BB* in Direction of Strike.

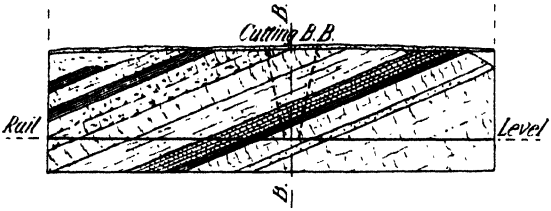


FIG. 2.—Section *AA* in Direction of Dip.

FIGS. 1—3.—Geological Plan and Sections of an Area Intersected by Cuttings.

to ensure stability, and many difficulties may be looked for, both in the construction and maintenance of the works of this cutting.

(3) CUTTING BETWEEN THE DIP AND THE STRIKE.—In the foregoing examples the cuttings are assumed to follow the dip and the strike respectively, but any other case may occur in practice where the line of cutting conforms neither to that of the

dip nor the strike, as in the direction *CC* (Fig. 1), which is assumed to be midway between them. The section along *CC* does not, therefore, show the geological structure correctly either as regards true dip or the natural thickness of the beds, although the sequence is correct, but only so far as the beds are cut. A cross section of the proposed cutting would show the strata dipping across the cutting, but at a less angle than indicated on Fig. 2. The slopes of this cutting will be unequal, but less so than shown on Fig. 2, and the difficulties to be contended with during execution and maintenance of the works would be of the same character as in the case of cuttings following the line of strike, although generally of a lesser degree.

Conclusions.—From the foregoing examples it is apparent that the data obtained from test borings, when made without reference to geological structure, are generally neither sufficient nor satisfactory on which to base designs and estimates for important engineering works, especially when the area under consideration is occupied by solid rocks, the boundaries of which are largely concealed. If, for instance, the geological section shown on Fig. 3 had been plotted from test borings, made without reference to the geological structure of the area, it might well be assumed, in the absence of further information, that the beds met with were horizontal throughout; and if the design and estimate of cost of the works had been based on this supposition, it would have been found necessary, after the works were begun, to revise the design to meet the actual conditions of the ground, as shown by cutting *BB* (Fig. 2), while the estimate would have been largely exceeded before completion of the works.

Works in Relation to Geological Conditions

Works are largely affected by geological conditions, and the general relationship may be indicated by drawing attention to certain features which commonly occur when dealing with :—

(1) Works in The Solid Rocks.

(2) Works in The Superficial Deposits.

(1) Works in The Solid Rocks

General Considerations.—In the case of the solid rocks, engineering questions must be considered in relation both to the structural arrangement and lithological character of the strata, as these are usually interdependent. The question, for instance, as to whether certain beds will stand at a given slope depends not only on their geological structure, but also on their lithological character, as although the rocks may be quite stable as regards their position in a natural formation, they may fail through the want of stability in composition. On the other hand, they may be stable as regards composition, but liable to slip out of position owing to peculiar conditions in the structural arrangement, such as a steep dip.

Cuttings.—Cuttings in solid rock involve largely the question of stability of the exposed beds when deprived of the natural support due to original continuity, and laid open to weathering.

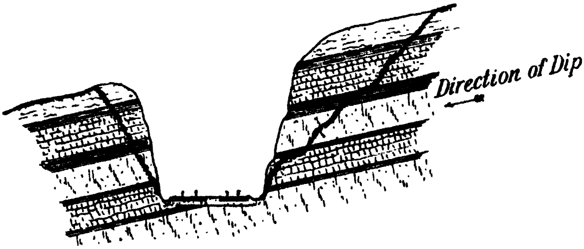


Fig. 4.—Cutting in Direction of Strike, with Natural Slopes.

The relationship of a cutting to the dip and strike of the beds exercises a strong influence upon their self-supporting values, in conjunction with the composition of the rocks themselves. The general effect of dip and strike has already been pointed out, but in the case of a railway cutting made in the direction of the strike (Fig. 4), a weak side is exposed, where the strata dip steeply into the cutting, and the edges of the beds having been sheared a considerable influx of water through the porous beds may be expected, together with slips of the materials into the cutting until the angles of repose are reached. It is apparent that the section of the cutting would require to be enlarged, as shown by the black lines, by benching back the beds, particularly on the right hand side, until security against slips is attained (Fig. 4), or a strong retaining wall of greater or less height constructed to hold them up, if the section of the cutting could not be enlarged, while a light facing wall may be necessary to arrest weathering and prevent small slips on the left hand side (Fig. 5). The influx of water from the porous beds would have to be dealt with by an adequate system of drainage, not only while the cutting was in course of construction, but also after its completion, so as to prevent the bottom becoming waterlogged, more particularly if it is composed of a non-porous stratum.

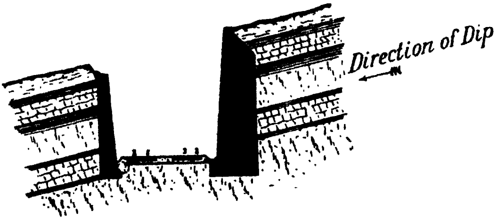


Fig. 5.—Cutting in Direction of Strike, with Supporting Walls.

Generally speaking, hard and homogeneous rocks, such as granite, free from numerous joints, may be reckoned to stand with a more or less vertical face, particularly if benched back at the bedding planes, and to withstand weathering. In such cases, owing to the non-porous character of the rocks, there will be little or no water present at the faces, and weathering consequently slow. On the other hand, porous and highly jointed rocks absorb much water, which, in conjunction with frost and aerial agents generally, leads to their early disintegration. Stratified rocks, unless of a massive, hard character, and free from numerous joints, such as certain sandstones and limestones, require to be sloped back, and the softer kinds, such as shales and marls, are liable to rapid disintegration when exposed to weather. When the rocks are of varying hardness, unequal weathering will result, as the softer layers are weathered more rapidly than the harder, thereby undermining them, and a fall or slip of the whole face results (Fig. 6). In such cases it will be necessary to protect the exposed surfaces with an artificial lining, or slope them back to the proper angles of repose.

Rocks with pronounced bedding planes require careful consideration before being opened up. Thus a road cutting on the face of a hill or cliff (Fig. 7), may be unsafe if the bedding planes dip towards it, as owing to the edges of the beds being exposed water finds access to and lodgement therein. Under the influence of frost and vibration from traffic, a slip of the lower part, *AB*, may take place bringing with it the upper, *BC*. If the line of the cutting is selected so that the bedding planes lie inwards from it, a condition of initial stability is ensured (Fig. 8).

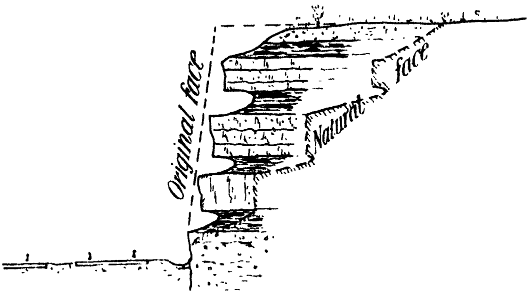


FIG. 6.—Unequal Weathering in a Cutting.

Faulted rocks may lead to great trouble and expense if their presence is unknown before constructional works are begun. The rocks are generally dislocated and shattered in the vicinity of a fault, and the faults themselves are usually the channels for the escape of water from the porous beds below.

In Fig. 9, a section is shown of faulted rocks within a proposed dock basin. Test borings, *BB*, put down in front of the dock walls in two parallel lines only would fail to reveal the presence of the fault, *F*. If it followed the line of strike of the beds the

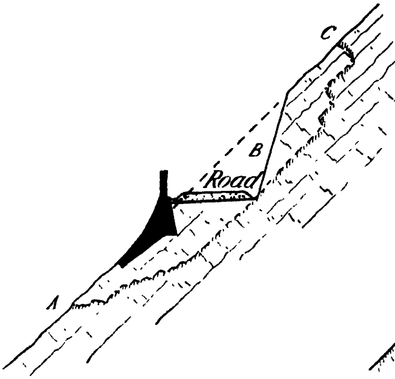


Fig. 7.—Unstable Bedding Planes.

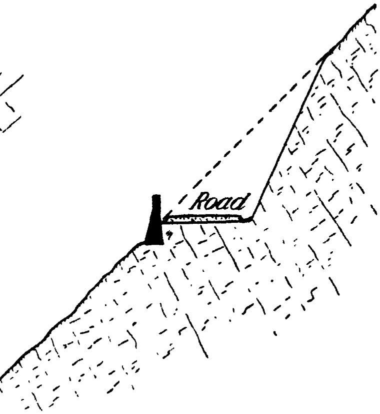


Fig. 8.—Stable Bedding Planes.

results of the borings would show the same succession and thickness of strata on either side lying at the same depths, and give the impression that they were more or less horizontal. Trouble would arise during construction from water finding its way into

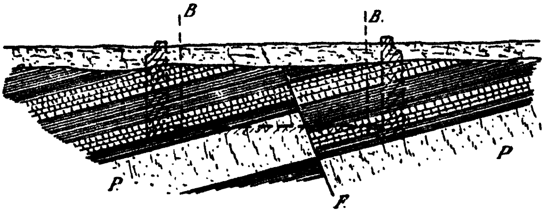


Fig. 9.—Dock Basin in Faulted Strata.

the wall trenches on either side, both of which are in communication with the fault by the porous beds, *P*, and when the materials between the walls were excavated to the dock bottom level, the right hand wall would tend to slide forward by forcing up the materials in front of the toe. If the water in the dock was impounded by gates, a considerable loss of depth might be anticipated during each tide, by reason of its escape through the fault to the porous bed on the left hand, marked *P*, on Fig. 9.

Embankments.—In the case of embankments the question of geological structure is the most important factor, as the rocks are not opened up and exposed as in the case of cuttings. The solid rocks may be trusted generally to carry heavy embankments if proper means are taken to remove soft and treacherous superficial accumulations, and to provide good drainage. When the strata are inclined and the surface deposits partake of a loose or slippery character, as at *A A* (Fig. 10), heavy slips of the embankment may take place, due to the movement of these deposits under the superincumbent load over the firmer surface of the rock (Fig. 10). The presence of water accumulating on the up

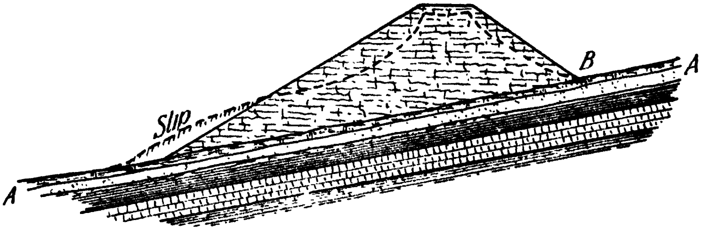


FIG. 10.—Embankment on Soft Overlying Ground, Unstable.

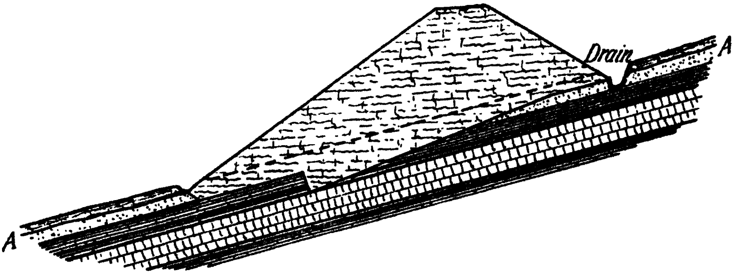


FIG. 11.—Embankment on Soft Overlying Ground, Stabilised.

side of the embankment, as at *B* (Fig. 10), further endangers the stability of the earthwork, and it may move bodily downhill under these conditions.

Should an examination of the ground by borings and pits reveal unfavourable conditions such as these, the loose and slippery materials should be removed, the ground properly drained in the vicinity, and the rock beds benched to form a good toe for the embankment (Fig. 11).

Tunnels.—Most that has been said in regard to cuttings in solid rocks applies equally to tunnels, but as tunnels are usually constructed at much greater depths below the surface the conditions are more complicated. In the case of tunnels, geological structure is the most important factor, as on it chiefly depends the choice of route, profile, and form, in so far as these are open, and the difficulties and cost of construction. Should artificial linings not be required to withstand the pressure of the strata, then the lithological character of the rocks will determine to what extent, if any, it is necessary to adopt lining to preserve the exposed surfaces from decay, or to carry the works through weak patches.

All information possible should be obtained in regard to the geological structure of the area through which it is proposed to drive a tunnel, and the necessity for a careful geological survey is apparent, together with deep test borings and shafts. When the thickness of the overlying strata is so great as to preclude deep borings and shafts being put down, the engineer has then to depend almost entirely on a geological survey for data, as in the case of deep Alpine tunnels. In massive, crystalline rocks and thick, horizontally bedded strata, reasonably free from joints, no great difficulties in construction need be anticipated, if the area is comparatively free from structural dislocation. The main object, however, of the examination of the ground is to discover in such cases if the rocks are really uniform in character and disposition from end to end, as the evidence derived from a few test borings and the general external appearance is not to be trusted.

The result of piercing bent strata without proper investigation as to its geological structure beforehand, is shown on Fig. 12, where the bed, *AA*, was assumed to be level throughout, as revealed by the borings, *BBB*, at the foot of the slopes. The tunnel passes out of the selected massive bed into a weak bed of shale, in which it would require to be heavily lined, and thereafter pierces the highly water-bearing stratum above, *P*, for the middle portion of its length. The difficulties and cost of construction, due to weak materials and water under these artesian conditions, would be enormously great as compared with the original conception of the work executed in firm, level beds throughout. The invasion of stratified rocks by an intrusive cill, *A* (Fig. 13), the presence of which the shallow borings, *BBB*, failed to reveal, introduces serious difficulties in the execution of the work of a tunnel, and would probably require a revision of the method of construction, and add greatly to the cost.

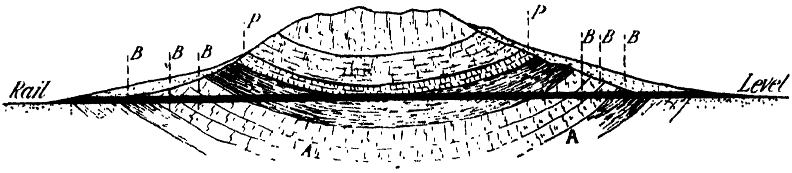


Fig. 12.—Tunnel in Bent Strata.

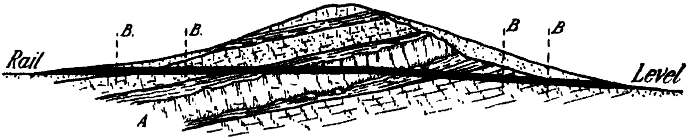


Fig. 13.—Tunnel Through an Intrusive Cill *A*.

As in the case of cuttings, the relationship of the line of the tunnel to the dip and strike of the beds exercises a modifying influence on its design. In the case of a tunnel following more or less the direction of dip of slightly inclined strata composed of firm and soft rocks (Fig. 14), the strike of the beds is generally at right angles to its longitudinal axis, and their side thrust may be treated as if they were horizontally bedded. There is thus little pressure from the strata on the sides and bottom of the tunnel, and light side walls will generally suffice as a lining. The roof, however, will require to be lined with an arch to support the downward pressure of the strata overhead, particularly where the sloping beds become thinned out as the tunnel passes from one to another, and where they are naturally weak (Fig. 13). Water may be expected where a pervious bed is pierced during construction.

If the tunnel is carried through the same area in the direction of strike (Fig. 15), there is considerable unsymmetrical pressure on the sides tending to shear it, due to the sliding of the hard beds upon the soft, and it then becomes necessary to use strong side walls, strutted by an invert, together with an arch to meet these conditions. A large quantity of water may be expected during construction from the edge, or edges of any pervious beds, cut lengthwise with the tunnel, which would have to be dealt with during the excavation of the works, and be evacuated by weep holes and suitable drainage on their completion to relieve the pressure on the lining.

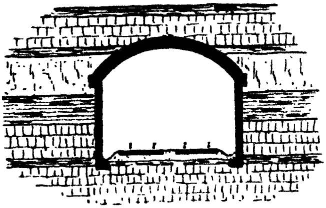


FIG. 14.—Tunnel following Dip of Beds.

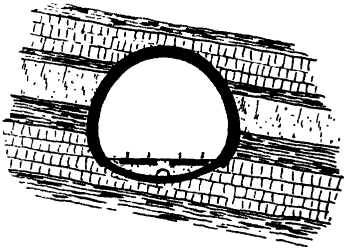


FIG. 15.—Tunnel following Strike of Beds.

In highly-inclined strata (Fig. 16), a tunnel following the line of strike is subject to great pressure from above, and would require to be lined throughout with a heavy lining, but less water might be expected, owing to the limitation of the catchment area over the tunnel, due to the verticality of the strata. If in any of the foregoing cases the tunnel is constructed in a massive bed of hard and homogeneous rock, such as granite, the work may be executed without special difficulty, so far as geological structure is concerned, and the question of lining would then depend principally upon lithological considerations.

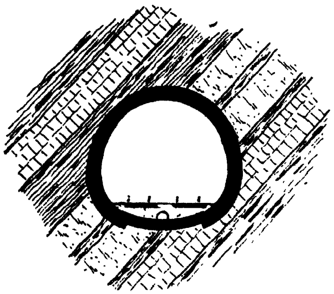


FIG. 16.—Tunnel following Strike of Highly-inclined Beds.

The effect of faulting on a tunnel is shown on Fig. 17, where a tunnel on a rising grade in hilly country eventually passes from the right hand side of a valley to its centre, where a concealed valley fault, *F*, exists. The tunnel pierces a hard, massive bed on the lower part of the grade, which presents no exceptional difficulties in construction, and affords a strong cover, but on reaching the centre of the valley encounters the fault with its shattered and dislocated beds, and enters a porous bed. The difficulties and cost of construction of this part of the work would be enhanced by reason of the weak materials of the beds, and the large volume of water for which the fault is the natural channel of voidance.

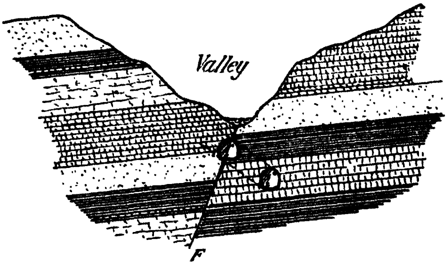


FIG. 17.—Tunnel Cutting Across a Valley Fault.

The lithological character of the rocks composing the area pierced by a tunnel is of great importance in deciding the strength and extent of artificial lining. Solid, crystalline rocks, such as granite and quartz, will stand when exposed without lining, and also the harder kinds of volcanic rock, such as basalt, while schists and schistose rocks generally need lining if the dip of the bedding planes is at a high angle or vertical. Stratified rocks generally require to be lined, unless they consist of massive beds of hard sandstone or limestone of close texture and free from many joints. Slatey rocks are liable to decomposition when exposed to the atmosphere, shales in particular being subject to rapid disintegration when water is present, and most volcanic tuffs and agglomerates require lining after being opened out for some time.

Impounding Reservoirs.—The examination of a site for an impounding reservoir in an area occupied by solid rocks, has for its primary objects the selection of a watertight basin or hollow from which the impounded water cannot escape by leakage, and a sound and stable foundation for the impounding dam. To meet these requirements it is evident that both the geological structure and lithological character of the rocks must be considered together. Rocks of a highly jointed, porous, and fissured character must be avoided as unsuitable for either a tight reservoir or a good foundation for the dam, and a much faulted, sharply folded, or dislocated geological structure generally has the same disqualifications.

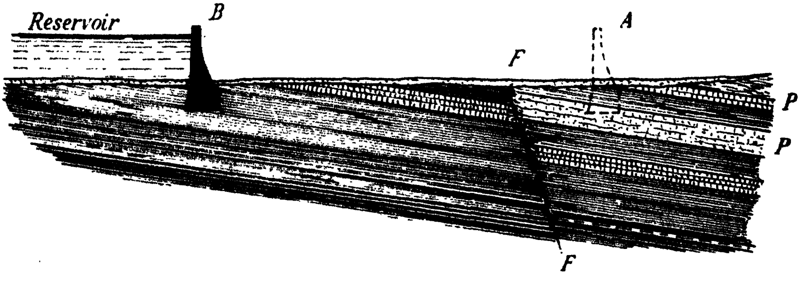


FIG. 18.—Selection of Site for Impounding Dam.

In illustration of the necessity for accurate geological data in selecting a reservoir site, the geological section of a valley in its longitudinal direction is shown on Fig. 18. At its lower end the strata dip downstream, and a fault exists at *F*, bringing the edges of the porous beds, *P*, to the surface. If the impounding dam was placed on a site, *A*, on the downstream side of the fault, *F*, the water in the reservoir would escape by the porous bed, *P*, and probably by the fault also, while the stability of the dam would be endangered by the access of water to the foundations through the porous stratum, and by the dislocations and fissuring of the strata in the vicinity of the fault. With the geological structure before him, the engineer would select a site further upstream, at *B*, where the solid impervious beds of massive shales would ensure tightness of the reservoir bottom, and afford a secure foundation for the dam. The geological structure of the sides of a valley requires consideration, as well as the bottom, up to at least the maximum water level of the reservoir. A geological cross section is shown on Fig. 19, where the strata dip at a low angle into the valley, and a porous bed, *P*, is exposed on both sides near the normal level of the reservoir. It is evident that leakage would take place through this bed at its low edge, where it is below the normal water level, and that the calculated capacity of the reservoir could not be maintained. A lower normal water level would, therefore, have to be adopted in the reservoir, with consequent reduction in storage capacity, or further examination might show that the porous bed could be cut off by a wing wall

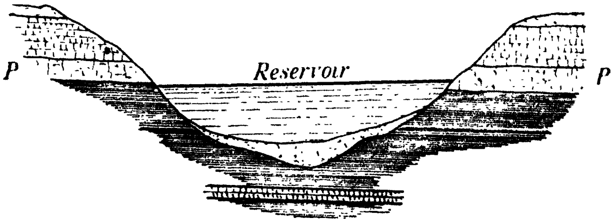


Fig. 19.—Reservoir with Porous Sides.

or trench, and made watertight if only submerged for a short distance.

(2) Works in The Superficial Deposits

General Considerations.—The superficial deposits comprise incoherent or non-consolidated materials in the form of sands, gravels, and boulder clays laid down in irregular sheets, usually complex in character. Engineering works are largely carried out in these deposits, and their geological structure and lithological character are of the greatest importance to the engineer. In addition to a general investigation of their geological structure, the rapidly varying character of these deposits calls for the closest examination of the ground by means of test borings and pits, in order to obtain reliable data where works of construction are concerned.

Fɪɢ. 0 —Cutting in Superficial Deposits in Direction of Strike.

Cuttings.—Generally speaking, cuttings in the superficial deposits require to be treated according to the nature of the materials opened out. All loose materials have a natural slope or angle of repose at which, under normal conditions, they are stable within the limits assigned, but their stability at these angles may be qualified by geological structure. As in the case of cuttings in solid rocks following the line of strike, a weak side is formed in cuttings in superficial deposits where the beds dip into the cutting (Fig. 20), necessitating a much flatter slope than if the beds had been level, or the support of a retaining wall. If this natural weakness is not allowed for, slips will take place into the cutting (Fig. 21).

Many superficial deposits, which when opened out stand at

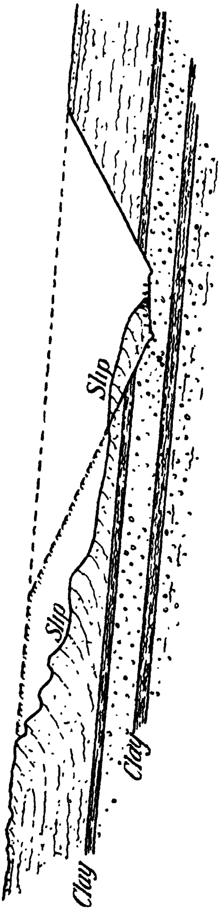


Fig. 21.—Slip of a Cutting through Inclined Slippery Beds.

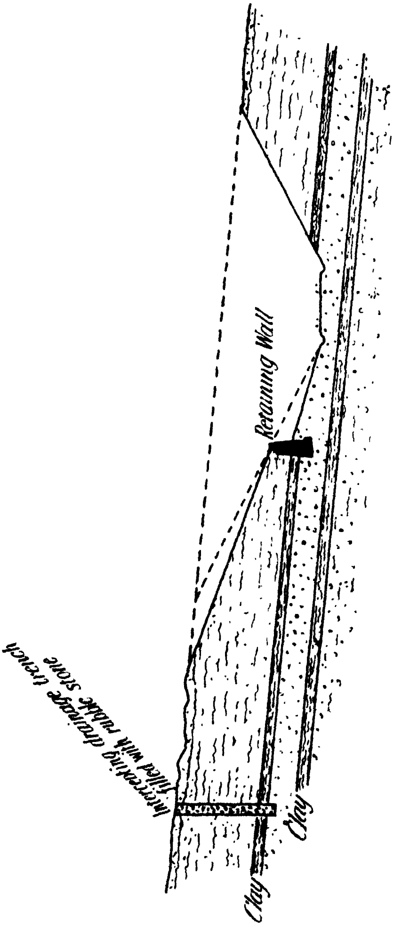


Fig. 22.—Treatment of Cutting Slip shown on Fig. 21.

steep slopes, lose cohesion rapidly on being exposed, and assume much flatter slopes. The lithological character of the various beds has, therefore, to be considered with a view to their proper treatment to secure permanency of form. Clays are amongst the most difficult materials to deal with, particularly when they are interlaminated with water-bearing sands. Cuttings in clay, which when newly exposed will stand at slopes of about 1 to 1, become highly unstable when waterlogged, especially at the foot of the slopes, where they will then assume a more or less level surface.

Cuttings in side-lying ground are liable to slips of the high side when the materials rest upon a slippery, non-porous bed, such as clay, the plane of rupture being generally that of the dividing bed (Fig. 21). In such cases the stability of the slope depends upon the successful interception, at some distance back from the top of the slope, of the drainage water which reaches and lubricates the surface of the bed, and is usually accomplished by cutting a trench, or driving a heading parallel to the cutting at the proper depth, and filling it with rubble stone. The treatment in this way of the slip shown in Fig. 21 is illustrated by Fig. 22.

Embankments.—In the case of embankments resting on superficial deposits, the question of geological structure is of most importance to the engineer, as slips due to the failure of the foundations are much more serious than ordinary slips arising from the composition of the embankment itself, which latter are chiefly concerned with the lithological character of the materials used in its construction. A high and heavy embankment tipped on soft or marshy ground is liable to heavy slips due to com-

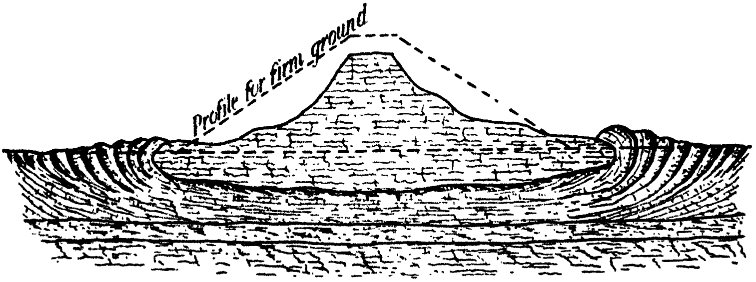


FIG. 23.—Embankment on Boggy or Marshy Ground.

pression and displacement of the soft materials on which it rests, and movement goes on until a condition of equilibrium is established; but this may not obtain until the volume of materials greatly exceeds that of the normal embankment based on the assumption of firm ground (Fig. 23). An embankment constructed in this way is liable later to slips of a serious nature when heavy traffic has been established over it, and is usually a source of much trouble and expense. A careful examination of the ground before work is commenced should forewarn the engineer to take special precautions to ensure stability by removing the soft materials, draining the area, or founding on a raft.

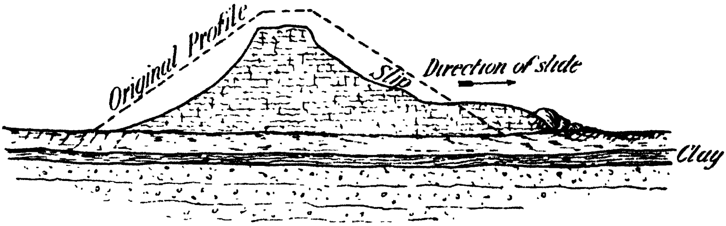


FIG. 24.—Embankment on Inclined Slippery Surface, Sliding Downhill.

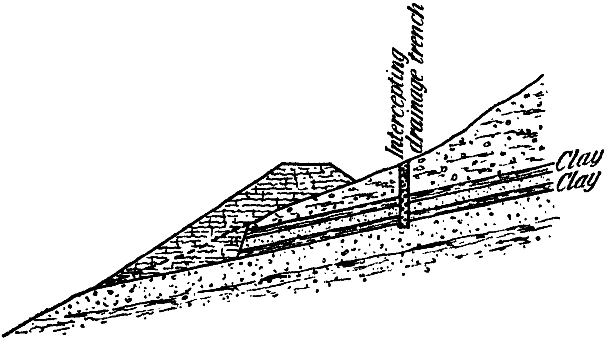


FIG. 25.—Embankment on Side-lying Slippery Ground, Treated to Secure Stability.

Embankments on side-sloping ground are liable to slips if the ground is wet and soft, and the area, therefore, requires thorough draining before the embankment is tipped (Fig. 24). When the surface materials rest on stratified beds which dip towards the railway, there is danger of the embankment moving bodily downhill, especially if there is an underlying slippery bed. In such a case the slippery bed should be cut away as much as possible so that the embankment may rest on a firm, porous stratum, and a deep trench cut parallel to the railway along the shoulder of the hill. This trench should be filled with rubble stone, and be tapped at intervals by cross drains passing underneath the embankment and discharging into the side drain on the lower side (Fig. 25). These considerations show the necessity for careful examination of the geological conditions of the ground before high embankments are constructed.

Tunnels.—Tunnels in the superficial deposits invariably require to be lined to resist the pressures put upon them by the more or less unstable materials of the beds through which they pass. The lithological character of such beds differs greatly, some giving a comparatively high power of cohesion and friction, as in the case of most compact clays, while others are practically without these properties, as in quicksands and mud. With the superficial deposits, the lithological character of the strata exercises a more direct influence upon the proper form and strength of the tunnel, as a rule, than geological structure. Thus in shallow tunnels constructed through loose materials, the superincumbent strata settle in wedge form along well defined lines of rupture, and the weight rests mainly on the roof, to meet which conditions the form of section adopted in practice is that of a high arch and side walls. In deep tunnels, in soft ground, and where the arching action of the strata relieves the roof pressure more or less, according to the joint cohesion and frictional resistance of the materials, an elliptical, or nearly circular section is used to resist the more uniformly distributed pressures, while in waterlogged, or highly unstable materials the form of section is circular, as being best suited to conditions which approximate to fluid pressure.

Geological structure, however, is the dominating factor generally in the choice of alignment and level, as the engineer would select, in so far as it was open to him, the conditions which would be most favourable for construction, as disclosed by the general geological structure. The knowledge that a suitable tunnelling bed was available, and could be relied upon throughout, would induce him to use it to the best advantage, and subordinate the design of the lining to its lithological character. Geological structure is also concerned directly with design and construction, as when a tunnel is carried through well defined beds of highly variable character, similar considerations as to dip and strike apply as to one constructed in the solid rocks. A tunnel pierced in the direction of the dip is subject to heavier pressures on the roof than on the sides, and heavy falls from the weaker beds overhead may be looked for during construction, and stronger linings be required in such places, while in dipping strata it may pass from impervious beds to a pervious one, and tap large quantities of water. On the other hand, a tunnel driven along the direction of strike is subject to unsymmetrical pressures on the sides, due to the tendency of the higher beds to slip, and must be designed to meet this contingency, while large volumes of water may gravitate from their cut edges into the heading. If, in either of these cases, the tunnel follows and is constructed wholly within a thick bed of naturally impervious material, such as firm clay, the execution of the work may be accomplished without special difficulties, so far as geological structure is concerned.

Tunnelling in the superficial deposits is usually a much more difficult matter than in the solid rocks, owing to the structural weakness, low cohesion and friction, and high variability of the former, as compared with the latter. The presence of large volumes of water in the superficial deposits is perhaps the greatest difficulty with which the engineer has to contend in tunnelling them, as not only has the water to be disposed of by draining and pumping during construction, but it affects certain materials, which, naturally firm and cohesive, become reduced to a plastic condition by its presence, and the difficulties and cost of construction are increased thereby. Thus a firm, self-supporting clay, if overlaid by heavily waterlogged sands and gravels, may be degraded to the consistency of soft putty by the percolation of water from above through its fissures when pierced, and sodden, laminated clays when opened out swell and bulge after a short exposure, and become amongst the most treacherous and difficult of plastic materials to tunnel. Tough and massive boulder clays may be tunnelled as easily as a soft rock, but are usually rendered difficult if interlaminated with water-bearing beds of sand and gravel. Water-bearing sands become "quick" when under pressure, and often cause serious damage to tunnel works when tapped, necessitating special means of voiding the water and detrital materials, and stronger timbering and tunnel lining.

From these, amongst other, considerations the need for an exhaustive examination of the ground is apparent, and a careful geological survey, with special attention directed to hydrological conditions, should be made, supplemented by many test borings and pits before tunnels are constructed in the superficial deposits. The information thus obtained will at least forewarn the engineer of the difficulties ahead, or suggest to him alterations in alignment and level by which they may be largely avoided, should circumstances permit of this being done. Borings should be carried down below formation level throughout, as shallow borings are likely to give erroneous impressions of the geological structure. In many tunnels, shafts are required for their construction, and afterwards for ventilation purposes. These are valuable for obtaining a fairly correct record of the sequence, dip, strike, thickness, and lithological character of the strata, and of the volume of water likely to be met with, and should be sunk before the tunnel works are commenced.

The construction of tunnels beneath the beds of rivers and estuaries is a difficult matter, owing to the natural presence of water, often with a great head. The deposits are usually mud, sand, gravel, and clay laid down in irregular sheets, which may change rapidly in extent, thickness, and composition. With such varying conditions it is necessary that the fullest information possible should be got regarding the ground. A geological survey of the superficial deposits should be made in the vicinity of the banks, supplemented by test borings and trial pits, and the river bed thoroughly investigated by numerous deep borings, as the conditions obtaining at the banks cannot safely be assumed to exist under the bed of the stream. For example, a tunnel commenced on the assumption that the sound bed of boulder clay, proved in the shafts on the river banks, must also occupy the bed of the river may be seriously in error, as it is frequently deeply eroded by a prehistoric stream, and its place taken by alluvial deposits. The greater part of the tunnel would thus be in loose and waterlogged strata, necessitating a change from the ordinary methods of construction, if in use, to that of the shield and compressed-air method (Fig. 26). Geological structure is here, again, the most important consideration in relation to subaqueous tunnels.

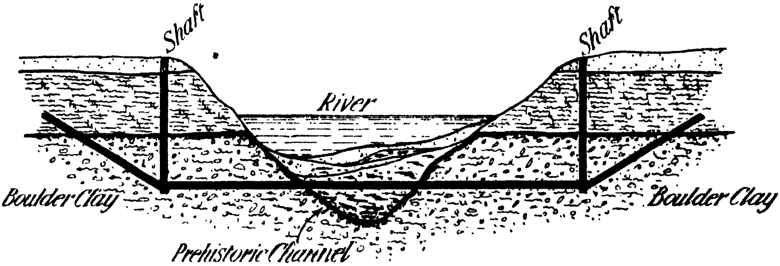


FIG. 26.—Subaqueous Tunnel, crossing Prehistoric Channel.

Impounding Reservoirs.—Many valleys are thickly coated over with glacial and alluvial deposits, and require careful investigation before they are selected as sites for impounding reservoirs. If the bottom and sides of a valley are thickly covered with clay of an impervious and homogeneous character, water may be successfully retained with little leakage when impounded (Fig. 27). On the other hand, if the hollow is occupied by beds of incoherent materials, such as mud, sand, gravel, or by clays interlaminated with water-bearing beds of sand, it is not likely to prove a satisfactory receptacle for water, as leakage will take place through the loose beds to the porous rocks below (Fig. 28). The tightness of a reservoir bottom is, therefore, dependent chiefly on geological structure, but the lithological character of the deposits has also an important bearing in this respect, as regards their composition, in being able to resist disintegration and remain watertight whilst constantly submerged under pressure.

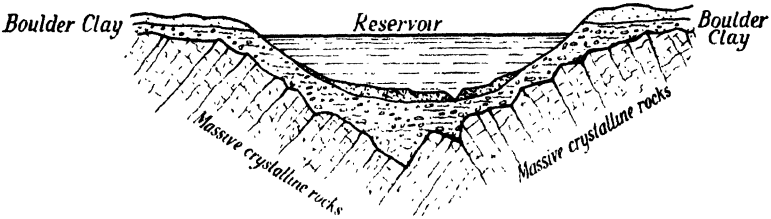


FIG. 27.—Reservoir with Impervious Bottom.

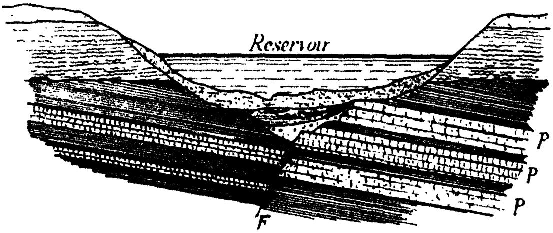


FIG. 28.—Unsuitable Site for Reservoir.

In the superficial deposits the foundation of the impounding dam requires to be carried down to a sound, impervious bed, and stability is thus primarily dependent on geological structure. The ground should, however, be proved by test borings and trial pits to a considerable depth below the intended level of the foundations, as the presence of a water-bearing stratum lower down is a source of danger. An embankment dam founded on a bed which is underlaid by a porous layer may be readily undermined by leakage, as in Fig. 29, but in this example a careful examination of the ground would have disclosed a suitable impervious stratum at a reasonably lower level, into which a tongue could have been carried, thus ensuring the stability of the dam by cutting off the water-bearing bed above (Fig. 30).

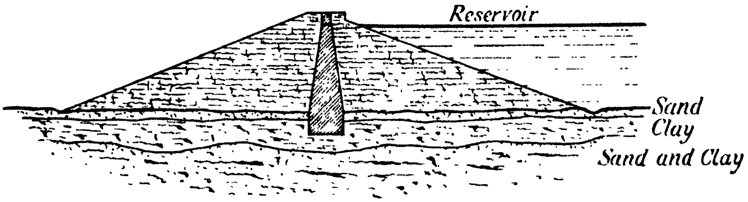


Fig. 29.—Impounding Dam, above Porous Strata.

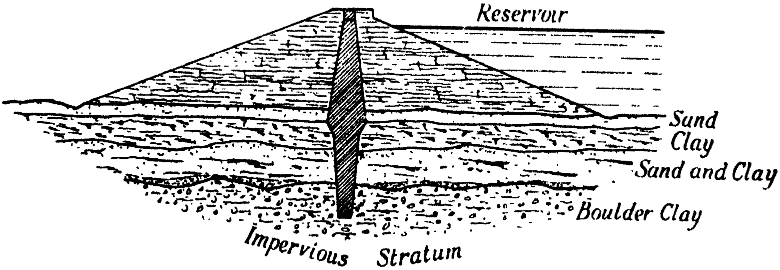


Fig. 30.—Impounding Dam, with Tongue Trench into Impervious Stratum.

In a dam of the embankment type, slips will occur if the strata on which it rests are of a treacherous character, and the ground requires to be proved by test borings and trial pits over the area occupied by its base and in the immediate vicinity. The geological considerations affecting embankments generally are equally applicable to earth dams.

CHAPTER II

METHODS OF EXAMINATION

THE methods of examination of the ground will be considered generally under the following heads, viz.:—

I. Probing.
II. Boring.
III. Pits and shafts.

I. Probing

General Considerations.—Probing is confined to shallow foundations of no great importance, and is perhaps the readiest method of ascertaining something of the true nature of the ground. The object of probing is to discover the presence and position of a compact stratum suitable for bearing a foundation. Such a stratum is usually expected to underlie a comparatively shallow covering of soft or loose materials, and by means of a probe or iron rod, pushed down as far as necessary, the ground can be sounded, and the firm bed located.

Probing is carried out under two distinct conditions, viz.:—

(1) Probing on land.
(2) Probing under water.

(1) PROBING ON LAND

Appliances.—The apparatus for probing on land usually consists of a probing bar of steel pointed at one end, and about 1¼ in. diameter, which is forced into the ground by working it up and down, jumper fashion, until a hard stratum is found (Fig. 31). When the resistance of the ground becomes too great a heavy hammer or mallet is used to drive the bar down, and an iron tiller or clamp is usually attached so that the bar can be rotated to facilitate its descent and subsequent removal. If the probing bar is long, a simple staging, consisting of timber trestles and cross planks for a platform, is erected to form a guide, and to bring the top of the bar within easy striking reach (Fig. 32). Sometimes thick iron or steel tubes, about 1¼ in. internal diameter, are used as probing bars, connected together by ordinary screw couplings, in which case the length of the bar can easily be varied to suit the ground. When tubes are used the bottom length is shod with a solid, forged, steel point, screwed flush or riveted on, and a solid, forged, steel cap is screwed to the top length to protect it from injury by the hammer (Fig. 33).

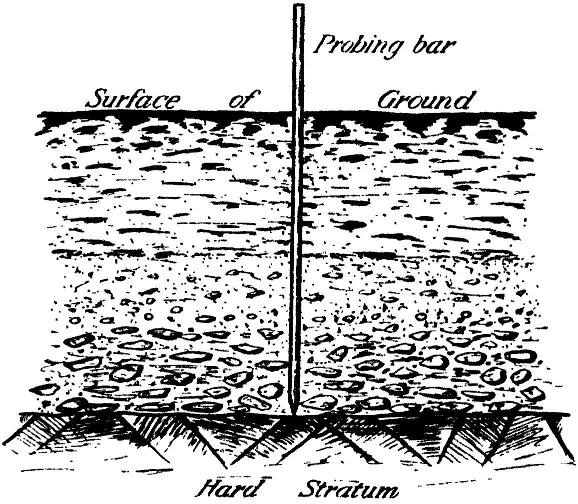


FIG. 31.—Probing Bar.

Setting out Probe Holes.—In an examination of the ground by probing, the holes are usually set out in a series of squares, varying in size from 5 to 50 ft., according to the amount of detail required. The holes are located at the intersections of the parallel lines, ranged at right angles to each other from two main base lines in the usual way, and should be marked by pegs

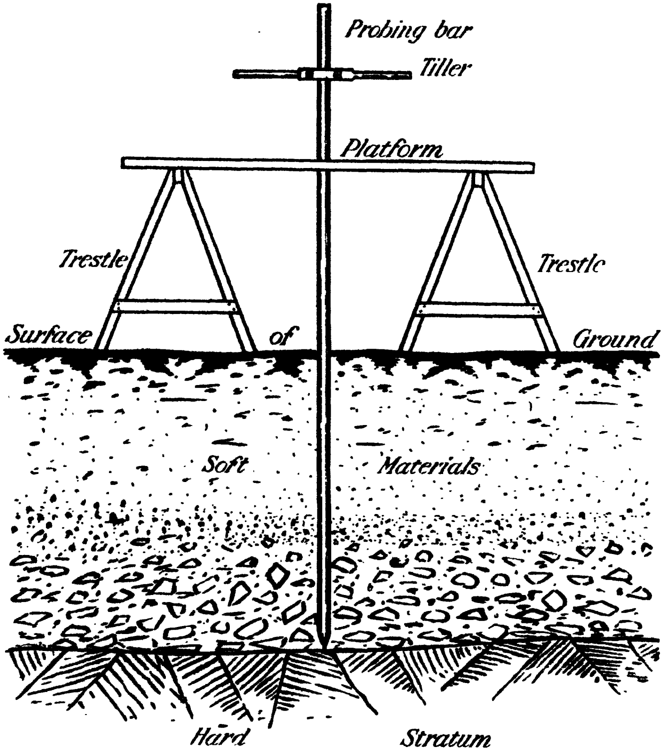


FIG. 32.—Probing Bar, worked from Platform.

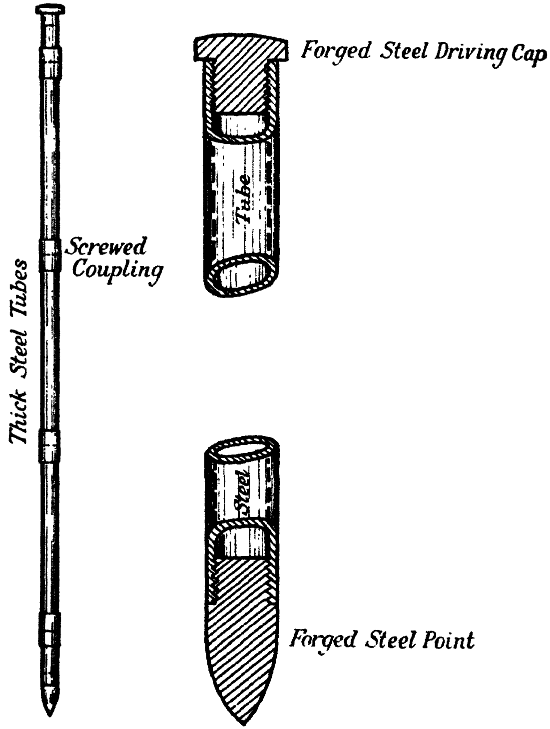


FIG. 33.—Tube Probing Bar.

(Fig. 34). Special holes not on the corners of the squares require to be carefully surveyed, so that they can be plotted in position. The surface levels should be taken at each point where a probing

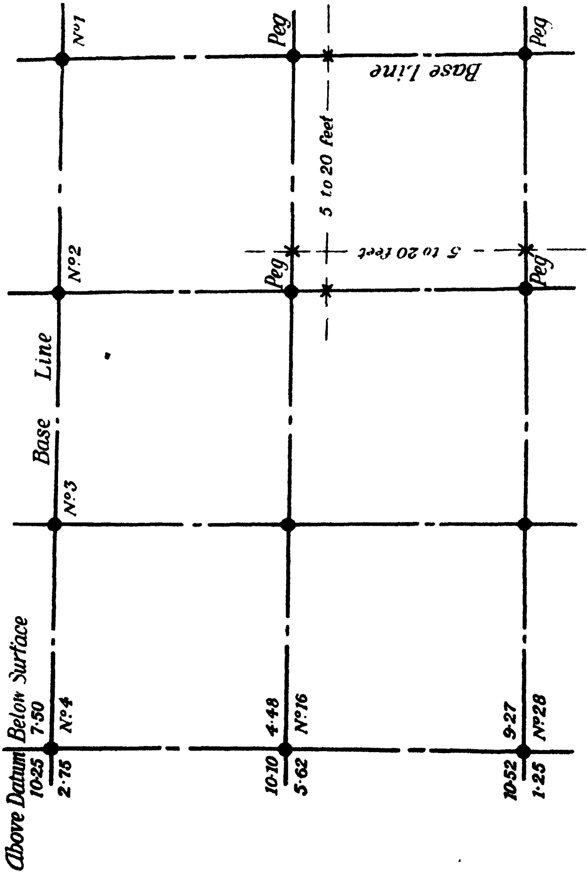


FIG. 34.—Setting out Probe Holes.

is made, and afterwards reduced to a suitable datum, together with any other levels taken on the probing bar during examination of the ground.

Procedure.—The length of the probing bar should be measured before it is entered into the ground, and any additions to or deductions from the initial length noted in course of driving. The bar is forced or driven down until it has entered hard ground, which is indicated by the resistance and "feel" of the bar, but it may be withdrawn and the point examined from time to time during driving for traces of the kind of ground passed through. Before being driven again, the bar should be thoroughly cleaned.

The distance from the surface of the ground to the top of the bar, or any convenient mark on it, should be measured before withdrawal, so as to locate the position and thickness of the stratum under scrutiny with reference to the level of the surface. When the bar has been forced down to refusal, a final measurement is made as before, and from the combined data the position of the hard stratum and the positions of the other strata located, can be plotted with reference to the surface of the ground and a datum line (Fig. 35). When probing bars or tubes are hard driven for a considerable distance, there may be difficulty in withdrawing them, in which case a hollow screw jack, or a toggle

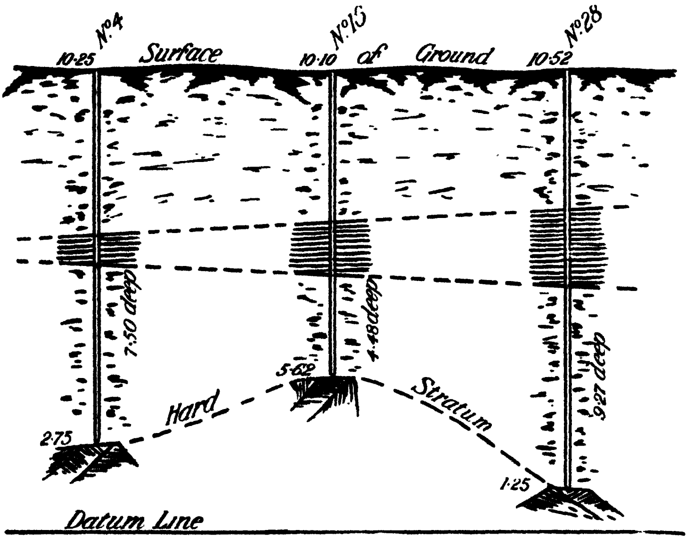


FIG. 35.—Section of Ground, Plotted from Probings.

gripper may be used for the purpose. If much time is likely to be expended in removing a bar, it is less costly to leave it in the ground altogether.

Probing can be carried to a depth of about 10 ft. in fairly compact materials, and to 20 ft., or even more, in very soft ground. It is a simple and inexpensive method of testing shallow ground, and in experienced hands gives fairly correct results, but it must be regarded in the light of a rough, preliminary examina-

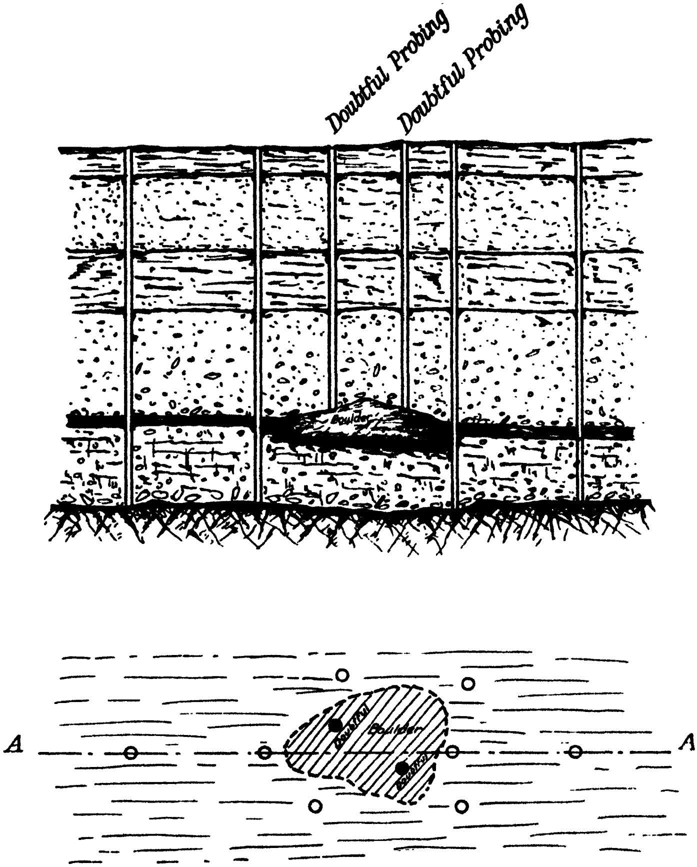


Fig. 36.—Testing Doubtful Probings.

tion only if used for constructional works of any importance. No reliance should be placed on the results obtained from casual probings, as the bar may easily be arrested by a stone or a boulder, thus giving misleading data (Fig. 36). It is only by multiplying the number of probings over an area that any sound inference can be made as to the nature of the ground generally.

Record of Probings.—The record of probings may be kept in the following manner :—

WEST POWER STATION. *Date: September 3rd*, 1922.

Probing No.	Reduced Levels.	Length of Bar.		Depth below Surface.		Nature of Ground.	Remarks.
	Ft.	Ft.	In.	Ft.	In.		
4.	10·25	10	0	0	0	Soft.	Surface of Ground.
	—	7	3	2	9	Loose and gravelly.	
	—	5	6	4	6	Soft and clayey.	Bar showed trace of clay.
	—	3	9	6	3	Hard and Stony.	
	2·75	2	6	7	6	Stones.	Bar would not go further; withdrawn.

Plotting Probings.—From the information recorded in the field book, a plan can be constructed showing the position of the hard stratum with reference to the datum at each probe hole, and also the depth at which the hard bottom lies below the surface of the ground (Fig. 34). The reduced levels of the surface of the ground and the hard stratum are written in place one above the other on the left side of each hole, and the depth of the hard stratum below the surface on the right. Cross sections in any required direction can be constructed as shown on Fig. 35, the nature of the ground being indicated by conventional markings or colourings.

(2) PROBING UNDER WATER

Appliances.—When the ground to be examined is under water, a probing bar, as already described, may be handled from a boat or raft. More usually, however, a special probing rod, or "pricker," is necessary for the purpose, consisting of a thin, tapered, steel bar, of round or square section, about ¾ in. across, sharp at the point, and about 4 ft. long. The bar has a socket at the upper end into which a wooden rod, about 2 in. diameter and 25 to 30 ft. long, is fitted and securely riveted in place (Fig. 37). The rod is graduated in feet and inches, or in tenths of

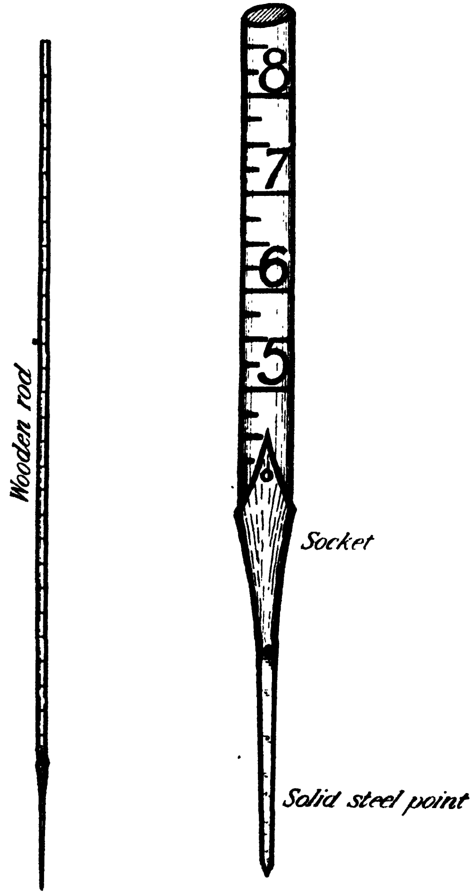


Fig. 37.—Graduated Probing Rod or Pricker.

a foot, reckoning from the steel point as zero, so that when forced into the ground the depths reached can be read off directly on the rod. In addition to the probing rod, a sounding rod is required to read the depths of water over the bottom, and usually a tide gauge to record the fluctuations in water level, as explained further on.

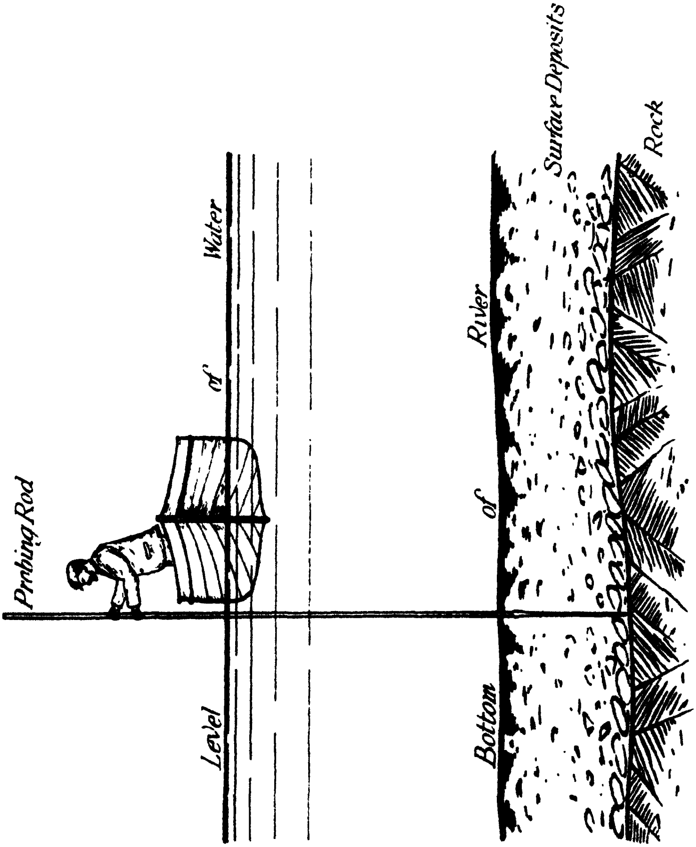


Fig. 38.—Probing under Water.

Procedure.—The boat is brought into position over the spot to be tested. A sounding is first taken on the spot, the tide gauge read, and the figures entered in the field book. The probing rod is then forced down into the ground on the spot where the sounding was taken by one or two men working it in a series of percussive thrusts, until the hard bottom is reached (Fig. 38). The water level on the probing rod is now read, and entered in the field book as in the case of probing on land, and the hardness and position of the stratum finally reached are judged by the resistance and " feel " of the rod. The length of probing rod which can be conveniently wielded in this way is about 25 to 30 ft. The relationship of the tide gauge reading, sounding, and probing to each other and to a common datum line, is shown on Fig. 49, under conditions of a fluctuating water level.

Setting out Probe Holes.—In probing under water the positions of the holes, and the accompanying soundings, must be carefully fixed. A general survey of the area to be investigated is usually made first, and the positions of the intended probe holes plotted on it. These are laid off in squares varying from about 10 to 50 ft. in size, according to the amount of detail required in any particular examination. In setting out the holes, shore sights are set up at each line of section at distances apart corresponding to the size of square chosen. These fix the alignment of the holes, and their location is usually made by a graduated, distance rope, ranged in the line of the shore sights (Fig. 39). The graduated rope is the quickest and most direct method to use if there are many holes, but positions can also be fixed by angles taken by one or two theodolites on shore, or by sextant angles from the boat to the shore.

Fixing Positions by Graduated Rope.—In fixing positions by graduated rope, some variation in procedure will arise, according as the sections are short or long. For sections up to about 100 ft. long, a manila rope, about 1 in. circumference, or a steel band may be used to measure off the distances of the probings along the line of site. If a manila rope is selected, it should be well wetted and stretched before it is graduated, and also before actual use. In the case of long sections, a light, steel or phosphor-bronze wire rope, about $\frac{3}{4}$ in. circumference, is best suited for the work. A steel rope should be kept in oil when not in use, but a phosphor-bronze rope does not corrode, and requires no special attention in this respect. Ropes are graduated by inserting pieces of red cloth between the strands at, say, every 10 ft., and tabs of thick, tough leather at every 50 ft. Each 100 ft. is marked by a tab of thick leather into which small copper rivets are clamped, one for every 100 ft. of length, until 500 ft. is

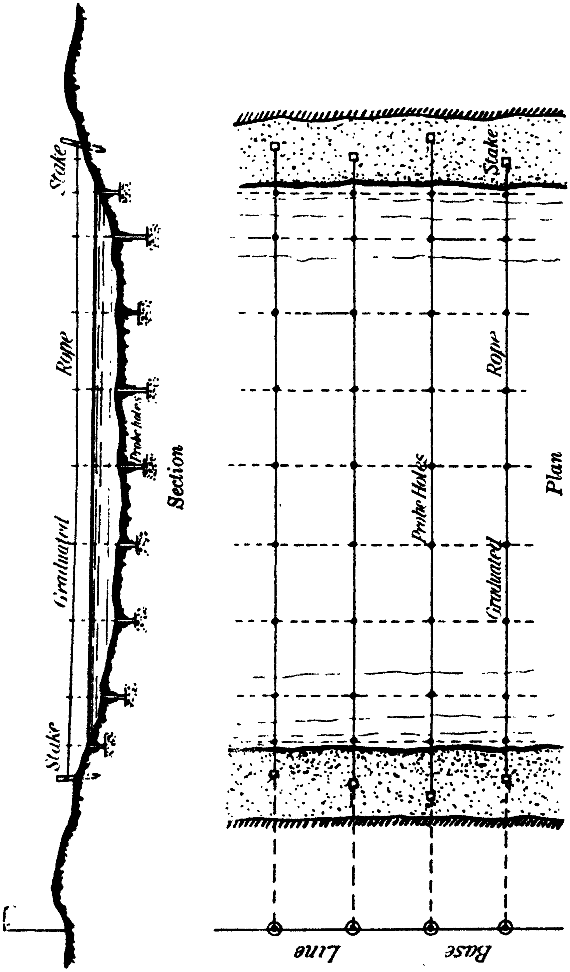


FIG. 39.—Probing the Bottom of a Small Stream.

reached, when an additional leather strip is added. If the wire rope is not intended to be wound on a reel, the graduations may be made by brass tabs or plates, hung on rings attached by wire lashings to the rope, with distance numerals stamped on them.

Short Distance Sections.—When the distance to be spanned is quite short, as in a narrow river or waterway, the rope or steel band is stretched across from bank to bank between two iron stakes in the line of sight, and drawn tight (Fig. 39). The probings and soundings are then taken at the required intervals by wading, if the water is shallow, and from a boat if deep (Fig. 38). When one line has been completed, the graduated rope is shifted bodily by two assistants, one on each side, to the next section, and there drawn tight between the stakes. In cases where it is not possible to stretch the rope from bank to bank, the methods described below for " long distance sections " should be used.

Long Distance Sections.—In the case of long distances, appliances of a more special character are required. The graduated rope should, in such cases, be one of steel or phosphor-bronze, $\frac{3}{4}$ in. circumference, wound on a large reel, about 12 in. diameter, and provided with two winding handles, so that a strain applied by four men can be brought upon it. The reel is carried in a boat to which it is securely attached. In carrying out the survey, the free end of the graduated rope is attached to a shore anchor on the bank, such as a stake or post, fixed in the line of sight. The reel boat is then moved outwards towards the far side, keeping in position by the shore sights, and the graduated rope is paid out from the reel until the required station is reached at the extreme end of the line. If the far side of the river or waterway can be conveniently reached, the reel boat is made fast to a shore anchor in the line of sight (Fig. 40), but otherwise the boat is moored in position by its own kedges or anchors (Fig. 41). The graduated rope is then wound in by means of the reel as tightly as it can be by two men on each handle. When this has been done the surveying boat, with the field party, proceeds along the graduated rope, and at each selected mark on it a sounding is taken and then a probing. On completion of the section, the reel boat is released from its moorings, the graduated rope wound in until the whole of the rope is on the reel, and the boat brought up again to the original starting point. The free end of the graduated rope is then transferred to the next section,

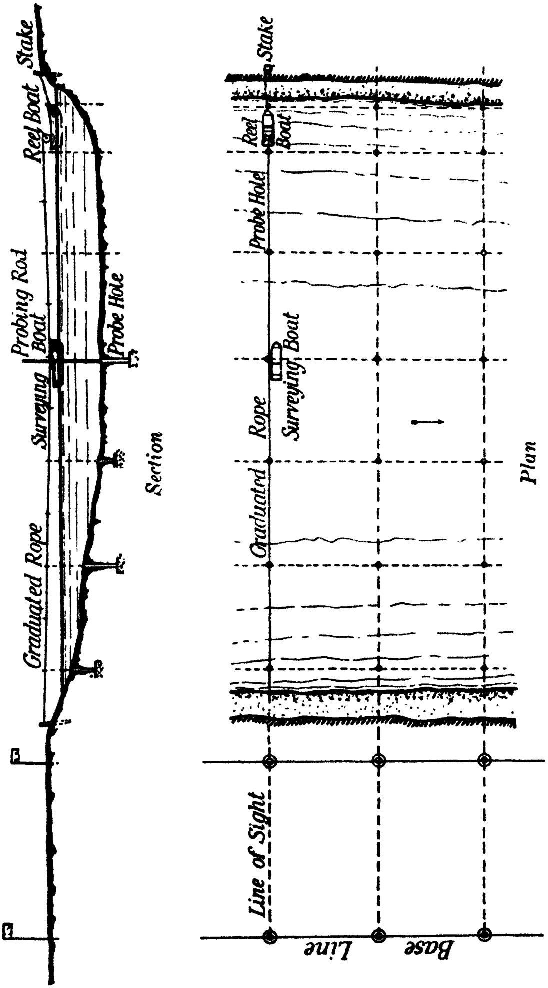


FIG. 40.—Probing the Bottom of a Wide and Deep Stream.

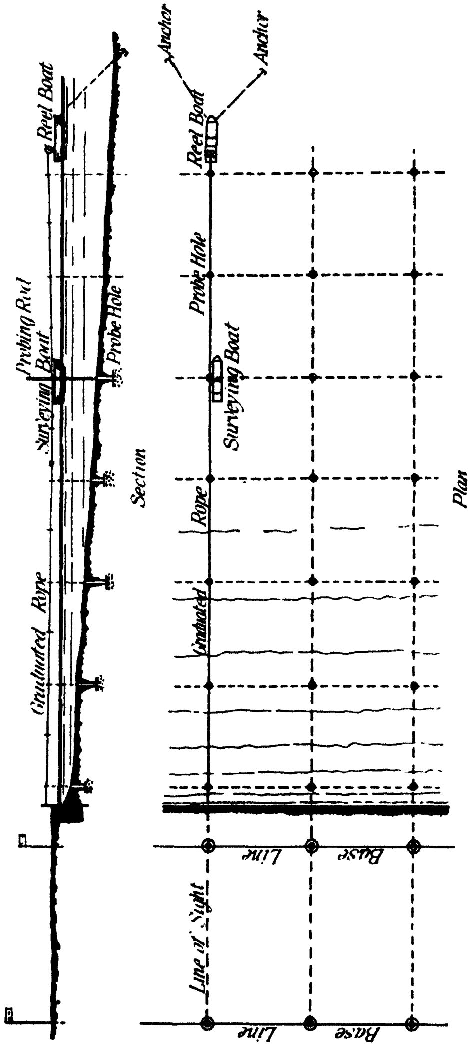


FIG. 41.—Probing the Bottom of a Wide Estuary.

there made fast, the rope again stretched over the new section by the reel boat, and soundings and probings taken as before.

Fixing Positions by Theodolite.—In cases where the graduated rope cannot be used, a shore base, *AB*, is first measured off, and the lines of sight set out. A theodolite is then set up at *A* (Fig. 42), for the purpose of reading the successive angles made by the boat with the base line as it is moved along any one of the lines of sight, such as *CD*. When a sounding and probing have been made, and before the probing rod has been withdrawn from the ground, a flag signal from the boat to the observer at the theo-

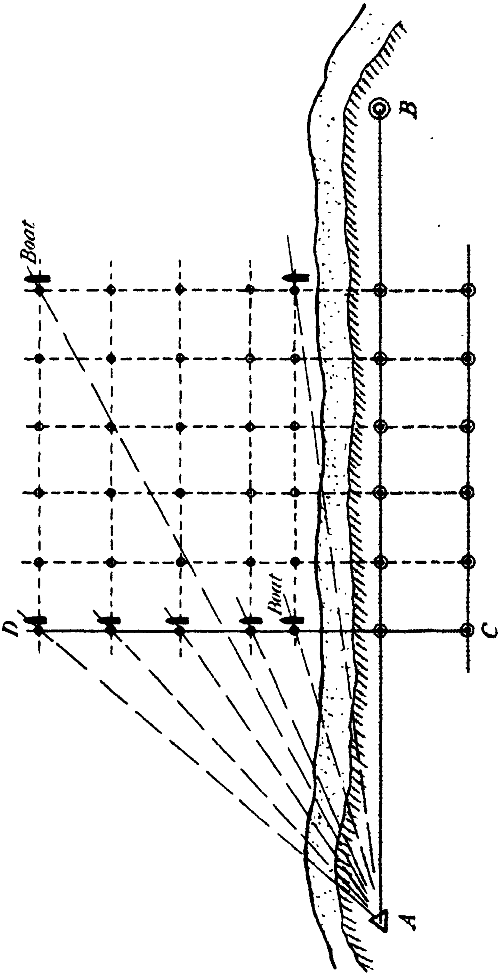


Fig. 42.—Fixing Positions on Water by Theodolite.

dolite indicates that the angle has to be read. As a means of checking the position of the boat, two angles may be read

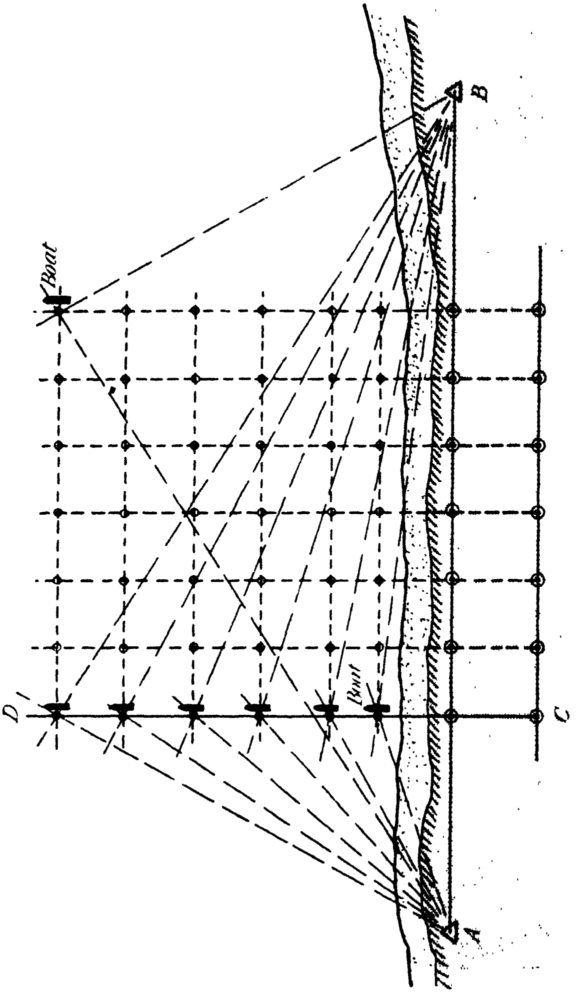


Fig. 43.—Fixing Positions on Water by two Theodolites.

simultaneously by two observers with theodolites stationed at *A* and *B* respectively (Fig. 43). Unless the distances covered are great, sufficient accuracy can be obtained by one instrument observer, provided that the boat is right in the line of shore sights when the angles are read. The positions of probings made at random, or without prearranged shore sights, can always be picked up by reading two angles simultaneously to the boat from the base line, or *vice versâ*, but in all cases where the boat is not

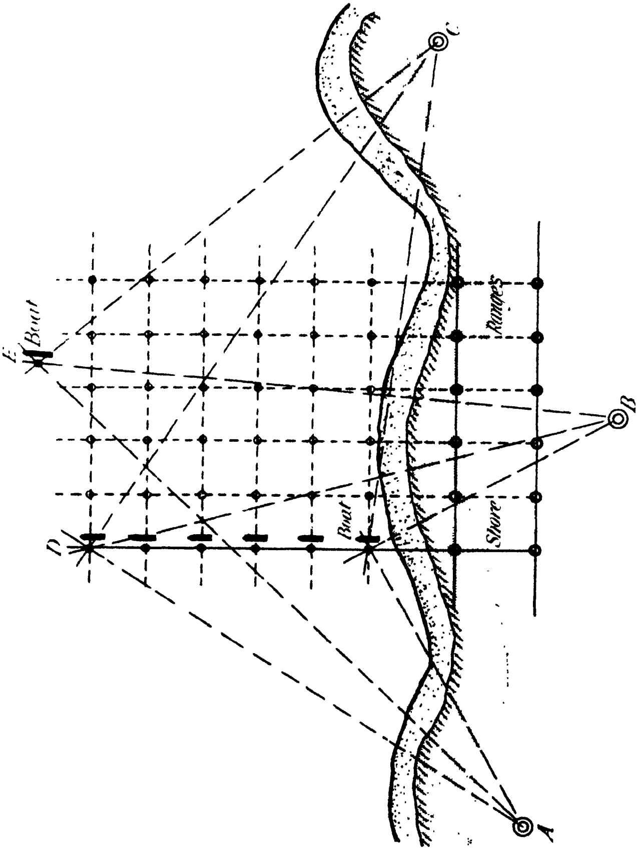


FIG. 44.—Fixing Positions by Sextant.

on a shore range, the base line should be chosen so that the intersecting angles cut each other as nearly as possible at right angles, *E* (Fig. 44). Angles less than 30 degrees should be rejected in such cases, as the accuracy of the location depends entirely on the good angle intersection.

Fixing Positions by Sextant.—The positions of the probe holes and soundings may be conveniently fixed by using a sounding sextant, preferably of the Admiralty pattern, from the boat.

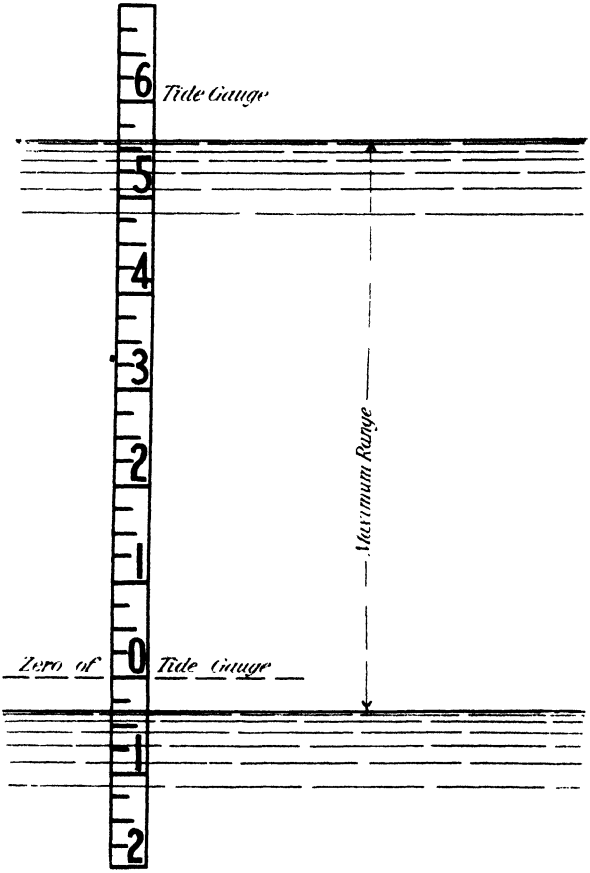


Fig. 45.—Tide Gauge.

This method can be used with advantage where the work is on an open coast, or at a considerable distance from the shore. Three shore stations, *A*, *B*, and *C* (Fig. 44), are selected, and at each probe hole the angles *DBA* and *DBC* are read by one or more observers in the boat, when steadied in position over the hole.

Tide Gauge.—If the examination of the ground is carried out in tidal waters, or where there is considerable fluctuation in the level of the water over short periods, it is necessary to set up a tide gauge with reference to a known datum, and continuously record the varying levels of the water surface. A simple form of tide gauge consists of a flat board, about 3 in. wide and 1 in. thick, marked off into feet and inches, or feet and tenths of a foot, as shown on Fig. 45. The board should be painted white, and the figures and division lines black for the sake of clearness. The tide gauge may be read by the surveyor from the sounding boat, but if it is at a considerable distance from the field of operations, an independent observer is told off to take the readings. The pocket watches of the gauge reader and the boat party should be carefully set to a common time immediately before commencing operations, and checked at the close of each day's work. In setting up the tide gauge, care must be taken to place it low enough to record the lowest stage of the water, and it should be sufficiently long to include the highest stage, thus including the maximum range. Readings are usually taken at intervals of 10 to 15 minutes in tidal waters, and hourly when the fluctuations are slow. If the tide gauge is in a position exposed to swell, the mean of the highest and the lowest reading during the passage of

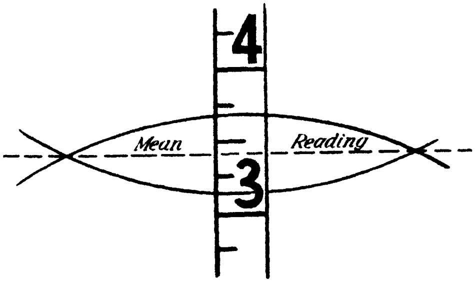


FIG. 46.—Tide Gauge Reading.

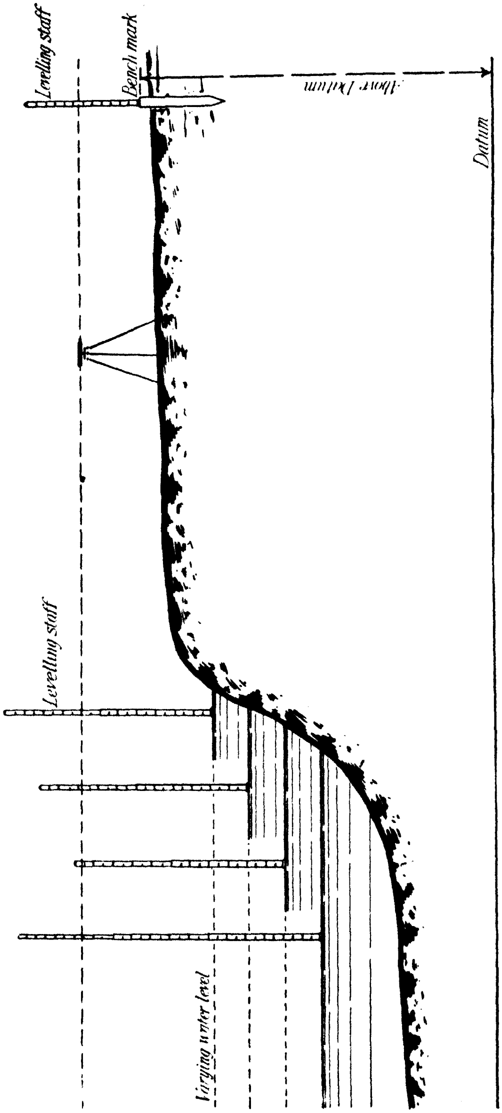


FIG. 47.—Recording Water Surface by Levelling.

an undulation is taken as the correct reading (Fig. 46). The tide gauge book may be kept as follows :—

HARBOUR REACH. *Date: October 3rd,* 1912.

Time. Hrs.	Time. Min.	Gauge. Ft.	Gauge. In.	Remarks.
11	20	16	0	Zero of tide gauge set to 8 ft. below ordnance datum by levelling.
	30	16	8	
	40	17	2	
	50	19	9	High water.
Noon.				
12	0	19	3	Strong westerly breeze.
	10	18	7	

Water Surface by Levelling.—In the event of a tide gauge not being used, the water surface may be fixed by levelling (Fig. 47). The readings must be taken at regular time intervals and connected with the datum, as explained for the ordinary tide gauge.

Soundings.—Where probings are made under water, a sounding to the surface of the bottom must first be taken with a sounding rod on the site of each probe hole, so as to obtain the level of the bottom at that particular point. The sounding rod consists of a timber pole, about 2 in. diameter, marked off in feet and inches, or feet and tenths, similar to the probing rod, and having a flanged iron shoe at the lower end to prevent it sinking into the soft materials of the bottom, as shown on Fig. 48. In taking soundings, the boat is brought to rest and the sounding rod thrust sharply down until the bottom is struck, when the depth is read off on the rod and booked. If the surface of the water is disturbed by waves or swell, the mean of the maximum and minimum readings is taken as the correct sounding (Fig. 46).

When the depth of water exceeds 30 ft. a lead-line or hand-lead must be used in place of a sounding rod. It consists of a lead sinker, about 8 lb. in weight, to which is attached a graduated lead-line of manila rope, $1\frac{1}{8}$ in. circumference. The graduations may be made by inserting cloth and leather tabs between the strands at 1 ft. apart, as described above for graduated position ropes. When soundings are taken, the lead is dropped upon the bottom, the line drawn tight, and adjusted vertically over the lead before the depth is read off. Sounding by the rod is more accurate than by the lead, and the former should be used for depths up to 30 ft., in which case the maximum length of the sounding rod is about 32 ft.

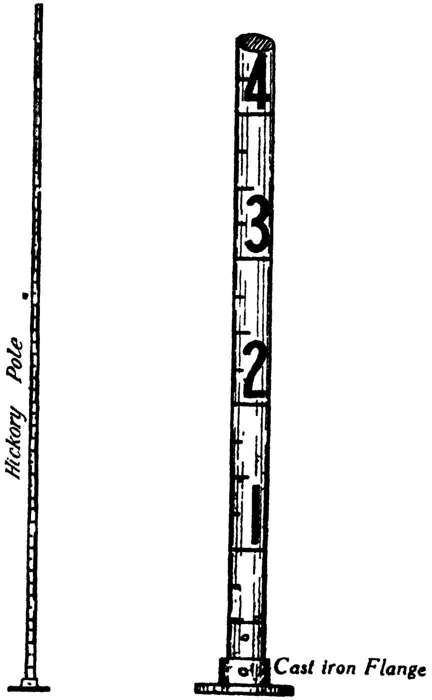


FIG. 48.—Sounding Rod.

Reduction of Soundings.—Owing to the variation of the water surface it is necessary to correct or reduce soundings to a common datum plane. In British tidal waters, mean low water of Spring tides is taken as the plane of reduction, but any convenient datum can be used which is suitable for the particular work in hand. The correction of each sounding is *plus* or *minus*, according as the water level was below or above the datum plane when the sounding was taken. This is shown in the following example, and also diagrammatically on Fig. 49, where two soundings, *A* and *B*, are recorded. In the case of *A*, the reading of the tide gauge is 9 in. below datum, and as the sounding is 8 ft. 2 in. the reduced sounding becomes 8 ft. 2 in. + 9 in. = 8 ft. 11 in. In the case of *B*, the reading of the tide gauge is 3 ft. 9 in. above datum, and as the sounding is 15 ft. 6 in., the reduced sounding becomes 15 ft. 6 in. — 3 ft. 9 in. = 11 ft. 9 in.

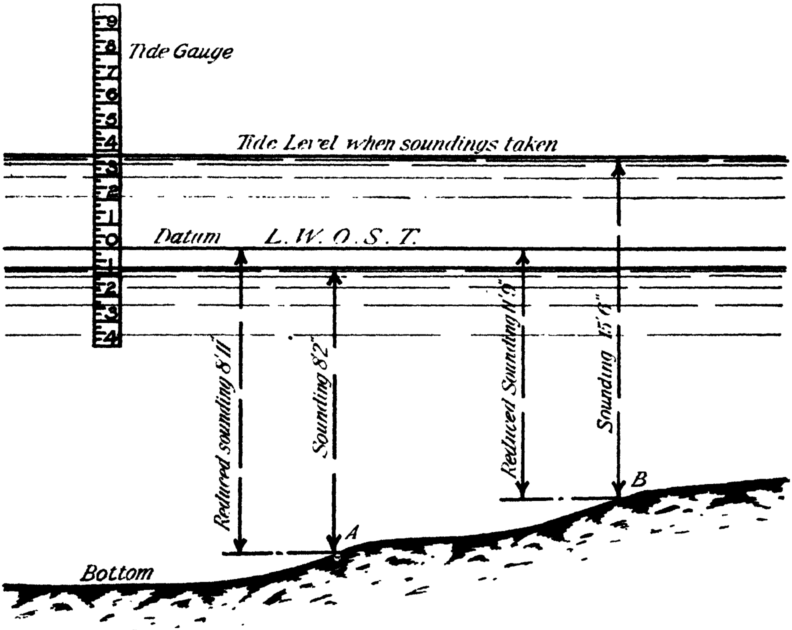


FIG. 49.—Reduction of Soundings.

Record of Subaqueous Probings.—Probings taken under water, when fixed by graduated rope, may be recorded in the following manner :—

GILL REACH. *Date: February 6th*, 1923.

Section No. II.

Time. H. M.	Distance. Ft. Ins.	Sounding. Ft. Ins.	Probing. Ft. Ins.	Gauge. Ft. Ins.	Correction. Ft. Ins.	Reduced Sounding. Ft. In.	Reduced Probing. Ft. In.	Nature of Bottom.	Remarks.
10 10 a.m.	130 0	8 5	17 7	0 5	0 5	8 0	17 2	Rock.	Covering of silt.
	140 0	10 8	22 11		0 5	10 3	22 6	,,	,, ,,
	150 0	16 11	24 3		0 5	16 6	23 10	,,	,, ,,
10 20	160 0	17 1	28 1	0 1	0 1	17 0	28 0	Hard gravel.	No rock reached. Silt on top.
	170 0	18 7	24 4		0 1	18 6	24 3	Rock.	Covering of silt.
10 30	180 0	18 11	28 11	0 4	0 4	19 3	29 3	Stones.	Large and loose stones. Silt on top.
	190 0	18 10	26 6		0 4	19 2	26 10	Rock.	Covering of silt.
10 40	200 0	18 9	22 9	0 6	0 6	19 3	23 3	,,	,, ,,
	210 0	19 0	23 3		0 6	19 6	22 9	,,	,, ,,

If the tide gauge is not read by an observer in the boat, the readings must be abstracted from the tide gauge book, kept by the independent observer, and entered in the allotted column of the field book, as above. When positions are fixed by angles only, these must be abstracted from the angle book and substituted for the "Distance" column in the above tabulation.

When the positions are fixed from the shore by one theodolite only, the angle book may be kept as follows :—

LOWER HARBOUR. *Date : June* 10*th*, 1912.

Section No.	Time. H. M. S.	Probing No.	Angles.	Remarks.
15	11 20 15	1	23° 10′	Theodolite on Station No. 3.
	23 10	2	25° 50′	
	25 30	3	27° 08′	Station No. 5 is zero.
	27 00	4	28° 32′	

If two theodolites are used, each observer requires to keep an angle book as above.

When the positions are fixed from the water by sextant only, the angle book may be kept in the following manner :—

WHITE REEF. *Date : May* 8*th*, 1911.

Section No.	Time. H. M.	Probing No.	Station.	Angle.	Station.	Angle.	Station.	Remarks.
20	1 33	8	C.	91° 5′	B.	53° 40′	C.	
			A.	144° 45′			C.	Check.
	1 36	9	A.	78° 15′	B.	52° 28′	C.	
			A.	130° 43′			C.	Check.

The angle observed between *A*, and *C*, is a check angle and should practically equal the sum of those taken between stations *A B* and *B C*. Instead of observing the whole angle *A C*, any other good angle may be taken as a check, in which case at least one additional shore station is required.

Plotting of Subaqueous Probings.—The positions of the probings should first be plotted on the plan, and the three methods, already referred to, of fixing them must, for this purpose, be separately considered, viz. :—

(*a*) Graduated rope.
(*b*) Theodolite.
(*c*) Sextant.

(*a*) GRADUATED ROPE.—In the case of probings fixed by graduated rope, the lines of sight are first laid down on the plan, and the points at which probings were made marked off according to the corresponding distances on the graduated rope (Figs. 39 to 41).

(*b*) THEODOLITE.—The base line, shore stations, and lines of sight are laid down on the plan to begin with. The observed angles are then laid off by protractor from the shore station, *A*. The intersection of any particular angle with the line of sight fixes the position of the probe hole to which it refers, as at *D* (Figs. 42 and 43). When two theodolites are used, the observed angles for any particular probing are laid off from the shore stations *A* and *B*, and the intersection of the lines when produced gives the required position. When these angles have been taken in conjunction with a line of sight, the three lines should cut each other at the point where the probing was taken, or enclose a small triangle of error, and a check is thus made upon the correctness of the observed angles (Fig. 43).

(*c*) SEXTANT.—In the case of sextant observations, the positions of probe holes are easiest plotted by setting off the two observed angles on the station pointer and moving it about until the arms pass through the shore stations *A*, *B*, and *C*. The required position, *D*, is then pricked off at the centre of the station pointer. When a station pointer is not available the angles observed from any position, *D*, may be plotted by protractor on a sheet of tracing paper. The sheet is then moved about on the plan until the lines pass through the shore stations, *A*, *B*, and *C* simultaneously. The required position is then at the intersection of the lines, *D*, and is pricked off on the plan accordingly (Fig. 44).

Preparation of Plans.—The results of a survey by subaqueous probing can be shown on a plan constructed from the information recorded in the field book. Fig. 50 shows a part plan of this kind made from an actual examination by probing to determine the rock bottom for a deep-water quay and shipping berths. The soundings are written in black and the probings in red ink on the original plan. Where the probe has failed to reach hard bottom a circle, or other distinguishing mark, is drawn round the figure representing the depth to which it has penetrated. The profile of the hard bottom is usually developed by drawing contour lines round the probe holes, but where the probings are close together it may be necessary to prepare two separate plans, one showing the river bottom as defined by the soundings, and the other the hard bottom as disclosed by the probings. The necessary sections are prepared in the manner shown on Fig. 51, which represents No. 1 line of probings of the same survey for which the plan is given on Fig. 50. Where hard bottom has not been reached, the contour lines are drawn in dotted on the sections between the points where it has been found, in order to complete the section.

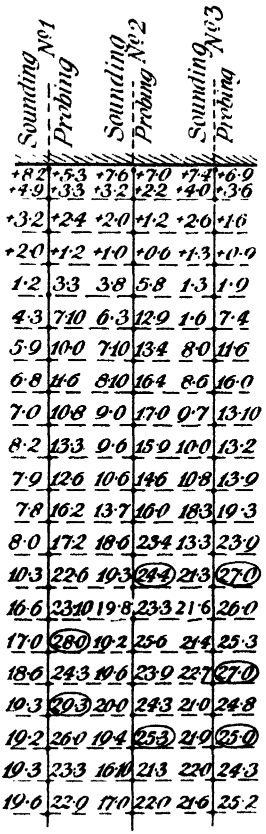


Fig. 50.—Plan of River Bottom, made from a Survey by Probing.

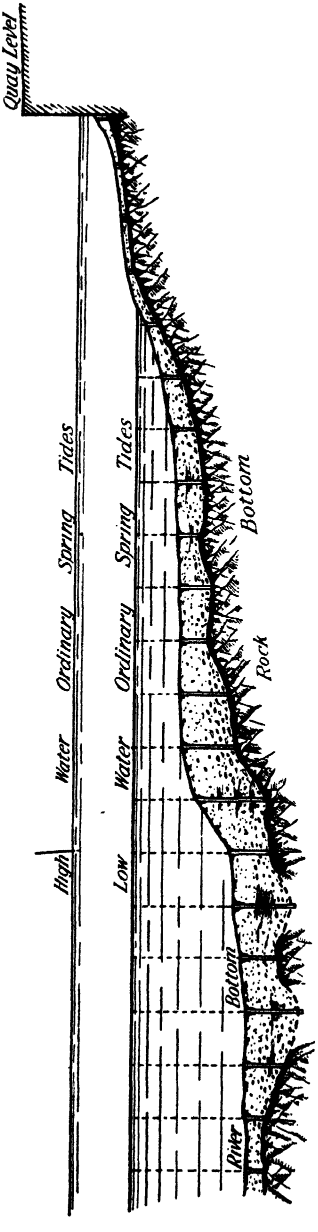


FIG. 51.—Section on Line No. 1, Fig. 53.

General Application of Survey Methods. — The foregoing methods of fixing and plotting probings are applicable to test borings and other means of examining the ground, as described hereinafter, where they have to be recorded under similar circumstances.

CHAPTER III

II. BORING

BORING operations are carried out under two well defined conditions, viz. :—

(*A*) Boring on land.
(*B*) Boring under water.

The methods followed in making test borings may be classified generally as follows :—

(1) Wash boring.
(2) Percussive boring.
(3) Rotary boring.

These systems may be used independently, or combined in various ways. Thus wash boring (1) is very frequently used with percussive boring (2), or with rotary boring (3) ; again, percussive boring (2) usually goes with rotary boring (3) ; while, in deep bore holes, where the strata are usually of a widely different character, wash (1), percussive (2), and rotary boring (3) are all combined.

(*A*) **Boring on Land**

(1) WASH BORING

General Description.—Wash boring, as its name implies, consists in penetrating the ground by washing out or displacing the materials in the line of the bore hole by means of water. It is a comparatively inexpensive method of proving the ground when the materials overlying a firm stratum are soft, and is commonly employed by itself for shallow borings, not exceeding 100 ft. in depth, through mud, silt, or gravel. In deep holes it is usually the preliminary to percussive or rotary boring. When materials are encountered which will not wash away, such as heavy shingle, boulders or rock, wash boring is ineffective, and must give place to percussive or to rotary boring.

Wash Boring Appliances.—The apparatus for wash boring consists of a steel or iron tube, from 1 to 2 in. diameter, called the jet or wash pipe, through which a stream of high-pressure water is driven by means of a force pump. The jet pipe is placed within an outer or casing pipe of considerably larger dimensions, so as to leave an annular space up which the return water flows, carrying with it the materials washed out from under ground

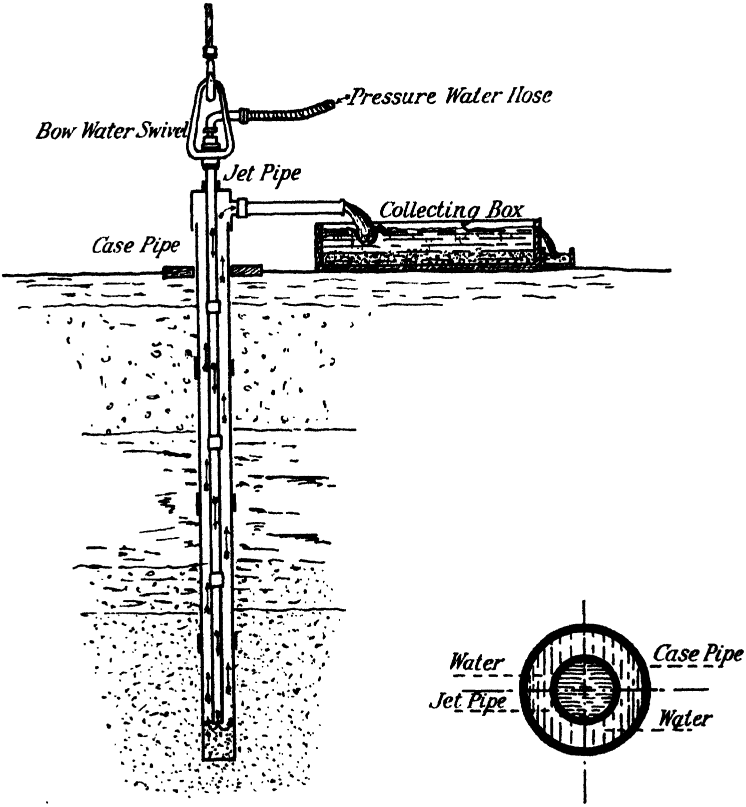


FIG. 52.—Wash Boring, Arrangement of Pipes.

FIG. 53.—Section of Jet and Case Pipes.

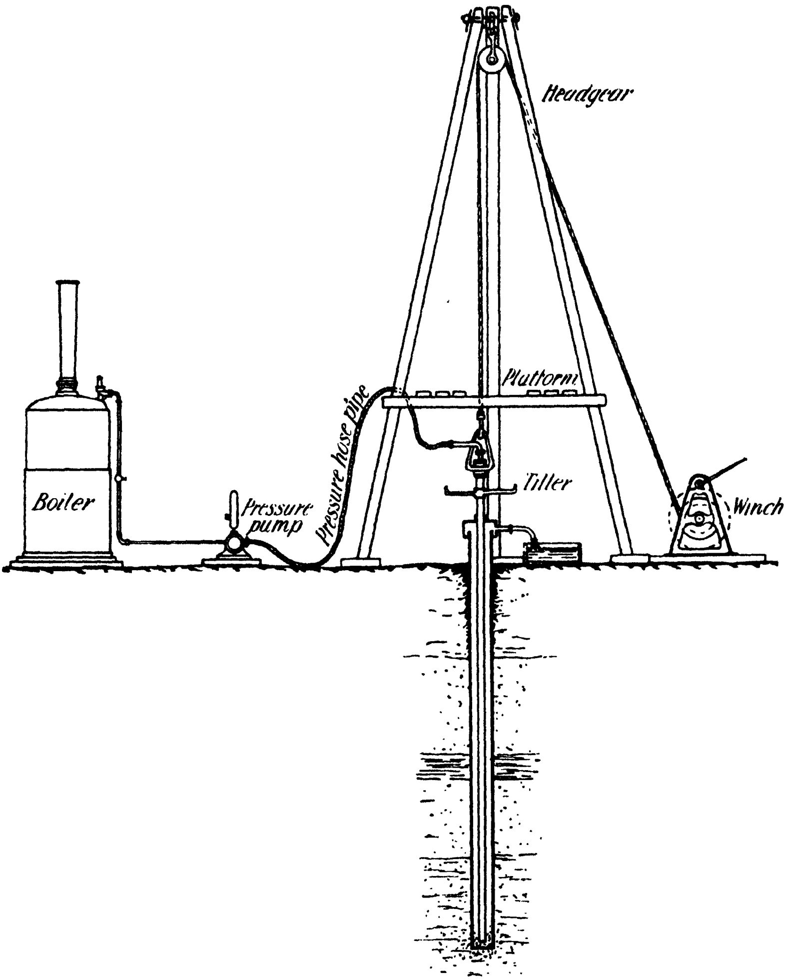


FIG. 54.—Wash Boring Plant for Shallow Holes.

(Figs. 52 and 53). For shallow borings in soft materials a hand pump, 1-in. jet pipe, and 3-in. casing pipe are sufficient, but in deep holes, and if the materials are of considerable size or compact, such as gravel or stiff clay, a power pump is required capable of delivering anything from 100 gallons to 300 gallons per minute, at pressures varying from 100 to 200 lb. per square inch. The casing pipe is made up of iron or steel tubes screwed together with external couplings or with flush-joints (Fig. 71), according as the ground is soft or hard, in which latter case it becomes necessary to drive the pipes down. A derrick or head frame, and hand or power winch are required for handling the pipes and suspending the water jet. Water is delivered from the pressure pump by means of a flexible, metallic hose, the junction with the jet pipe being made with an ordinary water swivel (Fig. 54). A wash boring plant for deep holes is shown on Fig. 55.

Procedure in Wash Boring.—In commencing a wash bore hole, the casing pipe is first set or gently driven for some distance into the ground and the jet pipe inserted. The pressure water is then admitted to the jet pipe, and as the materials are washed out from below the casing pipe it descends by its own weight. A hand tiller (Fig. 66), clamped on to the casing pipe, is used to keep it in line by turning and twisting when jetting with pressure water, and a similar appliance is fitted, when necessary, to the wash pipe to prevent it from sticking. When the skin friction becomes too great, the casing pipe requires to be driven down with a heavy wooden mallet, being rotated at the same time with the hand tiller to keep it free.

As the casing pipe descends new lengths of tube require to be screwed on, and a like adjustment made to the jet pipe, the tubes being manipulated by the derrick and winch. In sinking a wash boring care must be taken to regulate the position of the jet pipe with reference to the casing pipe. The jet pipe can be kept well in advance of the casing pipe in impervious materials, such as clay, but in sand, or open ground it must be maintained just at or a little above the foot of the casing pipe. If allowed to get below the cutting edge in open ground, the pressure water escapes from under it into the surrounding strata, and the progress of the boring is then arrested, as no materials are washed out at the top.

Obstructions in Wash Boring.—In wash boring, large stones or boulders are the most difficult kind of obstruction encountered.

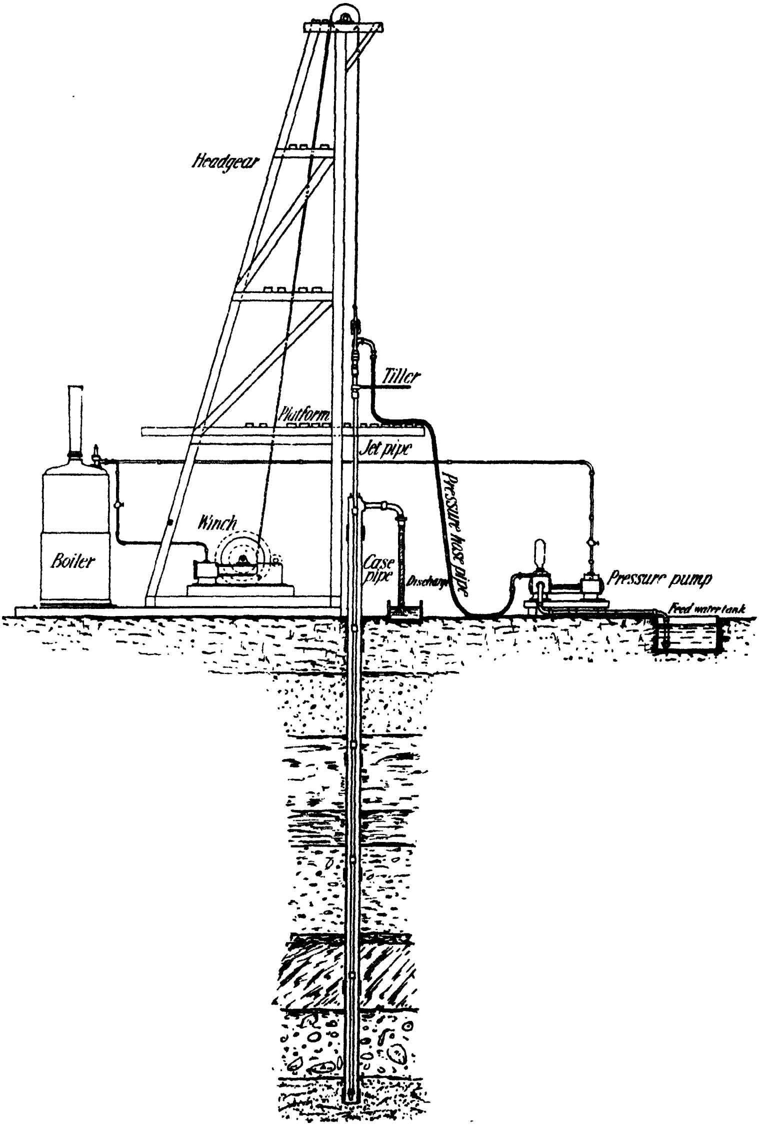


FIG. 55.—Wash Boring Plant for Deep Holes.

In the case of a large stone, persistent washing and working with the hand tiller usually enables the casing pipe to push it aside, but when a boulder forms the obstruction operations should be stopped and a new hole put down a few feet off from the first one. A few trial holes put down in this way within a circumscribed area will generally serve to locate an isolated boulder, as compared with solid rock, in the manner shown on Fig. 36. If other means than wash boring are available, boulders and similar obstructions may be pierced by percussive drilling, broken up by explosives, and cleared away with the sludge-pump, when wash boring may be resumed. In such cases, however, driving pipe must be used instead of casing pipe, sufficiently strong to withstand driving into the hard strata. Driving pipes are armed with a cutting shoe at the bottom, and have a protecting flange or driving cap at the top, and are forced down by a falling hammer, as described in Chapter VI, "Sinking of Bore Holes."

Samples from Wash Borings.—Samples of the ground from wash borings are obtained by intercepting the return water from the casing pipe in a collecting box or tank, provided with a small sluice door for emptying and cleaning it (Fig. 52). When it is desired to take a sample, the return water nozzle is turned upon the tank until a sufficient quantity of water has been collected from which a fair sample can be obtained. The nozzle is then put aside and the materials in suspension allowed to settle in quiet water, when they can be collected and set aside for examination. The selected samples may be kept in a box similar to that shown on Fig. 83. The materials brought up by wash boring vary from sediments and small grains up to gravel stones of about 1 in. diameter. No precise distinctions as to the strata can be made from the samples except between beds of a clearly different lithological character, the results being more of a comprehensive than of a detailed kind, and great care must be exercised, therefore, in assigning to the deposits a definite thickness and description in the records. In this respect, samples may be brought up by a sludge-pump (Fig. 73), at frequent intervals, or when there is any doubt as to the nature of the formation, as a check upon the ordinary wash work.

Setting Out Wash Borings.—Wash borings are set out in the manner hereinafter explained for percussive borings.

Record of Wash Borings.—In the case of wash borings the levels at which different strata lie are measured directly by the jet pipe. A note must be carefully made in the field book of the number and lengths of the various tubes put on, and it is advisable as a check to measure the pipes whenever withdrawn.

The record of wash borings is kept as follows:—

WASH BORINGS AT HEATH HALL. *Date: May 12th,* 1910.

No. of Boring.	Red. Levels on Boring.	Depth below Surface.		Nature of Ground.	Remarks.
	Ft.	Ft.	In.		
No. 2	24·50	0	0	Made-up ground.	Surface.
		4	0	,, ,,	Sample No. 1.
		6	6	Coarse sand.	Sample No. 2.
		8	6	,, ,,	Sample No. 3.
		9	0	,, ,,	
		9	4	Loamy soil.	Sample No. 4.
		12	6	,, ,,	
		14	3	,, ,,	Sample No. 5.
		14	6	Sandy mud.	Sample No. 6.
		16	3	,, ,,	
		17	0	Fine red sand.	Sample No. 7.
		20	0	,, ,,	
		21	0	Stones.	Boring stopped.

Plotting Wash Borings.—Wash borings may be plotted, both as regards plan and sections, by the methods described in connection with probe holes and percussive bore holes.

(2) PERCUSSIVE BORING

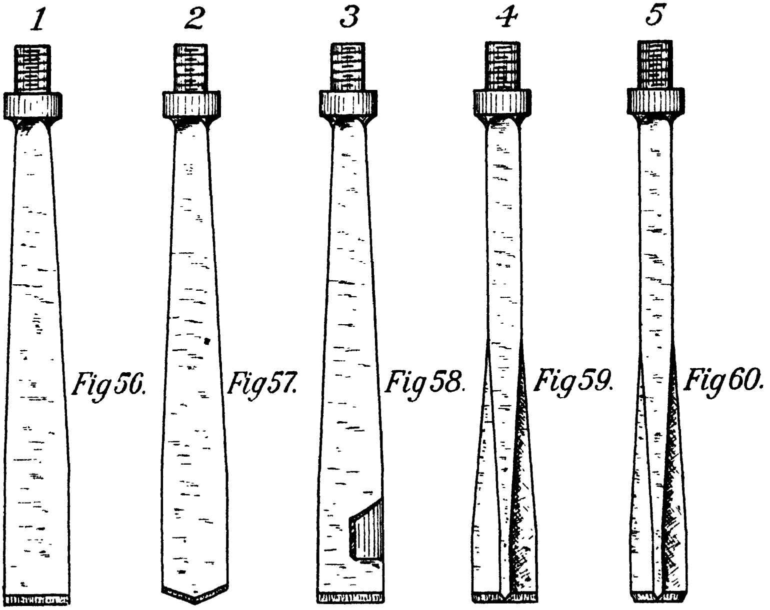
General Description.—Percussive boring consists in penetrating the ground by a series of blows delivered continuously from cutting tools of some weight. By this means the materials encountered are broken up or pulverised, and require to be removed from the bore hole from time to time to allow of the free descent of the boring tools. The materials thus removed constitute the samples of the strata passed through, and give information as to the character and thickness of the beds.

When hard materials, such as rock, are bored in this way the samples are more or less of a fragmentary character, and afford qualified evidence only of the natural condition of the strata pierced, as compared with the more perfect results obtained by extracting solid cores from them by means of rotary boring, but on account of its simplicity and cheapness the percussive method is largely used in engineering practice where it is considered sufficient to penetrate the rock for 10 to 20 ft. only in order to prove it, as for a foundation. On the other hand, percussive boring is indispensable for piercing a thick layer of loose or unconsolidated materials overlying rock, as the rotary method is best adapted to, and is used with few exceptions for drilling in rock only.

Percussive Boring Appliances.—The appliances for percussive boring consist essentially of cutting tools in the form of chisels and augers of various designs, which are suspended from boring rods, and manipulated by hand, or by steam, oil, or other power.

In shallow borings, the work is usually carried out by hand, but in deep borings power of some kind becomes essential, steam or oil being the usual factor. For convenience in handling the various parts of the boring gear and operating the cutting tools, a frame or headgear of some height is required. In hand boring it takes the form of a simple derrick or tripod, but where power is used a more elaborate and permanent kind of headgear is adopted in keeping with the greater requirements of the work.

Chisels or Bits.—The chisels or bits are made of steel specially tempered, about 18 in. long and 2 to 3 in. wide, and are of the various forms shown on Figs. 56 to 60. Flat, straight-edged chisels (1) are used for ordinary loose strata, flat or diamond-pointed (2) for harder materials, and flat tee for rock (3). When rock is bored through of very unequal composition, much jointed or fissured or very hard, the cross forms of chisel are used (4 and 5), as being less likely to stick or follow the lines of joints and fissures than flat tools. The bore hole is thus kept straight, and the section round. For the purpose of attachment to the boring rods, each chisel or bit is shaped with a bearing collar or flange



Elevations.

Sections.

Figs. 56—60.—Boring Chisels. (1) Flat Straight Edge; (2) Flat V; (3) Flat T; (4) Cross Bit; (5) Y Bit.

and screwed end, which latter fits into a corresponding socket on the boring rod.

Augers.—Shell augers, or scoops, are used chiefly for cutting through clays and stiff, clayey soils, and are made of steel in the form of a half tube, the bottom being shaped as an auger. The top end of the tube has a length of square or round rod forged or riveted to it, provided with a bearing collar or flange, and a screwed end by means of which it is attached to the boring rods (Fig. 61). For shallow bore holes augers are usually about 3 ft. long, and for deep holes about 5 ft. Screw augers, of the form shown on Fig. 62, are generally used for cutting through compact, sandy, and gravelly soils.

Fig. 61.—Shell Auger.

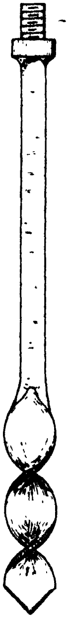


Fig. 62.—Screw Auger.

Fig. 63.—Boring Rods.

Fig. 64.—Swivel Rod.

Boring Rods.—The boring rods are made of wrought iron or mild steel, usually about 1 in. square in section for shallow, and 1¼ in. for deep holes, and in lengths varying from 1½ to 3 ft. for shallow holes in hand boring, and 5 to 10 ft. for deep holes. One end is formed with a screwed socket, and the other with a bearing collar, and a screw having at least six threads (Fig. 63). The pitch and diameter of the screw threads are uniform throughout, so that the rods are interchangeable, and the bits, or other tools, can thus be fixed to any one of them. A short length of boring rod, fitted with a swivel eye and termed the "swivel rod," is used for the purpose of attaching a line of rods to the hoisting rope of the winch when necessary (Fig. 64).

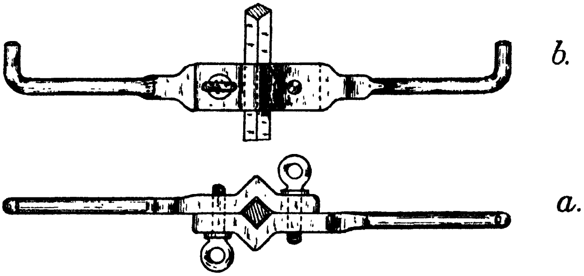


FIG. 65.—Rod Tiller: (*a*) Plan; (*b*) Elevation.

Rod Tiller.—The rod tiller is a double-handed lever made of iron, which can be clamped to or unclamped from the boring rods as desired (Fig. 65). It is used in power boring instead of a bracehead, and serves the purpose of turning or twisting the rods during boring operations, thus causing the chisel to cut uniformly.

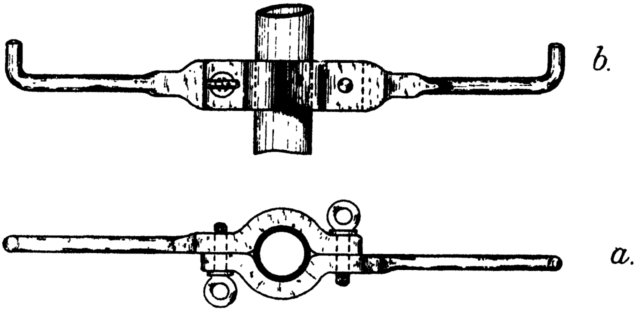


FIG. 66.—Pipe Tiller: (*a*) Plan; (*b*) Elevation.

Pipe Tiller.—The pipe tiller is similar to the rod tiller, and is clamped to lining pipes for the purpose of rotating them when boring (Fig. 66).

Rod, and Pipe Clamps.—When it is necessary to suspend boring rods or lining pipes in a bore hole, they are secured by clamps which can be fixed to them by adjustable screw pins. A pipe clamp is shown on Fig. 67, and rod clamps are of similar design, arranged to grip the rods. When in use, the clamp rests upon the ground or on a small timber platform over the bore hole, and so takes the weight of the rods or tubes to which it is attached, and prevents them from dropping down out of reach.

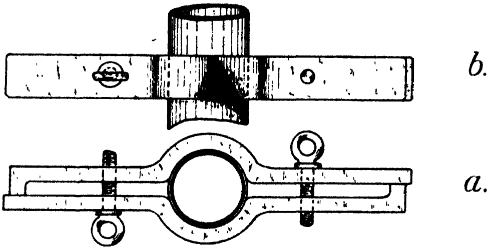


FIG. 67.—Pipe Clamp: (*a*) Plan; (*b*) Elevation.

Nipping Fork.—The nipping fork, or hand dog, is used for holding up the length of rods in the bore hole when the rods are being screwed and unscrewed (Fig. 68). It rests upon the top of the casing pipe during this operation.

Rod Wrench.—The rod wrench, or key, is used for screwing and unscrewing lengths of boring rods, and is shown on Fig. 69.

FIG. 68.—Nipping Fork.

FIG. 69.—Rod Wrench.

Lifting Dog.—When boring rods require to be manipulated in long lengths, a lifting dog may be conveniently used (Fig. 70). When in use, the forked end is inserted under a handy collar joint of the rods, and the ring attached to the hoisting rope of the winch by a spring hook. The weight of the suspended rods is then carried by this joint, resting in the fork of the lifting dog.

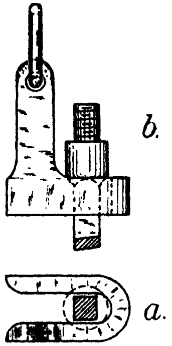


Fig. 70.—Lifting Dog. (*a*) Plan: (*b*) Elevation.

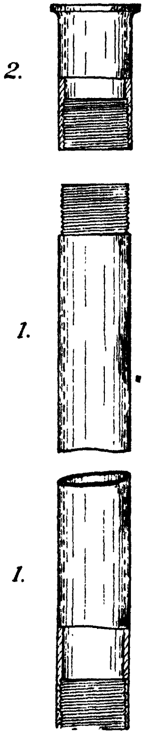


Fig. 71.—Lining Pipe. 1. Plain Pipe. 2. Protecting Cap.

Fig. 72.—Auger Shell.

Fig. 73.—Sludge Pump.

Fig. 74.—Foot Valve Sludge Pump.

Lining or Casing Tubes.—Lining or casing tubes are made of iron or steel, generally with flush-jointed, screwed connections

(Fig. 71). For shallow bore holes, and when severe driving is not required, the tubes are about 3 to 4 in. external diameter, about $\frac{1}{8}$ to $\frac{3}{16}$ in. thick, and in lengths of 3 to 10 ft. They are used to protect the bore hole in places where the ground is weak and liable to cave in, and are sunk by rotating them with a pipe tiller, or are driven down gently with a wooden mallet. For driving purposes a cap or thread protector is screwed on to the top length, as shown in Fig. 71.

Sludge Pump or Shell.—The sludge, shell pump, or bailer is required for removing the pounded materials from a wet bore hole. It consists essentially of a short tube, open at the top, with a flap or hinged valve at the bottom, which automatically opens and shuts as the sludge pump is worked up and down at the end of the boring rods. A short piece of boring rod is riveted to the top of the tube by means of forks, so that it can be screwed to the boring rods (Fig. 73). When in use, the pumping action of the boring rods forces the loose materials past the flap valve into the tube, where they are retained by the closing of the valve on the up stroke (Fig. 74). When the tube is full it is withdrawn to the surface.

Auger Shell.—Another form of this tool for clearing the bore hole, either when dry or wet, is shown on Fig. 72. It consists of a split tube with an auger edge, which is gently rotated in the bore hole so as to work the loose materials into the tube. When the tube is open at the foot only, the materials are cleared out through a slot hole at the top, as they usually become hard packed at the bottom end.

Bracehead.—The bracehead is attached to the top length of a line of boring rods for the purpose of lifting and turning them by hand when boring, and also for lifting and lowering the rods when connecting and disconnecting separate lengths without using a head gear. It consists of two or four arms of ash or oak, about 3 ft. long overall and 4 in. square, tapered and rounded down to a diameter of 2 in. at the ends to form the gripping handles. The arms are secured at their intersections by two light iron plates, and a short length of boring rod, having a screw socket at the lower end, is passed through the centre and bolted down upon the top plate (Fig. 75). A small bracehead with two handles is used, in hand boring, for shallow holes up to a depth of about 30 ft., and is worked by two men, while the large bracehead with four handles, or "double bracehead," is adopted for holes about 60 ft. maximum depth, and is worked by four men.

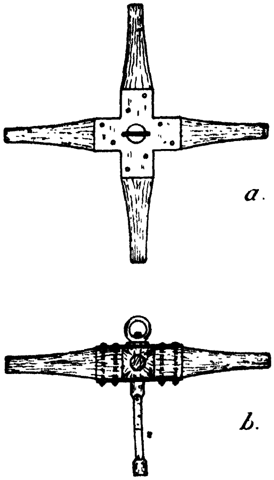


Fig. 75.—Double Bracehead. (a) Plan; (b) Elevation.

When bore holes exceed this latter depth, it becomes necessary to use mechanical means of handling the increased weight of rods. In hand boring the power is supplied by a small hand winch, by means of which the rods are raised and dropped, whilst the rotary movement is given by the bracehead (Fig. 78). A modification of this method is shown on Fig. 79, where a tripping lever with a hook at one end is used to trip the rods when raised, so as to give a sudden drop to the chisel, while the rotary movement is made by using the long arm of the lever as a tiller.

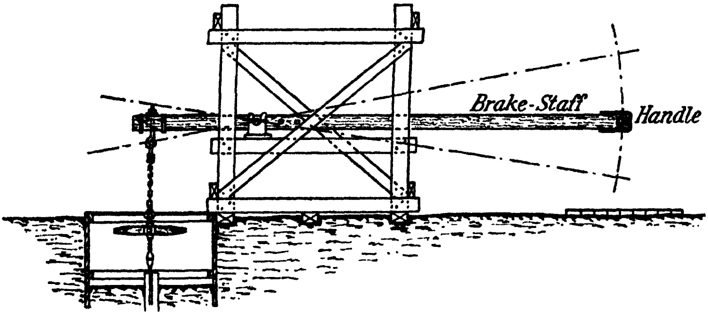


Fig. 76.—Brake-staff and Frame, Side Elevation.

Break-staff.—When a headgear is not used, the necessary power to deal with the weight of the rods may be got by using a break-staff, as shown on Figs. 76 and 77. The staff or pole is of timber, usually 15 to 20 ft. long, 6 to 8 in. square, and is provided with a cross-handle at one end, about 6 ft. long and shaped like a bracehead, and a strong hook at the other from which the rods are freely suspended. The staff is worked as a rocking lever, and is hung on a moveable fulcrum carried by a timber frame, so that the leverage can be adjusted to suit the weight of the rods.

Headgear.—For shallow bore holes the headgear, or derrick, is usually a tripod formed of spars or iron tubes, but may have four legs. In the case of deep bore holes, a trestle timber tower is specially erected for convenience in dealing with the longer sections of boring rods.

The simplest form of headgear consists of three spars connected together at the top by an iron bolt or pin, and carrying a gin block or pulley, over which passes the rope to a small portable winch for hoisting the boring rods and other parts of the appliances (Fig. 78). More usually, however, a small hand winch is fixed to one of the legs for this purpose. A more permanent and convenient form of headgear consists of a tripod made of steel tubes, and having the winch fitted permanently upon the tripod, which thus combines lightness with portability, as it can easily be taken apart and transferred to new sites (Fig. 79). It is advantageous to have the tripod of considerable height, as a greater length of boring rods can be disconnected in one piece, instead of one by one when the headroom is limited. The height of the tripod should, therefore, always be a multiple of the boring rods, measured from at least one clear foot above

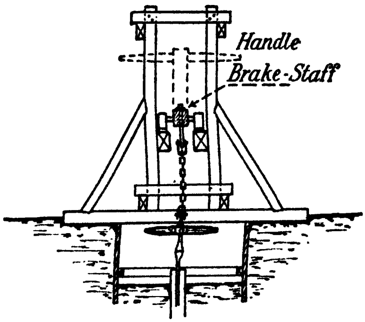


Fig. 77.—Brake-staff and Frame, Front Elevation.

the level of the bore hole to the head block or pulley to give easement.

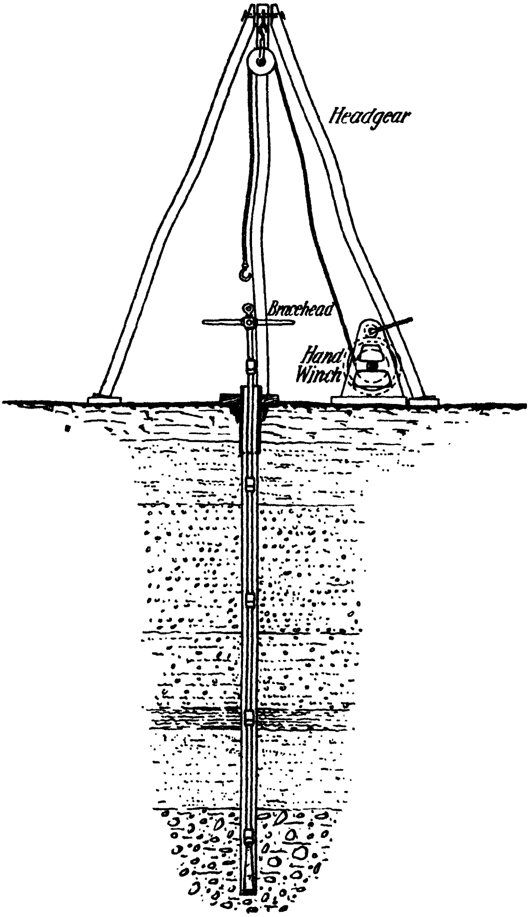


FIG. 78.—Percussive Boring, Hand Plant with Headgear.

A headgear suitable for a deep bore hole is shown on Fig. 81. It consists of a braced, trestle, timber tower, 50 to 60 ft. in height, with platforms at suitable heights to allow of two or three men standing thereon when manipulating the rods. As the time taken to connect and disconnect the boring rods forms a large part of the total time spent in making a bore hole, the advantage of increased height in the headgear for deep holes is obvious, as long lengths of rods can be removed at one time by unscrewing only every fourth or fifth joint.

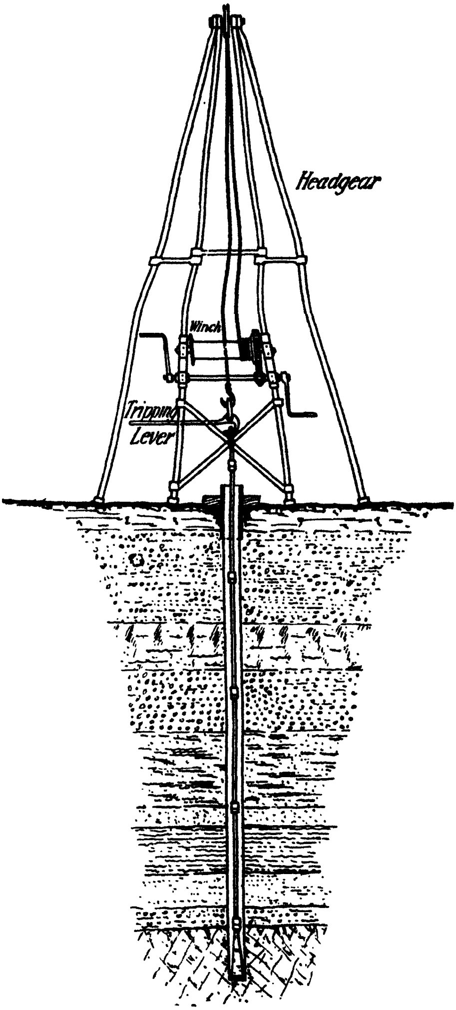


FIG. 79.—Percussive Boring, Hand Plant with Tube Headgear.

Hoisting Machinery.—In the simple form of hand boring apparatus, the hoisting machinery consists merely of a winch with single purchase spur gear operated by handles (Fig. 78). The winch is usually fixed to one of the tripod legs (Fig. 79), and serves the double purpose of handling the various parts of the boring gear and of raising the rods when boring instead of a brace-head. For bore holes over 60 feet in depth, it is desirable to use power to deal with the greater weight of rods. Steam is the usual form of power employed, and the hoisting machinery

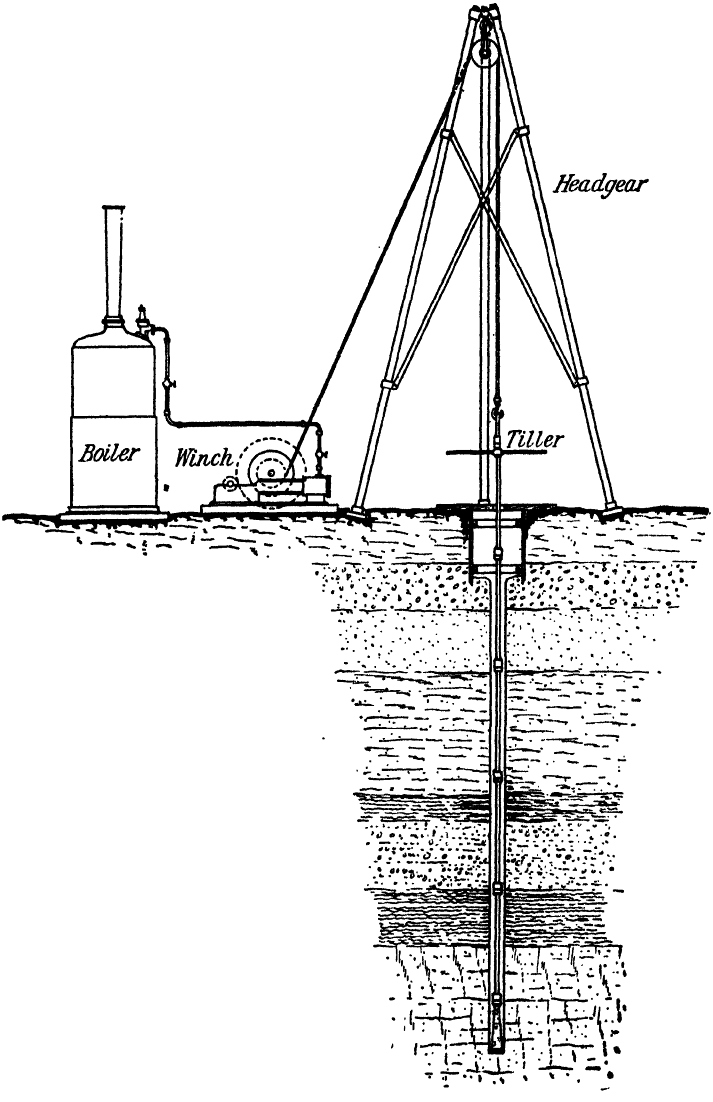


Fig. 80.—Percussive Boring, Power Plant with Tube Headgear.

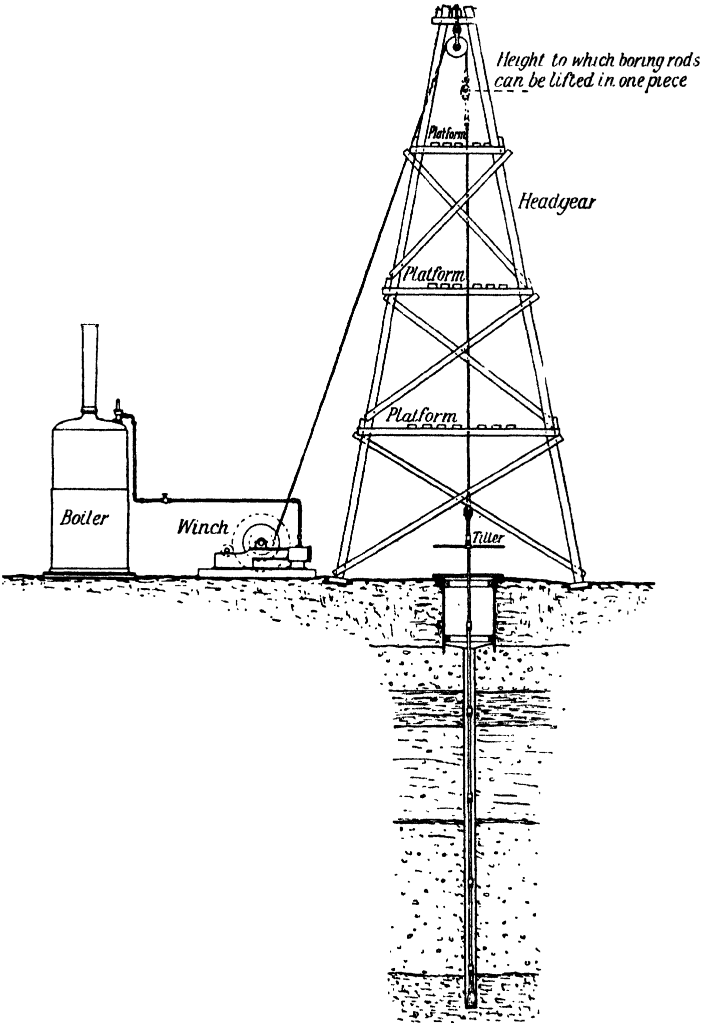


FIG. 81.—Percussive Boring, Power Plant for Deep Holes, with Trestle Headgear.

then comprises a steam winch and boiler (Figs. 80 and 81). A simple method of operating the rods with a power winch is to take three turns of the hoisting rope round the drum, leaving the end free. The winch is then run continuously in one direction, and by keeping strain on the free end of the rope the rods are lifted. When the necessary height has been reached, the man at

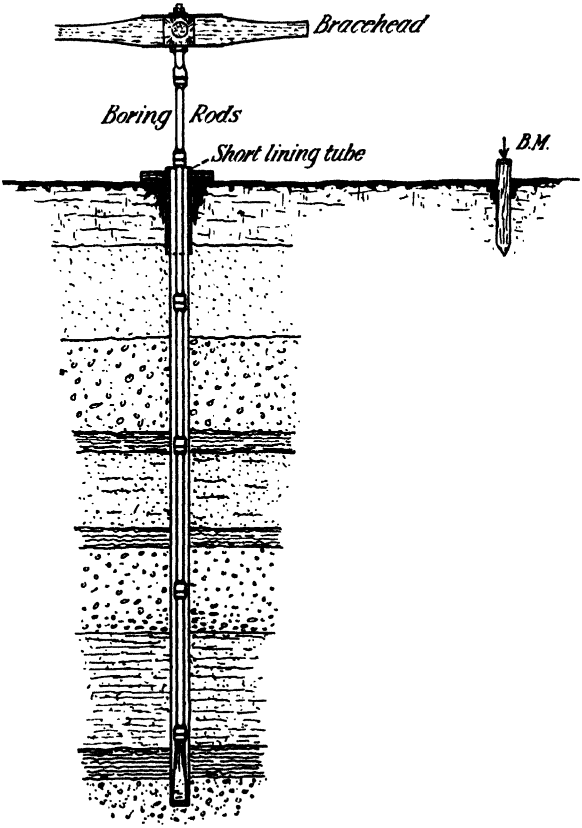


Fig. 82.—Percussive Boring with Hand Plant.

the free end of the rope suddenly releases it and, there being no friction then on the drum, the rods drop sharply. The rods are again raised by the friction of the drum when strain is put upon the rope. In more elaborate arrangements the hoisting rope is automatically tripped by mechanical means, a special disconnecting clutch being fitted to the winch for that purpose, similar to the device on a friction winch for pile driving. Two arrangements of percussive power boring plant are shown on Figs. 80 and 81, for shallow and deep bore holes respectively.

Commencing a Percussive Bore Hole.—The first operation in starting a bore hole is to erect a tripod or headgear right over the spot fixed for the bore hole. If the surface materials are loose they must be secured before commencing to bore, as otherwise they will fall into the bore hole and choke it. The usual practice is to drive a short iron lining pipe into the ground with a wooden mallet, of sufficiently large diameter to admit of lining the hole with casing pipe if required, leaving the end of the tube about 6 in. above ground level to prevent odd things from falling into it. The height of this tube above the ground should not interfere in any way with the free working of the bracehead, and the tube itself should be steadied in position by a small timber platform (Fig. 82). When the ground is very loose it is often advisable to commence the bore hole with a small timbered pit, about 3 ft. square for shallow holes, and about 6 ft. square for deep holes (Figs. 80 and 81). This also permits of a greater length of boring rods being disconnected at one time, as it is equivalent to an increase in the height of the headgear.

Boring.—The site having thus been prepared, the chisel is screwed to the end of the first boring rod, the necessary number of boring rods then added, and the line of rods with the chisel lowered by means of the tripod into the hole until the chisel rests on the ground. If hand worked, the bracehead is then screwed on to the last rod and boring commenced by the men at the handles lifting up the rods from 1 to 1½ ft. and letting them fall freely, so as to deliver a percussive blow (Fig. 82). As each blow is given the men keep moving round in a circle to ensure the chisel falling upon a fresh spot each time, thus maintaining the hole circular in form, as well as preventing the cutting tool from jamming. As the chisel descends it is necessary to add new lengths of boring rods. To effect this the rods are suspended by inserting the nipping fork under the nearest joint, the bracehead then unscrewed, and a fresh length of boring rod added. Care should be taken that the additional rod is not too long, so as to leave the bracehead too high for proper handling, the correct position being about breast high.

In power drilling, the bracehead is usually dispensed with and a swivel rod substituted (Fig. 64), and connected to the spring hook of the hoisting rope. The rods are now lifted and dropped by mechanical means, and the turning is done by the rod tiller under the guidance of the foreman driller. Additional rods are fixed as required by inserting the nipping fork (Fig. 68), and disconnecting the swivel length as before.

Examination of Chisels and Bits.—In sinking a bore hole care must be exercised to frequently examine and gauge the size of the chisel, as it often wears rapidly at the corners and produces a smaller hole than originally intended. This is best done by calipering the chisel when it is first attached to the rods, and applying the calipers each time the rods are withdrawn. If the chisel in use is found to be worn it must be removed and a new chisel substituted. The fresh chisel should then be lowered carefully and completely turned round at intervals in order to ascertain where the diameter of the bore hole has become diminished, as it is apt to stick if forced down at once to the bottom of the tapering hole. From that point cautious boring should be commenced until the original bottom is again reached, when the usual operations may be resumed.

Clearing the Bore Hole.—When the rods become difficult to move, or when it is desired to obtain a sample of the materials, the bore hole must be cleared of the fragments or *débris* by means of the sludge pump, or the auger shell. To attach the sludge pump, the whole of the boring rods and chisel must be withdrawn from the bore hole, and the advantage of being able to disconnect the boring rods in long sections is thus apparent. To remove the rods when hand boring, the bracehead must first be unshipped. This is done by lifting the rods sufficiently far to permit of the nipping fork being inserted under the second joint collar, when the bracehead can be unscrewed, and the length of rod taken off below it by the rod key (Fig. 69). This operation is repeated until the whole of the rods have been withdrawn.

In power boring, the rod tiller is first unclamped, and the rods then raised by the swivel rod as far as the height of the headgear permits. When the joint at which the rods are to be parted is just above the lining tube or platform, the nipping fork is inserted under the collar, and the rods then gently lowered until the weight rests upon it as it lies upon the top of the tube. A rod key is then applied to the neck of the boring rod immediately above the nipping fork, and the joint unscrewed by wrenching with it against the resistance of the nipping fork. The length of rods thus disconnected is lowered to the ground, the swivel rod unscrewed, and again attached to the rod resting on the nipping fork, and the operation repeated until the whole of the rods have been removed from the bore hole.

The chisel is now unscrewed from the last section of the rods, its place taken by the sludge pump, and the section lowered into the bore hole until the last rod again rests on the nipping fork. The next section is then added, the rods slightly raised to allow of the nipping fork being withdrawn, and the whole then lowered bodily until the last collar is near the top of the tube or platform, when the nipping fork is again inserted below this collar to take the weight. In this way the rods are lowered section by section until the sludge pump rests on the bottom, when the bracehead or swivel rod is finally attached. The lifting dog (Fig. 70) may be also conveniently used when handling long lengths of rods in this way.

Operating the Sludge Pump.—In order to fill the sludge pump, the rods are lifted up and let fall as in boring with the chisel, but more gently, and are revolved by the bracehead or tiller. The sludge pump is usually filled before it is withdrawn, and this is regulated by making a chalk mark on the rods when the sludge pump is at the bottom of the bore hole, and measuring off the length of the sludge pump above it. The rods are then worked until they have descended a distance about equal to the length of the sludge pump, as indicated by the top chalk mark.

To withdraw the sludge pump, the same operation as that for recovering the chisel has to be gone through, that is, the rods have to be removed from the bore hole in sections. When the sludge pump has been withdrawn from the bore hole, it is unscrewed and the contents carefully emptied on a board for examination and subsequent transference to the sample box. The sludge pump is lowered as often as may be necessary into the bore hole until the loose materials are cleaned out, and if it does not act freely owing to the materials being dry, water must be added to flush the hole. This should be used sparingly, however, as a large quantity of water may cause the sides of the hole to be washed in during sludging operations if not lined with casing tubes.

Lining of Bore Holes.—When soft materials are passed through, it may be necessary to line part or all of the bore hole with casing tubes to prevent collapse of the sides (Fig. 71). The need for lining will become apparent by the boring tool failing to descend to the same level as was reached before being withdrawn, owing to the bore hole being partly choked. Materials falling into the bore hole from the strata already passed through are a frequent source of error in estimating the thickness and character of the beds.

Obstructions in Percussive Boring.—In course of boring, large boulders, pockets of stones, tree trunks, and other isolated obstructions are frequently met with, causing much delay in completing the bore hole. In the case of very large boulders it is difficult to distinguish them from solid rock, but pockets of stones, and sunken timber are easily noted from the "feel" and sound of the boring rods when the chisel strikes the bottom. A fair and persistent effort should always be made to penetrate obstructions, but if a bore hole is not rigidly confined to a particular spot, and little progress is made, it is better in the long run to abandon the hole altogether and start one or more new holes in the immediate vicinity. In this way it is possible to prove whether the obstruction is local or not (Fig. 36). If lining tubes are used, the obstacle may be removed or displaced by blasting, as described in Chapter VI, but with unlined holes an explosive ought to be used only under circumstances where the nature of the ground is such that the shot will not shake it so much as to bring down the sides and block the bore hole.

Samples from Percussive Borings.—The samples from percussive borings are obtained direct by the sludge pump, or the auger shell. The selection of suitable positions in the bore hole from which samples are to be taken depends on the judgment of the engineer, or the foreman driller in charge, but at least should be obtained at every change of stratum. An experienced driller can usually tell by the " feel " and sound of the boring rods when such a change in the ground occurs, but if the work is not under experienced hands the safest way is to sample the materials frequently. Incidentally, a large quantity of materials will be brought up from the bore hole, and they should all be included, in the first instance, amongst the samples laid aside for examination. It is not usual, however, to retain all the materials extracted, but to make a careful selection typical of the various strata passed through. To enable this to be done all the materials brought up are laid out on clean boards in the order found, and when a stratum has been pierced a representative selection is made from amongst them. The selected samples should be carefully placed in sample boxes for further examination and reference.

Sample Box.—A suitable sample box can be made of sawn white pine, ⅝-in. thick and about 27 in. long, 14 in. wide and 3 in. deep inside, divided up into pockets, as shown on Fig. 83. The sides, ends, and bottom should be screwed together, and a good fitting screw-down lid, ⅝-in. thick, should be provided to prevent samples being tampered with or getting mixed up in course of transit. For convenience and care in lifting and stowing, each box should be provided with handles. As each pocket is filled it should be carefully marked with an untearable label tacked on to the compartment, or to the underside of the lid, directly over the compartment, bearing a full description of the sample, as, for example, " Boring No. 10, Sample 4, Coarse Sand, 10 ft. from surface." This should be written in ink and, if the samples are to be transported, Indian, or some other indelible ink not liable to be affected by the atmosphere, should be used. As samples of borings usually form an integral part of a contract, the greatest care should be taken to preserve them in perfect order, as in the event of disputes they may form an important part of the evidence in settling claims.

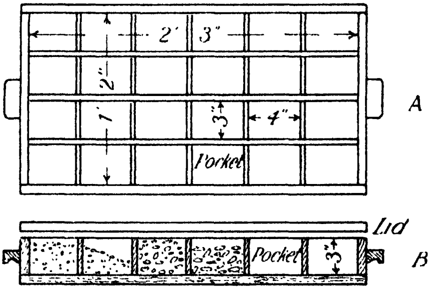


Fig. 83.—Sample Box. *A*. Plan ; *B*. Section.

Setting Out Borings.—When a close series of borings is to be made over a limited area, such as the site for a building, they may be set out by squares in the manner described for probe holes. Borings intended to test the ground over the route or site of a proposed railway, aqueduct, docks, or similar works require to be set out from a correct plan and sections on which the positions of intended works are marked, such as bridges, tunnels, cuttings, embankments, quay walls, and dock entrances (Fig. 85). The positions of the borings as selected should be laid down on the plan, and also on the sections, and be numbered consecutively. The sections should show the maximum depths of the proposed foundations of the various works as a guide to the least depth necessary to be proved in the borings. In the field, the centre line of the works is first set out in the usual way, and the positions of the bore holes then pegged off in accordance with the plan and sections. The surface level at each boring must be carefully ascertained, and checked with reference to a datum line.

When borings deviate from the positions laid down on the plan and sections, and when it is necessary to make additional borings, they should be carefully surveyed and plotted on the plan and sections, so as to make the record complete.

Record of Percussive Borings.—In percussive boring the depths reached are measured direct from the boring rods, as shown on Fig. 82. The lengths of the various boring rods should, therefore, be carefully noted as they are added, and opportunity be taken when they are withdrawn to measure the lengths as a check on the work. The record of borings (Fig. 84), may be kept in the following manner :—

BORINGS AT BASIN NO. 1. *Date: June 10th,* 1913.

No. of Boring.	Red. Levels on Boring.	Depth below Surface.		Nature of Ground.	Remarks.
	Ft.	Ft.	In.		
10	+ 2·25	0	0		Above datum.
	1·25	1	0	Soil.	,,
	— 2·25	4	6	Sand.	Sample No. 1.
	3·75	6	0	Clay.	Sample No. 2.
	15·25	17	6	Fine sand.	Sample No. 3.
	22·00	24	3	Shingle.	Water found. Sample No. 4.
	31·50	33	9	Marly clay.	Sample No. 5.
	39·00	41	3	Shingle.	Sample No. 6.
	45·75	48	0	Coarse sand and clay.	Sample No. 7.
	48·50	50	3	Shingle.	Sample No. 8.
	54·00	56	3	Soft marly rock.	Sample No. 9.
	61·00	63	3	Hard marly rock.	Sample No. 10.

Plotting Borings.—The positions and depths of the borings, as completed, are usually marked on the general contract plan and sections of the proposed works, and, in addition, special sheets are prepared showing in detail the results of the borings. These are included in the contract drawings, and form an important and integral part of the contract. Two methods of plotting the borings are adopted :—

(1) Separate sections.

(2) Continuous sections.

The first method is used to give the full details of each boring independently, without any attempt to correlate the borings generally, while the second partakes more of the nature of general geological sections in which the information from each individual boring is worked into a coherent scheme of geological structure. Borings should always be plotted by the first method, and, when the geological data is complete and reliable, also by

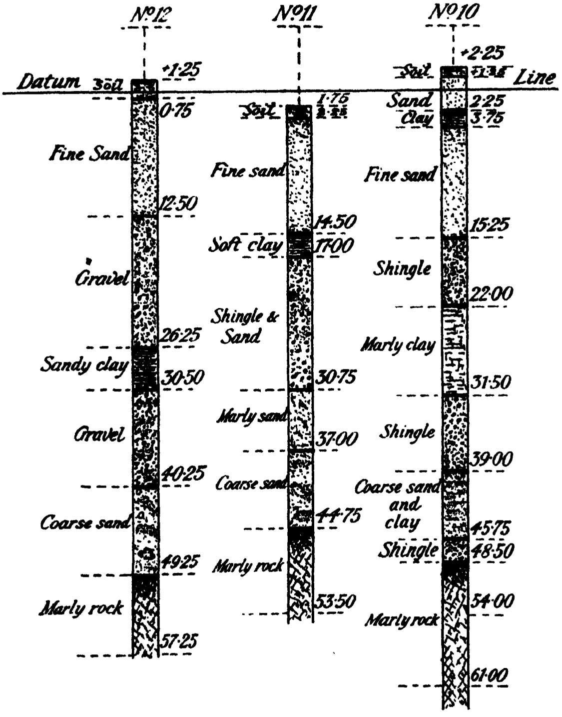


FIG. 84.—Borings Plotted in separate Vertical Sections.

the second, as these together furnish the most complete exposition of the structure and lithology of the ground.

(1) Separate Sections.—When the borings are plotted in separate sections, each boring should be drawn to a true vertical scale, and the various strata described in writing and coloured, or otherwise marked to distinguish their character. The depths at which the strata lie, with reference to a datum, should also be clearly written opposite each, as shown on Fig. 84. The number of each of the borings should be given, and their positions located and numbered on an accompanying site plan, or key plan, drawn to a small scale. In this method no attempt is made to express the continuity of any stratum, but is simply a record of the results of the actual examination of the ground at particular spots.

(2) Continuous Sections.—On the other hand, a geological section constructed from borings is an attempt to define the general structural arrangement of the strata over the area examined, and requires the greatest care and judgment in its preparation.

A continuous longitudinal section is first prepared in the usual way, to convenient horizontal and vertical scales, and a suitable datum line. For sections of considerable length, where the horizontal scale is necessarily small, the vertical scale must be selected much larger than the horizontal in order to show clearly the thickness of the various strata, as in the general longitudinal section of a railway. On this section the positions of the bore holes are plotted, and the levels of the various strata, as found from the borings. The levels of each individual bed are now connected by sketching in continuously between the known points, so as to define its position and form. Where beds finish in an abrupt manner, discrimination should be exercised as to the extent to which they should be produced past the borings where they last appeared. In the superficial deposits, for instance, beds do not as a rule terminate suddenly, but tail off naturally and disappear. Again, a boring, out of several nearby, may strike certain materials once only, and the reasonable inference is that these form an isolated pocket, and should be so indicated on the section. The depiction of the strata on a section of this kind is largely a matter of practical skill in correctly interpreting the geological evidence obtained from the general borings, and is simplified if the geological structure has been ascertained by survey beforehand, as serious misrepresentations are not then likely to be made when filling in the details. The data obtainable from a detailed geological survey should, therefore, always be used in conjunction with the engineering test borings and pits in constructing sections of this kind.

The strata should be tinted in distinct colours, or artistically treated by conventional markings on the sections to bring out clearly the various beds and geological features of the area examined (Fig. 86). If the scale is large enough, the names of the materials should be printed on, but otherwise a small, key legend may be drawn in a prominent position on the section showing the various conventional colours or markings used, and their equivalent names.

It should be borne in mind, however, that a geological section cannot be laid down with certainty from a single line of borings, as these give no indication of the dip of the strata on either side of that line or, necessarily, of faults and other structural dislocations. This is an important matter where the works under consideration have considerable width, as in the case of a high reservoir dam, or large dock wall where it would be necessary to open wide trenches. In such cases a quick dip of the strata across the line of the works might, if unforeseen, lead to great trouble in dealing with timbering of the trenches, large quantities of water, and slipping foundations. Wide foundations should, therefore, be proved by supplementary lines of borings on each side of the centre line. With this additional information geological cross sections can be drawn which, together with the geological longitudinal section, will give a true conception of the strata, so far as can be deduced from borings and the other data

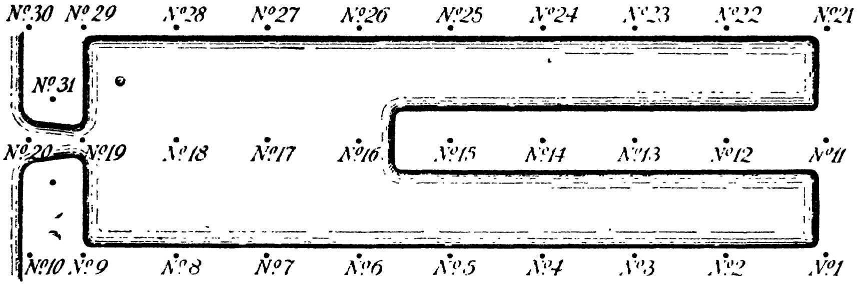


FIG. 85.—Plan of Dock, Showing Positions of Test Borings.

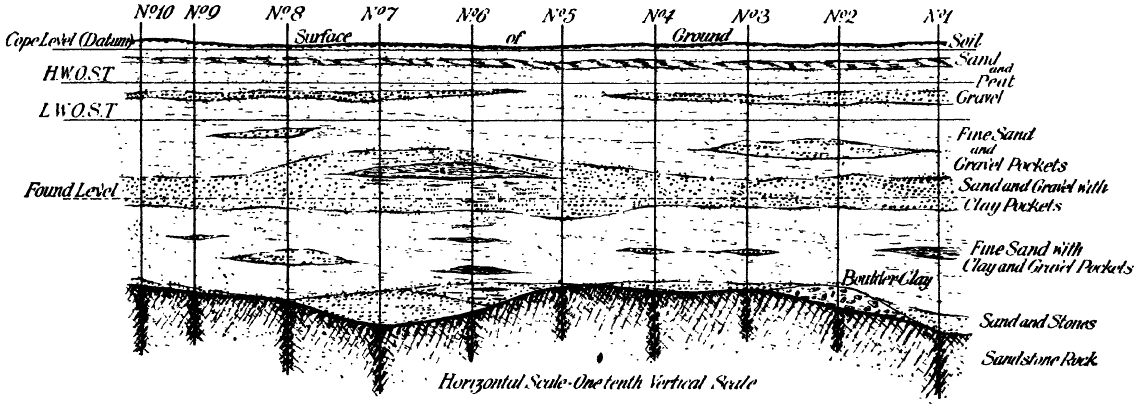


FIG. 86.—Geological Section, Constructed from Borings Nos. 1—10 (Fig. 85).

available. Sections of this kind are usually plotted as shown on Figs. 85 to 87, which illustrate the test borings put down for a large tidal dock. The plan (Fig. 85) shows the positions of the borings, and the longitudinal section (Fig. 86) the geological structure between borings 1 to 10 inclusive, while the cross section (Fig. 87) is taken through borings 2, 12, and 22. To complete the work, two longitudinal sections are required, one on

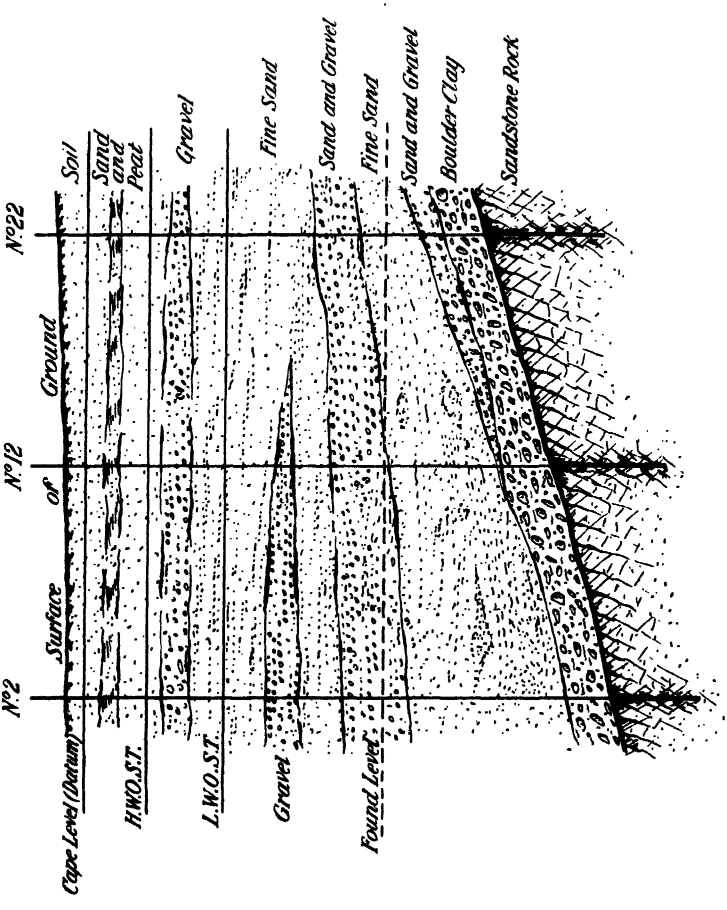


FIG. 87.—Geological Cross-section, Constructed from Borings Nos. 2, 12 and 22 (Fig. 85).

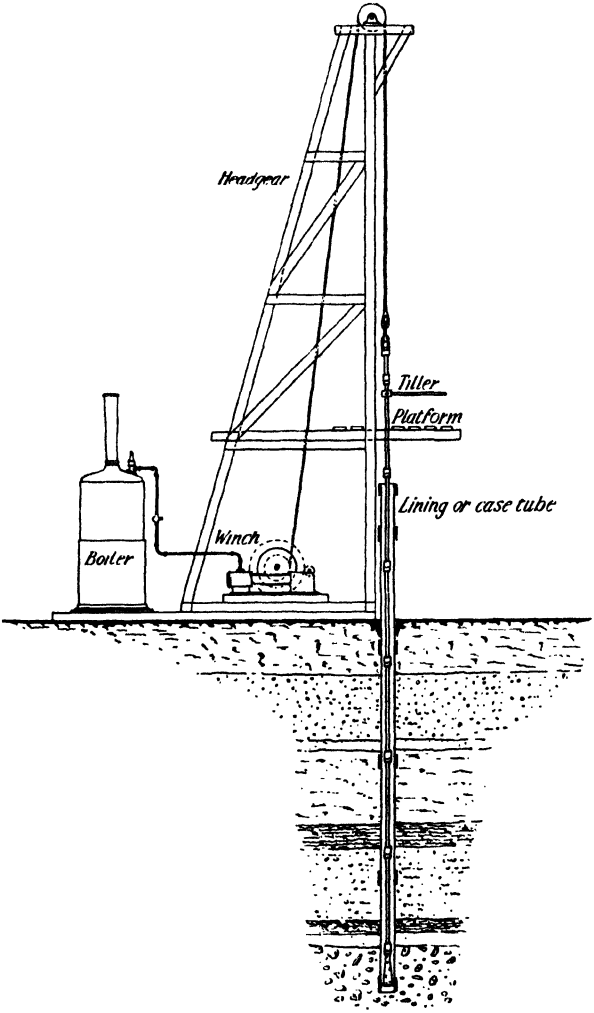


Fig. 88.—Percussive and Wash Boring Power Plant, with Timber Frame Headgear.

the centre line, including borings 11 to 20, and one on the dock side, including borings 21 to 30, and sections, similar to that shown on Fig. 87, across the dock. Incidentally, the cross section through borings 2, 12, and 22 shows that the surface of the rock dips across the dock, and that the boulder clay immediately overlying it is continuous from side to side, facts which a longitudinal section alone would have failed to disclose. In this case the area was occupied by superficial deposits with only a few partial exposures, and the disclosure of its geological structure and lithology in detail was thus almost entirely dependent upon the information derived from the engineering test borings and pits.

Combined Wash, and Percussive Boring

General Description.—Wash, and percussive boring may be used together in sinking a bore hole, particularly when the materials are soft or loose with occasional compact beds. In such cases, wash boring may be carried on until the size or weight of the materials is such that they will not wash up to the surface. The jet pipe should then be withdrawn, and the ordinary percussive boring rods and chisels used to break up the compact stratum, when wash boring can again be resumed.

Combined Wash, and Percussive Boring Appliances.—The appliances necessary for carrying out wash, and percussive boring in the same bore hole are those of the two individual systems combined, so as to suit either as required. All bore holes sunk by wash boring must be lined with casing pipes, so that if the two methods are to be used together, lining should be put down at the commencement to avoid the necessity of enlarging them by reamering if percussive boring is used first. The general arrangement of a boring plant, suitable for either wash or for percussive boring is shown on Fig. 88.

Making Combined Wash, and Percussive Borings.—Combined wash, and percussive borings are made, recorded, and plotted in the manner already described in detail for each method.

CHAPTER IV

II. BORING (*continued*)

(3) ROTARY BORING

General Description.—Rotary boring consists in penetrating the ground by the abrasive or grinding action of a revolving cutting tool of hollow section. This system differs fundamentally from percussive boring in that the materials cut through are not broken up or pulverised, but are brought to the surface in the form of a solid core, which shows the natural character of, and order in which the strata actually exist. Rotary boring, however, is only suited to materials of considerable consistency and hardness, from which a core possessing sufficient coherence can be withdrawn more or less entire from the bore hole. The percentage of core recovered from a rotary test boring is largely the measure of its success, and the best results are obtained in firm rock or materials of an equivalent character. For important bore holes of considerable depth in hard ground, this system gives the best results, and is the most economical. In all applications of the rotary system an annular cutting tool or crown of some specially hard material is essential, along with the means of rotating it at high speed and keeping it constantly flushed with water when in operation.

Systems of Rotary Boring.—There are two systems of rotary boring, viz. :—

(*a*) With diamond crowns.
(*b*) With steel crowns of various kinds.

In deep test borings for engineering purposes, where cores of large diameter are not required, the diamond crown system is that most commonly used, and generally best adapted to all of the exigencies of difficult situations. The essential difference between the two foregoing systems of rotary boring is in the design of the cutting tool or crown, and it is chiefly on account of the high cost of the diamonds that steel crowns have been substituted in other rotary systems with a view to doing the same kind of work at less initial cost.

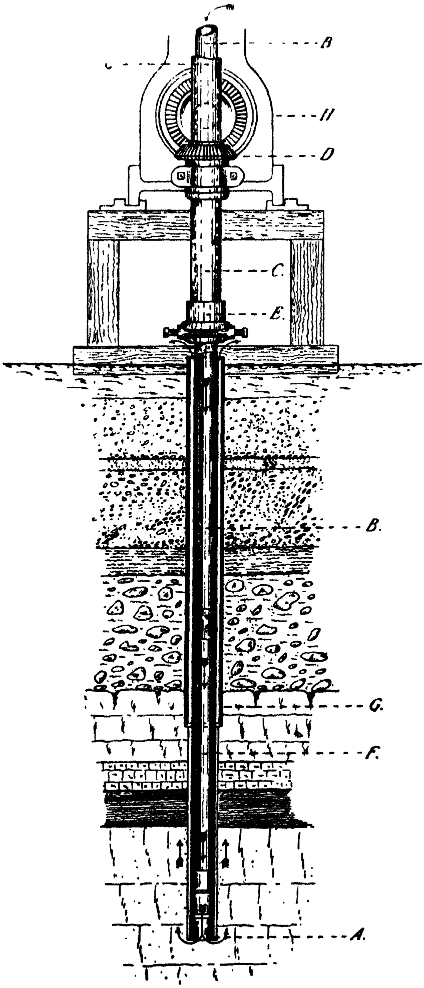


Fig. 89.—Rotary Boring with Diamond Crowns, General Arrangement.

(*a*) Boring with Diamond Crowns

General Principles.—The general principles of diamond boring are illustrated by Fig. 89, which shows the general arrangement diagrammatically of the boring apparatus. The diamond crown, *A*, is attached to hollow boring rods, *B*, which pass up into the drill, *H*, through an external sliding tube, *C*, driven by bevel gearing, *D*. By means of a driving chuck, *E*, the sliding tube and the rods can be clamped and made to revolve together, thus giving rotary motion to the crown, while its advance into the rock is provided for by the downward sliding motion of the hollow tube, which is controlled by a suitable feed gear (Figs. 106 and 107). As the crown penetrates the rock, a solid cylindrical core is cut, of slightly less diameter than the inside of the crown, which passes up into the core-barrel or upper tube, *F*, a special part of the hollow rods (Fig. 90), from which it can be extracted when desired. To flush the crown, and to wash up the grit made by the diamonds when at work in the rock, pressure water is pumped down the hollow rods, which escapes from under the crown and flows to the surface in the clearance space left between the bore hole and the crown and rods, as shown by the direction arrows in Fig. 89 and in Fig. 92. The bore hole, where it passes through the loose materials overlying the rock surface, is secured by lining pipes, *G*, sunk by percussive and wash boring, and

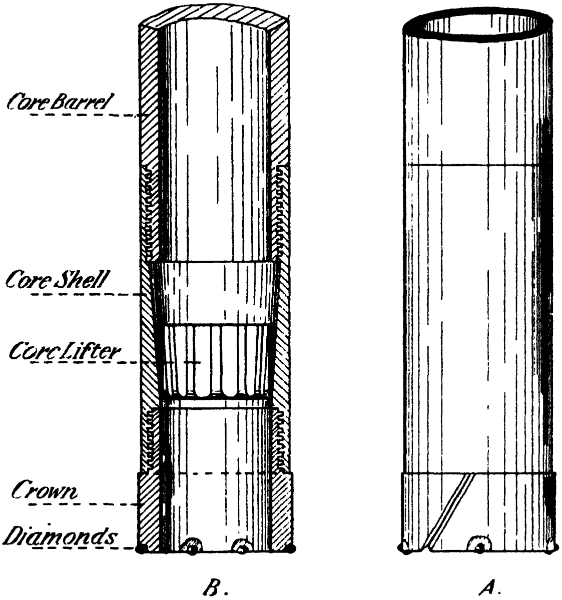


FIG. 90.—Diamond Crown Drill, Working Parts. *A*. Elevation; *B*. Section.

driven into the rock to make a tight joint to prevent the escape of pressure water.

Diamond Boring Appliances.—Diamond boring appliances for test borings consist essentially of a crown, in which the diamonds are set (Fig. 91); a core-shell, core-lifter, and core-barrel, which preserve and bring up the core (Fig. 90); a force pump which supplies the pressure water for flushing the crown, and for jetting down lining pipes in the preliminary stages of boring; hollow boring rods through which the stream of water is forced to the crown (Fig. 96); hollow chisels or bits for sinking lining pipes and breaking up obstacles (Figs. 97 to 101); head gear or derrick, and winch for manipulating the various parts of the outfit; and, in deep bore holes, engine motive power for rotating the drill and operating the hoisting winch and pressure pump (Figs. 103 and 104).

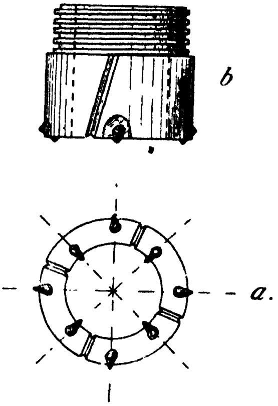


Fig. 91.—Setting of Diamond Crown. (*a*) Plan of Face; (*b*) Elevation.

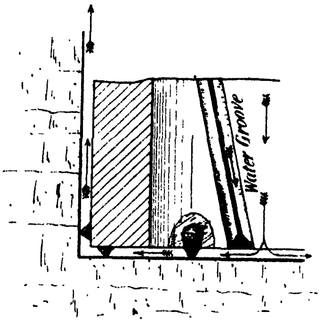


Fig. 92.—Clearance of Diamond Crown.

Crown and Diamonds.—The crown and diamonds are the most important parts of a diamond drill. The crown is a steel cylinder which occupies the extreme end of the boring apparatus, and is of slightly less diameter than the intended bore hole. It is screwed to the core shell with square screw threads, and in it are fitted the diamonds which do the actual cutting work (Fig. 91). These diamonds or carbons are commonly termed "black diamonds," as distinct from the brilliant or clear diamond of commerce, and are found only in a few places in Brazil in decomposed conglomerate. Their colours are black, grey, and brown, and the sizes range from small pieces up to 100 and 500 carats. The suitability of carbons for drilling hard rock lies in the fact that they are imperfectly crystallised, and thus have no cleavage planes, as in the case of the perfectly crystallised brilliant, and wear gradually by attrition only.

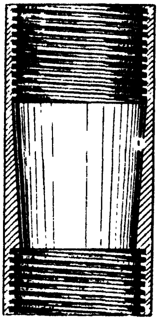


FIG. 93.—Core Shell.

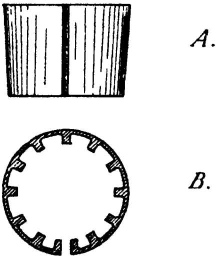


FIG. 94.—Split-ring Core Lifter.
A. Elevation; *B.* Section.

As the value of a diamond drill depends on the enduring qualities of the carbons, the stones require to be specially selected. The best form is that of a cube, as irregular stones wear more rapidly on their thin edges, and cannot be set in the crown with the same security. The cubical form is usually obtained by breaking the natural stones to that shape, which has incidentally the important advantage of disclosing their colour and texture. The best carbons for drilling purposes are those of the finest homogeneous appearance, and of a grey or green-grey colour. Bortz, or imperfect white diamonds, obtained in South Africa, are also used for crowns when drilling through soft and regular rocks, but although as hard as carbons they are not so tough, and have cleavage planes. The cost of these stones is much less than carbons, but they have not the reliable qualities of the latter, and are less used on that account.

Setting of Diamonds.—Eight carbons are usually fitted to crowns suitable for cutting a core from 1 to 2 in. diameter, the usual size for test borings, and the sizes of the carbons vary from one to four carats. Crowns above 2 in. diameter are armed with a proportionate increase in the number and sizes of carbons.

The setting of carbons in the crown requires the greatest care, in order to maintain uniform wear on the carbons themselves, and to ensure the drill running regularly and smoothly. The operation of setting is done entirely by hand, with the aid of drills and chipping and caulking chisels. The crown is divided into eight equal parts, so as to allow of equal spacing of the carbons, which are placed four on the inside cutting edge, and four on the outside edge (Fig. 91). The four largest and best carbons of nearly equal size are selected for the outside edge, in order to maintain the diameter of the bore hole as true as possible, and the four smaller stones for the inside edge. It is important that the stones of each set should be uniform, as otherwise there will be unequal strain on the smaller stones, and consequent danger of their being torn out of the crown when the drill is in operation.

As the stones differ from each other in size and form, the seat for each requires to be specially made. For this purpose the blank crown is placed in a vice and a hole drilled with a twist drill less than the general size of the carbon to be set. The holes for the exterior carbons are drilled from the face, and the interior holes from the end of the crown, and enlarged with a small chipping chisel to suit generally the particular shape of the carbon. This must be done carefully by trying the carbon in the hole from time to time until it is truly and firmly bedded. The metal of the crown is then worked back round the hole with the carbon in place by means of caulking chisels, so as to form a claw or grip all round the carbon, but finally leaving it projecting slightly past the vertical face and the under edge of the crown. The process of working up a grip on the carbon is usually carried out by first making two deep incisions with a cutting chisel near the hole, and then working the metal within the area of the incisions over towards the carbon. The greatest of care must be taken to work the steel of the crown equally all round the carbon, so as not to displace it from the proper gauge in the process of setting. When a hole has to be greatly enlarged to suit an irregular carbon, the material of the crown is supplemented by caulking in a piece of copper or soft Swedish iron to make the bearing and grip as full and solid as possible.

Clearance of Diamonds.—For the purpose of freeing the boring tool and providing the necessary water passages, a clearance or slight projection past the surfaces of the crown is given to the diamonds. In the case of hard and homogeneous rocks, the projection is usually one sixty-fourth of an inch each way, but in soft and friable rocks one thirty-second of an inch or a little more is allowed. The same amount of clearance is given to both the outside and the inside diamonds, each stone having of course two projecting faces, one on the outside or inside surface as the case may be, and one on the face or lower end of the crown. The outside studding of stones cuts the necessary clearance vertically for the crown, core-barrel, and water circulation, that on the inside surface cuts the vertical clearance for the core and the water circulation, while both do the cutting or abrading of the materials laterally under the face of the crown necessary for its advance in the bore hole, and for flushing. The general object of clearance is shown diagrammatically on Fig. 92.

Cutting Out Diamonds.—When it is necessary to reset diamonds a new crown must be used. The diamonds are cut out of the old crown by making a saw cut across its end near the stone to be removed, or a deep incision with a file, and then carefully chipping away the metal surrounding the stone. Great care must be taken not to strike the stone with the chisel, as the result will be to splinter it.

Water Grooves.—When a crown has been completely set, grooves are cut between the diamonds on its face and on the outside and inside surfaces in order to permit of the free circulation of water round the crown, and thus keep it cool when in operation (Fig. 91). These are usually V-shaped, and are cut with a special chipping chisel. The proportions should be ample, as otherwise the abraded materials are not washed out fast enough from the bore hole, and the crown in consequence quickly becomes worn, or so warm that it may even seize in the bore hole. When a crown seizes badly the heat generated by friction is sufficient to burn the steel and allow the diamonds to drop out. The recovery of lost stones from a bore hole is always a difficult matter, and if not recovered they may cause the destruction of succeeding crowns.

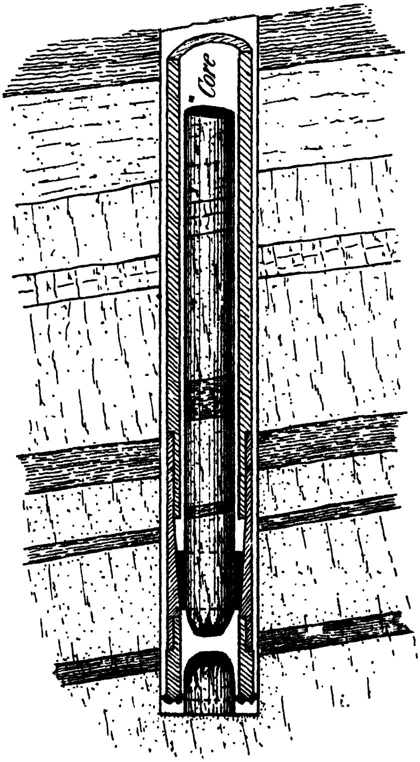


Fig. 95.—Diamond Drilling, Extraction of Core.

Core Shell.—The core shell is a thin, steel tube screwed directly to the crown by square screw threads. It is of uniform external diameter, but cone-shaped inside to suit the form of core-lifter (Fig. 93). The core-barrel is screwed directly to the top end of the core-shell.

Core Lifter.—The core lifter is used to grip the core and retain it when being lifted from the bore hole. It is usually a thin, split, steel ring, in the

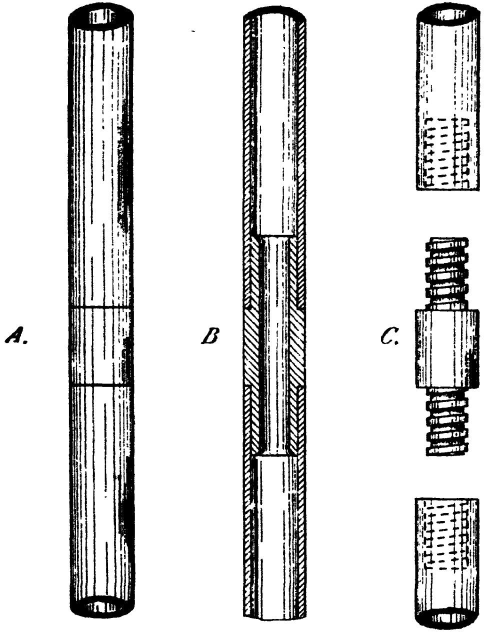
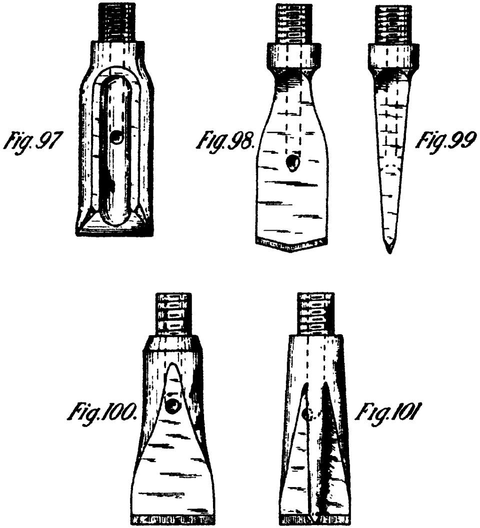


Fig. 96.—Hollow Boring Rods. *A*. Rods connected. *B*. Section. *C*. Rods disconnected.



Figs. 97—101.—Hollow Chisels and Bits.

form of a truncated cone with water grooves inside (Fig. 94). When boring operations are in progress the core-lifter is forced, under upward pressure of the core, into the top part of the recess provided for it in the core-shell, but on the rods being slightly raised it slips to the bottom of the recess under the weight of the core and release of downward pressure on the boring rods. The core is then gripped or throttled by the small end of the core-lifter, and breaks off, as a rule, immediately below it as the rods are withdrawn (Fig. 95). The core-lifter thus forms an artificial bottom to the core-box, and prevents the core from falling out as it is raised from the bore hole.

Core Barrel.—The core barrel is a plain, steel cylinder screwed directly to the core-shell by square screw threads. For test borings it is usually about 10 ft. long. The boring rods are screwed directly to the top end of the barrel by means of a hollow coupling (Fig. 96). When the core is in process of being cut, it passes up into the core-barrel, from which it can be recovered when required by raising and unscrewing the rods. Owing to the clearance of the inside diamonds in the crown, a core of rather smaller diameter than the core-barrel is produced, and this clearance permits of the free circulation of the water to the cutting face of the crown during boring operations (Fig. 92).

Hollow Boring Rods.—The boring rods are of steel tube, in lengths of from 5 to 10 feet, and are connected together by means of hollow couplings, forged from the solid, turned and bored, and screwed at each end with square screw threads. When screwed into the boring rods, the turned faces of the rods bear hard upon the shoulders of the coupling, thus taking the weight and shock off the screw threads when boring (Fig. 96). The joints when made are flush with the outside of the rods, but the couplings project for about one-half their thickness within the inside diameter. Thus for 1⅝ in. outside diameter rods, the inside diameter of the couplings is about 1 inch, and forms the waterway (Fig. 96).

Hollow Chisels and Bits.—Hollow chisels and bits are used for breaking up obstructions when sinking lining pipes through loose materials overlying the rock surface, and the usual forms are shown on Figs. 97 to 101. A flat, grooved, straight-edged chisel is shown on Fig. 97 ; a flat, diamond-pointed chisel on Fig. 98, and its side elevation on Fig. 99 ; a cylindrical straight-edged chisel on Fig. 100 ; and a cylindrical cross-bit on Fig. 101. The chisels are attached to the end of the boring rods by square screw threads, and are provided with holes for the outlet of the pressure water, so that jetting and cutting can be carried on together (Fig. 139).

Hoisting Plug.—The hoisting plug, or lifting swivel, is used for suspending the boring rods when being hoisted or lowered, and consists of a short, forged steel, hexagonal bar, screwed at the lower end, and fitted at the top with a forged steel, swivel eye, of suitable dimensions for the hook of the winch hoisting rope (Fig. 102).

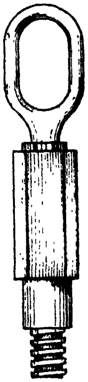


Fig. 102.—Hoisting Plug.

Water Swivel.—The water swivel is screwed to the last length of the boring rods, which passes through the hollow driving spindle of the drill itself. It is used to connect the hose of the pressure pump to the boring rods, and is fitted with a watertight gland or stuffing box, which permits the boring rods to rotate while the swivel and hose remain stationary. The common water swivel is shown on Fig. 106, but a form fitted with a swivelling bow which dispenses with the need of a hoisting plug is often used (Fig. 109).

Driving Chuck.—The driving chuck is screwed to the bottom of the hollow driving spindle of the drill. It is provided with two vice grips, which are adjusted each by a pinching screw, to grip the boring rods (Figs. 89 and 106). When secured in the chuck, the boring rods rotate with the driving spindle.

Safety Clamp.—The safety clamp is used for automatically gripping and sustaining the weight of the boring rods when suspended. It consists of two steel vice jaws, secured in a strong iron frame, and so arranged that they open under an upward and close under a downward pull of the rods (Fig. 102A). When the clamp has been set for the rods it is automatic in action, and is a safeguard against accident to the boring rods by breaking or slipping of the hoisting rope.

Drills.—The modern power diamond drill consists of three essential parts, the engines, the feed gear for regulating the speed of boring, and the hoisting winch. These parts are usually combined as one machine upon a strong cast iron bed plate and side frames. The bed plate rests upon a strong timber under frame, and can be moved longitudinally by means of iron rack gear on the frame, so that the whole drill can be shifted clear of the bore hole and reset in position again as required. Each of the three parts of the drill can be run independently. The general design of a power diamond drill is shown on Fig. 103, which illustrates a " Sullivan " diamond core drill capable of cutting a $1\frac{1}{8}$ in. diameter core at a depth of 1,500 feet. In this machine the " feed," or advance of the crown when boring, is regulated by a hydraulic cylinder (Fig. 106). Another type of " Sullivan " power drill is shown on Fig. 104, with a screw feed, driven by

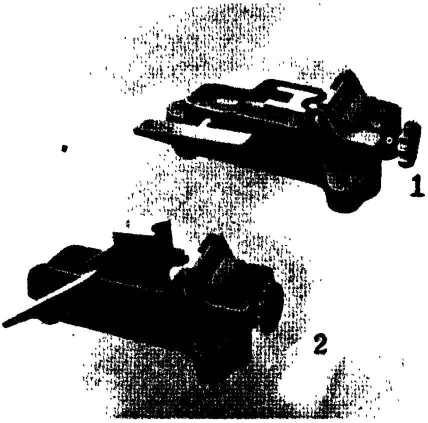


Fig. 102A.—Safety Clamp. (1) Clamp Closed. (2) Clamp Open.

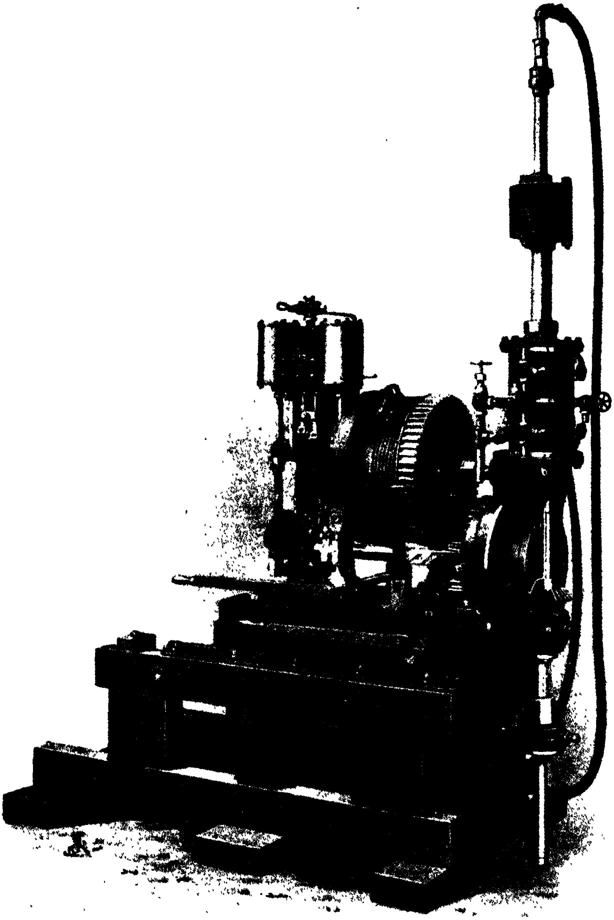


Fig. 103.—Power Diamond Drill, with Hydraulic Feed.

differential gearing (Fig. 107), and capable of cutting a 1⅛ in. core at a depth of 1,500 ft. The engines of both of these drills are steamed from a 12 h.p. boiler, and the pressure water supplied by a horizontal duplex pump, having 6-in. cylinders, 4-in. pump barrels, and a 6-in. stroke. The boring rods are 1⅝ in. outside

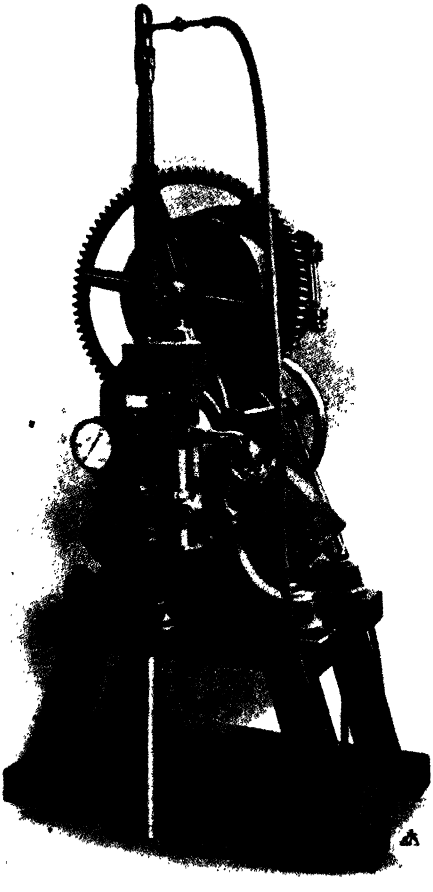


FIG. 104.—Power Diamond Drill, with Screw Feed.

diameter. A hand-drilling machine by the same makers is shown on Fig. 105. This drill is capable of boring to a depth of 300 ft. and producing a core $\frac{15}{16}$-in. diameter. The feed is of the screw and differential gear type, and the drill, hoist, and pressure pump are all worked by hand.

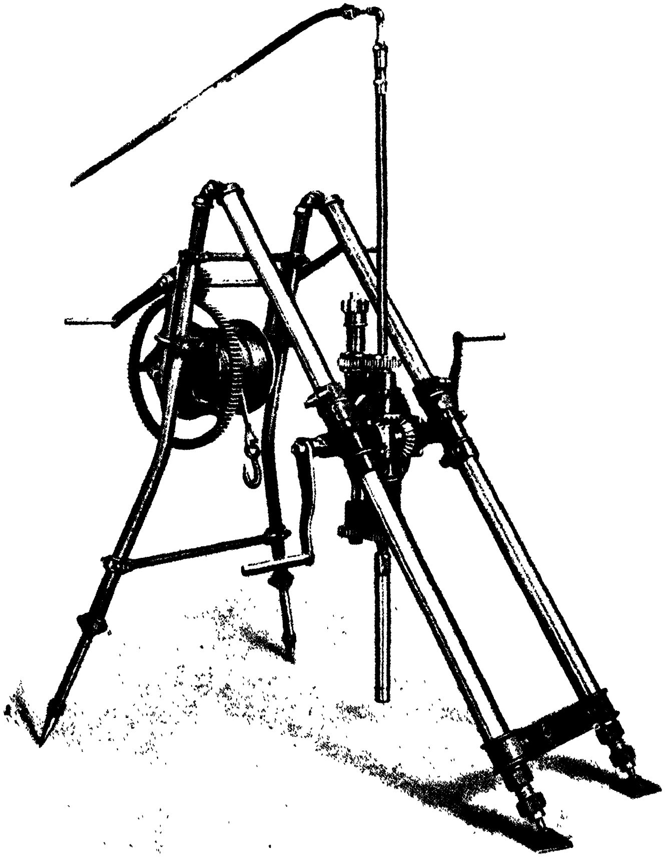


FIG. 105.—Hand Diamond Drill, with Screw Feed.

Drill Feeds.—Two kinds of feed apparatus are fitted to diamond drills, namely :—

(*a*) Hydraulic feed.

(*b*) Screw feed.

The hydraulic feed maintains a constant pressure on the crown when boring, while the screw feed advances the crown at a constant speed regardless of pressure.

(*a*) HYDRAULIC FEED.—The type of hydraulic feed fitted to the "Sullivan" diamond drills is shown diagrammatically on Fig. 106. It consists essentially of a hydraulic cylinder and piston to which water from the pressure pump is admitted by four ports, controlled by valves, and so arranged that an up or down stroke can be given to the piston as required by manipulating the proper valves. In the figure, *A* is the hydraulic cylinder, *B* the piston, and *C* the hollow piston rod, to the top of which is fitted the ball-thrust bearing, *D*. This bearing consists of a top and bottom plate connected together by three bolts, and having between them a drive flange or collar, *E*, running on a top and bottom race of ball bearings. The drive flange is screwed fast to the hollow driving spindle, *F*, and the last boring rod, *G*, is passed through it and clamped at the bottom of the driving chuck, *H*. The vertical motion of the hydraulic piston is thus transmitted to the boring rods, *G*, since the hollow piston rod and the drive spindle descend together, the latter revolving within the former, but independent of it. The driving spindle, *F*, is locked with the mitre wheel, *J*, by means of long slots and feathers which permit it to slide up or down whilst revolving, and the driving power to *J* is taken from the engine through the crankshaft and bevel gear. Water is admitted to the hollow boring rods from the pressure pump by the water swivel, *K*.

The admission and exhaust of pressure water from the pump is regulated by the four valves, 1, 2, 3, and 4 respectively, valves 1 and 2 being the admission, and 3 and 4 the exhaust valves. When valves 1 and 3 are open and 2 and 4 closed, the pressure water is admitted to the top of the piston and exhausted from below it, thus giving the down stroke. When valves 2 and 4 are open and 1 and 3 closed, the reverse or up stroke is made. By closing valve 3 the feed is instantly stopped. With the hydraulic feed, the speed can be regulated as desired by adjusting the admission and exhaust valves. Changes in the resistance of the strata are

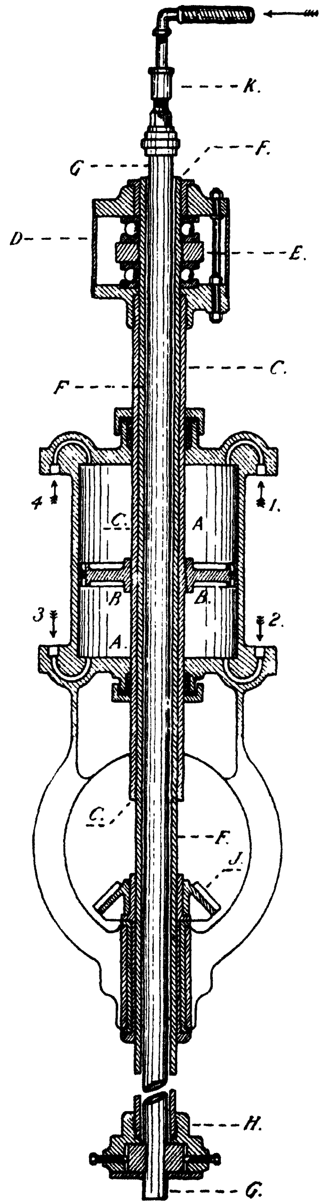


Fig. 106.—Diamond Drill, Hydraulic Feed.

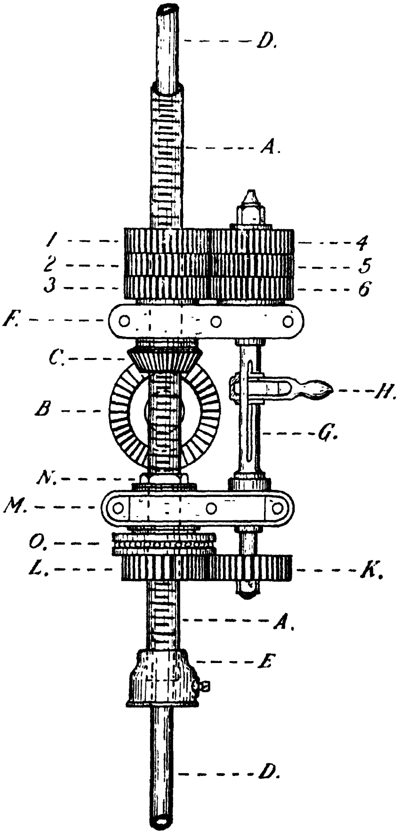


Fig. 107.—Diamond Drill, Screw Feed.

indicated by a pressure gauge on the hydraulic cylinder, and the speed of the feed can thus be regulated to meet changed conditions, and the pressure on the crown maintained at a uniform amount. Should the crown suddenly enter a pocket, fissure, or cavity, the whole weight of the boring rods is sustained on the water cushion below the piston, and the regularity of the feed not interfered with, as the piston can only descend by the release of the water through the exhaust port.

(*b*) SCREW FEED.—In the case of the screw feed, the last boring rod is passed through and clamped to the hollow feed screw, which can be given fixed amounts of advance for each revolution by means of a series of differential tooth wheels. The range of feed in practice varies from $\frac{1}{50}$th in. to $\frac{1}{2400}$th in. for each revolution of the feed screw, and the crown is advanced uniformly at these rates in boring under normal conditions. The various parts of the screw feed of the drill, shown on Fig. 104, are illustrated diagrammatically on Fig. 107, and of which latter the following is a general description: The hollow screw feed spindle, *A* (Fig. 107), is driven off the engine by the bevel wheels, *B*, and *C*. Wheel *C* engages with the spindle, *A*, by means of feathers working in long slots in the spindle, so that it can move freely up or down through the wheel whilst rotating. The last length of boring rod, *D*, passes through *A*, and can be made to rotate with it by locking the clamp, *E*, and thus any vertical movement of the feed screw is also given to the rod. A set of three gear wheels, 1, 2, and 3, having different numbers of teeth, is keyed rigidly to the hollow cylindrical boss of the bevel wheel *C*, above the main bearing, *F*. A similar set of gear wheels, 4, 5, and 6, run idle on a countershaft, *G*, but any one of which can be thrown into gear with the wheel opposite on the screw spindle, *A*, by means of the lever *H*, when the countershaft, *G*, is put in motion. The wheel *K*, at the bottom of *G*, engages with wheel *L*, on the screw spindle, *A*. The boss of wheel, *L*, is extended upwards into the main bearing, *M*, as a hollow cylinder, and is held in place by the nut, *N*, against vertical movement. This hollow cylinder is screwed inside to fit the screw spindle, *A*, and any rotary movement therefore of *L* causes *A* to move up or down, according to the direction of revolution of the former. A ball bearing, *O*, is placed between wheel *L* and the main bearing, *M*, to take the upward thrust of the boring rods. The feed of the drill thus depends upon the gear ratios, the pitch of the feed screw, *A*, and the engine revolutions. Thus, if the number of teeth in a gear train, composed of wheels 3, 6, *N*, and *M*, are respectively 40, 38, 24, and 25, the screwing nut of wheel *M* will make 96 as against 95 revolutions of the feed screw, which will, therefore, move downwards a distance equal to its pitch. If the pitch of the screw is taken at $\frac{1}{4}$ in. the screw will descend 1 in. in 380 revolutions. The pressure on the crown is registered by a thrust gauge (Fig. 104), so that the feed can be adjusted as may be necessary when boring. For this purpose the positive feed given by the differential gearing can be regulated within the limits of the gear, and when required by a leather, friction, driving gear, introduced between the drill spindle, *A*, and the countershaft, *G*.

Headgear.—A simple headgear for diamond boring consists of a tripod either of spars or steel tubes, with a clear height of 30 ft., similar to those shown on Fig. 80. High towers, of the type shown on Fig. 81, are advantageously used for deep bore holes of over 800 ft., as the boring rods can then be handled in long lengths.

Hoisting Machinery.—A hoisting winch is part of the combined modern power diamond boring outfit, and is sufficient to do all the necessary hoisting and lowering of boring rods and lining pipes when boring operations are going on. It is driven by the engines of the drill, and can be thrown out of gear when not required, and controlled by the brake only, as in lowering the boring rods. The engines are of a simple and compact type, with few wearing parts, and can be run by steam, compressed air, or oil (Figs. 103 and 104).

Pressure Pump.—The pressure pump for supplying water to the crown, or to hollow chisels and other tools when boring, is usually worked at a pressure of 150 to 200 lb. per square inch. The capacity of the pump depends on the diameter and depth of the bore hole, and the motive power may be steam, compressed air, or oil.

Boring.—Before commencing a diamond drill bore hole, it is necessary to penetrate the loose materials, or drift, overlying the solid rocks, with wash and percussive boring tools, as already described. The bore hole requires to be lined throughout the loose ground with casing or driving pipes (Figs. 89, and 136), which should be sunk until embedded in the rock so as to form a close seal with it, and thus prevent the inrun of loose materials into the diamond bore hole, or loss of pressure water, as explained in Chapter VI, " Sinking of Bore Holes."

When the bore hole has thus been prepared, the drill is placed over it and racked back on the timber underframe clear of the opening. The diamond crown and core-lifter are then screwed up to the core-barrel, and the whole of this section lowered into the bore hole, being held by a safety clamp while the first length of boring rod is screwed into the core-barrel. The hoisting plug is then screwed into the top of the first rod, and the whole section lifted a little, by means of the hoist, to allow of the rod clamp being disconnected. The section is now lowered on the brake of the hoist, the safety clamp put in place, and the operation repeated until all but the last boring rod is connected up. The drill is now racked forward to the centre line of the bore hole, the last length of boring rod passed through the driving spindle, or the feed screw, screwed to the line of boring rods already connected up, and the whole lowered to the bottom of the bore hole. The water swivel is then attached, the hydraulic or screw feed run up to the highest point, and the boring rods clamped in the chuck of the driving spindle, when boring can be commenced.

When the hydraulic feed has reached the bottom of its stroke, the boring rods are released in the chuck and rest on the bottom, or on the safety clamp. Valves 1 and 3 of the hydraulic cylinder are shut, and valves 2 and 4 opened, when a quick upward stroke of the piston is made, and the feed is ready again for the slow, down stroke. When additional rods are required, the water swivel is uncoupled, the rods added, the swivel again attached, and boring resumed. A similar operation is carried out for a screw feed drill. When boring operations are in full progress, the diamonds require to be reset after about every 10 ft. drilled in hard rock, and a complete spare crown is kept in readiness to replace the worn one without loss of time. The diamonds of the worn crown are re-caulked whilst the spare crown is in use, but if a crown is much worn it is discarded, and the diamonds from it set again in a new blank bit.

Samples.—The samples of the strata bored through pass as a more or less continuous core into the core-barrel (Fig. 95). When the bore hole has been sunk for a depth equal to about that of the core-barrel, the drill is stopped and the rods hoisted up until the nearest joint is above the surface, and a disconnection made there. The safety clamp is then inserted, the drill racked back clear of the bore hole, and the rods pulled up and disconnected in the longest sections that the head gear permits of. When the core-barrel is reached, the core-shell is unscrewed, the core removed in the exact order found, and laid aside on flat boards or core trays for inspection. Should the core-barrel be found only partly full after the boring has been advanced a depth equal to its length, 10 ft., it is evident that some of the core has been lost. This kind of loss frequently occurs, and allowance must be made accordingly when laying out the cores end to end on the core tray as they come up. In diamond boring, the percentage of core recovered is highest in hard, uniform, and unweathered rocks, and least in loose and soft rocks. The following are some averages, Quartzite, 90 per cent.; granite, 85 per cent.; sandstone, 70 per cent.; limestone, 60 per cent.; shale, 50 per cent.; and slate, 40 per cent.; but these figures are not applicable on a rigid basis, as some hard rocks will yield nearly 100 per cent. and soft rocks only about 10 per cent. of core. When the cores are preserved, as is the general practice, they are packed in shallow boxes with screw-down lids, 5 to 6 ft. long, and with longitudinal compartments for five to ten cores, into which they should fit easily. Wooden cross divisions are inserted where necessary to mark off one core from another. In addition to the usual descriptive tablets attached to each, the number of the bore hole, depth reached below the surface, or datum, and the date of extraction are painted on the cores themselves as a precaution against the loss of tablets.

Inclined Bore Holes.—One outstanding advantage of diamond boring is that the bore holes can be made at any practicable angle to the horizontal. This feature is valuable in carrying out test borings, as it affords a means of checking the data obtained from bore holes sunk vertically. In the case of foundations for large impounding dams, or the construction of deep tunnels, for instance, it is of great importance to the engineer to know with certainty that solid rock, proved by vertical borings made at considerable distances apart, exists continuously between the points proved. Inclined diamond drill bore holes can be driven so as to intersect the lower ends of the vertical bore holes, and afford the required information as to the nature of the strata along the line proposed to be followed by constructional works.

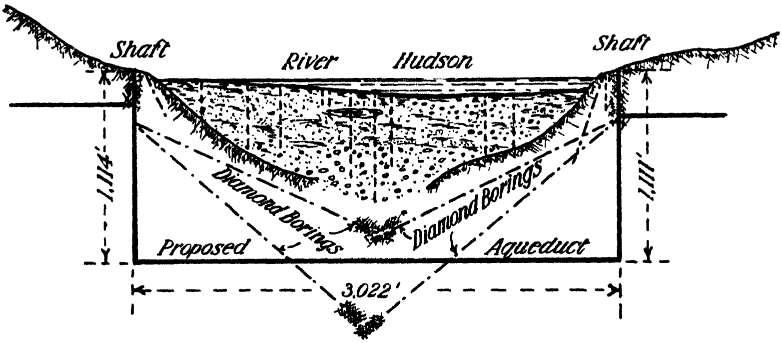


FIG. 108.—Inclined Diamond Test Borings, River Hudson.

An example of this method of testing the ground on a large scale is shown on Fig. 108, which was carried out at the Hudson River tunnel of the pressure aqueduct of the New York water supply. The inclined diamond borings were driven through solid, granite-gneiss rock, and the core recovery varied from 55 per cent. to 75 per cent.

(*b*) Boring with Steel Crowns

General Principles.—The general principles of boring with steel crowns are very similar to those for diamond crowns. The general arrangement of the apparatus is shown diagrammatically on Fig. 109, where *A* is the bit or cutter, which is screwed to the core-barrel, *B*. The core-barrel is attached at the top to a core-barrel plug, *C*, which divides it from the upper sludge tube or "calyx," *D*. The hollow boring rods, *E*, are screwed to the core-barrel plug and pass up into the driving mechanism of the drill, *G*, from which they receive rotary movement. The downward movement is given by the yoke, *L*, and drum gear, *K*. Pressure water is forced down the hollow boring rods to the crown, and returned to the surface in the clearance space cut by the crown between the core-barrel and the bore hole, as shown by the direction arrows on Fig. 109. As the core is cut it passes up into the core-barrel, but as the grit made by the steel cutter consists generally of larger and heavier fragments than those from the diamond crown, it is washed up for some distance only and falls back into the sludge tube or calyx, which is open at the top end. By this arrangement it is possible to flush the cutter at a reduced water pressure, and the finer particles alone reach the surface with the circulating water. The bore hole, where it passes through loose overlying materials, is secured by lining pipes, *H*, as in diamond drilling.

Steel Crown Boring Appliances.—The appliances for test boring with steel crowns consist mainly of cutters of various designs to suit the materials passed through (Figs. 111 to 113); a core-barrel for the reception of the core; a sludge or upper tube or

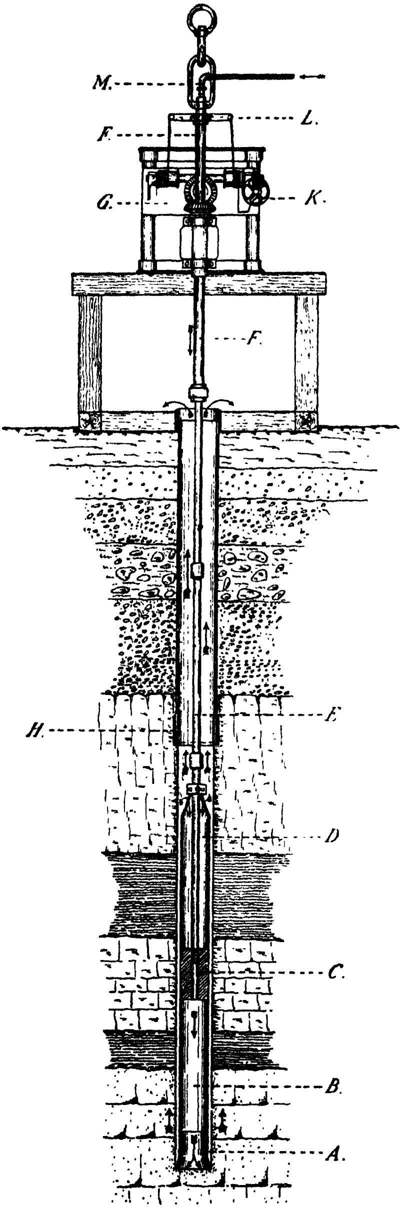


Fig. 109.—Rotary Boring with Steel Crowns, General Arrangement.

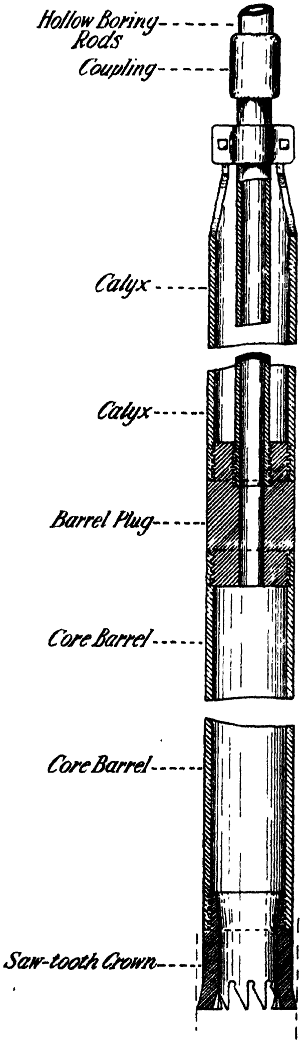


Fig. 110.—Steel Crown Drill, Working Parts.

calyx into which the chippings from the crown or cutter are washed; hollow boring rods through which the pressure water from the pump is conveyed to the crown (Fig. 110); a headgear or derrick (Figs. 80 and 81) for handling the rods and tools; and, in power drills, an engine for operating the drill, pressure pump, and winch.

Steel Tooth Crowns.—The "saw-tooth" crown or cutter is used for boring through the softer kinds of solid rocks, such as sandstones and shales, and even through loose formations, such as stiff, homogeneous clays. The common form is shown on Fig. 111, and consists of a hollow cylinder of toughened steel, with saw-shaped teeth, set like a saw. An improved form of cutter, and that usually adopted for test borings, is the Davis cutter, which is shown on Fig. 112. The crown itself is a thick cylinder of toughened steel, with thick and thin corrugations on the outer surface, and is attached to the core-barrel by a square thread screw (Fig. 110). The teeth are formed out of the thick corrugations, and are set to project alternately past the outside and the inside diameters of the crown by about $\frac{1}{8}$ in., and are shaped with a vertical front cutting edge, and a back edge sloped about 60 degrees. The thin corrugations between the teeth have semi-circular notches, and as the teeth wear these indentations are cut back to maintain the teeth of the required length. The projections of the teeth, in all saw-tooth crowns, perform the identical

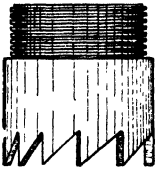


FIG. 111.—Saw-tooth Crown.

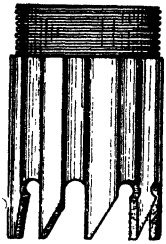


FIG. 112.—Davis Saw-tooth Crown.

functions of the outside and inside diamonds in the diamond crown, in cutting like clearances for water circulation and in freeing the core. Saw-tooth crowns penetrate rock by cutting and abrasion in a jerky manner peculiar to themselves, as compared with the smooth and regular grinding of a diamond crown.

Setting of Teeth.—The setting of the teeth of steel crowns is done on an anvil and crown-plate with special hand tools, the amount of set being regulated by the kinds of materials to be bored. The crowns shown on Figs. 111 and 112 are unset, and that on Fig. 110 shows the effect of set upon clearance in the bore hole.

Steel Shot Crowns.—When the strata are hard, as in crystalline rocks, the saw-tooth crown is inoperative, and has to be replaced by a " shot-crown ", which works in conjunction with steel shot. This is a plain, specially toughened, hollow, steel cylinder, made from the solid, having a narrow slot cut in one side of the bit, and is screwed directly to the core-barrel (Fig. 113). Chilled steel shot is fed through the water swivel, and then passes down the hollow boring rods to the crown, where it lodges between its annular edge and the rock. The rotation of the crown upon the shot, together with the pressure due to the weight of the rods and feed gear, cuts a circular groove in the rock, and so forms the core which passes up into the core-barrel. The chilled steel shot is made by atomising molten iron or steel and suddenly chilling the small particles, which then become of a hardness that will scratch glass. The average size of shot for boring purposes is about $\frac{3}{32}$ in. in diameter. The shot automatically cuts the necessary clearances for itself inside and outside of the shot-crown, but when the materials are of such a nature that the core would become a close fit in the core-barrel, two grooves are cut lengthwise inside the crown to permit of the shot passing freely to the bottom of the bore hole.

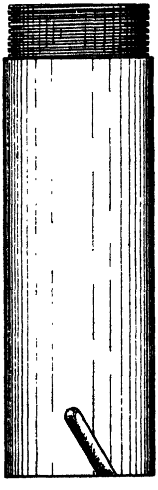


FIG. 113.—Shot Crown.

The "Calyx" Core Drill.—Test borings may be made with steel crowns to a depth of about 400 ft., and cores from 1½ to 3½ in. diameter successfully extracted. Beyond this depth larger cutters must be used, which give correspondingly larger cores not necessary for engineering test borings. The outfit is less costly than that of the diamond drill, as diamonds are entirely dispensed with. A typical machine of this kind is the "Davis-Calyx" core drill, manufactured by the Ingersoll Rand Company. It is arranged on the general principle shown on Fig. 109, and the details of the working parts are similar to those shown on Fig. 110. It is designed so that either a Davis saw-tooth cutter or shot-crowns can be used in the same machine, the slower speed required for the Davis cutter, and the faster for the shot-crowns being provided for respectively by a feed changing gear on the drill. The boring rods, *E* (Fig. 109), are screwed to the hollow driving spindle, *F*, which passes through the hollow sleeve of the lower wheel of the engine-driven bevel gear, vertical movement being provided for by a slot and feather arrangement, as in the diamond drill. The water-swivel, *M*, is attached to the top of the driving spindle, *F*, and connected to the pressure pump by a flexible hose pipe. The downward pressure on the drill is given by two ropes attached to a yoke, *L*, on the water-swivel, *M*, and coiled round two small drums on the drill frame, so that when these are put in motion by the hand, worm and screw feed gear, *K*, the rods are pulled downwards by the tightening of the yoke ropes (Fig. 109). An ordinary water-swivel is used for saw-tooth cutters, and a specially combined water and shot swivel for shot-crowns. The prime mover, pressure pump, winch, and head-gear are all similar to those used in diamond boring, although arranged differently.

Boring.—Boring with a calyx drill is carried out in much the same way as for diamond boring. When a shot-crown is used, the shot is fed from a hopper through a special valve on the water-swivel, a few grains at a time, and the current of water adjusted so that it is carried down the hollow boring rods in a scattered condition to the crown, this being essential for safe and proper boring. As the core-barrel of the calyx drill is a plain tube, without a mechanical core-lifter, a special process is adopted for extracting the core. This consists in pumping a quantity of small gravel of irregular size down the boring rods before the core-barrel is lifted, and by increasing the water pressure from the pump, the gravel becomes wedged in the clearance space between the core and the core-barrel. The rods are then rotated, and the gravel becomes sufficiently compacted to cause the core to break off by torsion, when it can be safely lifted to the surface. The core-barrel is tapped smartly with a hammer to loosen the gravel packing, and the core can then be taken out.

Setting Out.—Rotary borings may be set out in the manner already described for probings and percussive borings.

Records.—Records of rotary borings may be kept as described for percussive borings. Care must be taken to assign the various core lengths their proper places in the depths bored.

Plotting.—Rotary borings may be plotted in the manner described for percussive borings.

CHAPTER V

II. BORING (*continued*)

(*B*) BORING UNDER WATER

SUBAQUEOUS boring comprises test borings put down in harbours, docks, and tidal waters generally, and also in rivers, streams and lakes. The difficulties encountered in such places are usually much greater than for borings made wholly on dry land, and special methods and plant require to be used. Perhaps the most difficult of all subaqueous borings are those made on an open coast or rapidly flowing tidal river. Lakes and sluggish rivers do not present, as a rule, any unusual difficulties, except when subject to strong winds and floods.

Methods of Making Subaqueous Borings.—The usual methods of making test borings under water are :—

(1) From floating plant.
(2) From fixed temporary stagings in the water.
(3) From shore supports.

In many cases a combination of these methods can be used with success.

(1) Boring from Floating Plant

General Description.—Subaqueous boring from floating plant includes wash, percussive, and rotary boring from barges, pontoons, rafts, and boats on which the boring appliances are fitted up, and the plant capable of being moved from point to point as required. As a rule, floating plant is used where the water is too deep for staging, or subject to severe floods, which may be accompanied at times by floating ice. It may be chosen, on the other hand, solely on account of its mobility where there is shipping traffic, even in cases when conditions are favourable for staging.

Boring Barge.—The boring barge is usually built of timber, rectangular in shape, and with a flat bottom. This form of craft draws less water than the ship type, and, being less liable to roll, forms a steadier platform. It must be sufficiently large to carry the complete boring plant and stores, and afford deck space

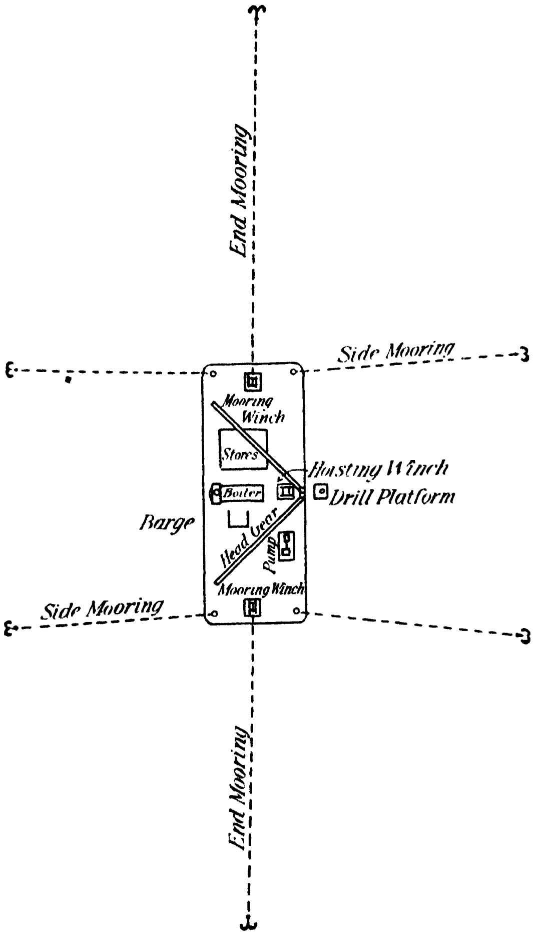


Fig. 114.—General Plan of Boring Barge.

for the operators, and, when necessary, living space for the crew.

The boring plant consists of the drill itself, hoisting machinery, derrick or headgear, steam boiler, and pressure pump. The headgear and hoisting machinery are usually arranged opposite to the boiler, either at the extreme ends or at the sides, so as to keep the barge on an even keel. The rectangular plan makes the best working deck, and allows of more living space for the crew and storage room for spare gear.

The barge is moored at each end by means of a strong wire rope and heavy anchor, worked by the hand or the power winch, and these moorings are also used for adjusting position longitudinally by warping. Lateral adjustment is provided for by means of two lighter wire ropes and anchors at each side, run away from four strong mooring posts placed at the corners of the barge, and these moorings also keep the barge steady when at work. The barge should be moored whenever possible lengthwise with the direction of the current or tidal stream. In a tideway the end moorings take the strain alternately at the times of flood and ebb, and should be long, as the barge rides easier on a long than on a short cable, and there is less tendency to drag the anchors. Where the stream is very rapid and turbulent, it is better to use long chain cables for the end moorings. The general arrangement of such a boring barge is shown on Fig. 114.

Wash Boring under Water.—When wash borings are made from a barge the outfit comprises a steam boiler, force pump, headgear, and hoisting winch, along with casing and jet pipes of various diameters and lengths. The casing pipes are placed in position by the winch and derrick, and are supported loosely by an overhanging platform on the barge, which also affords the necessary accommodation for the operators when making joints or rotating the pipes (Fig. 115). The water jet is suspended from the derrick, and the materials of the bottom are washed out by a stream of high pressure water from which samples can be obtained, as explained in Chapter III. When it is necessary to

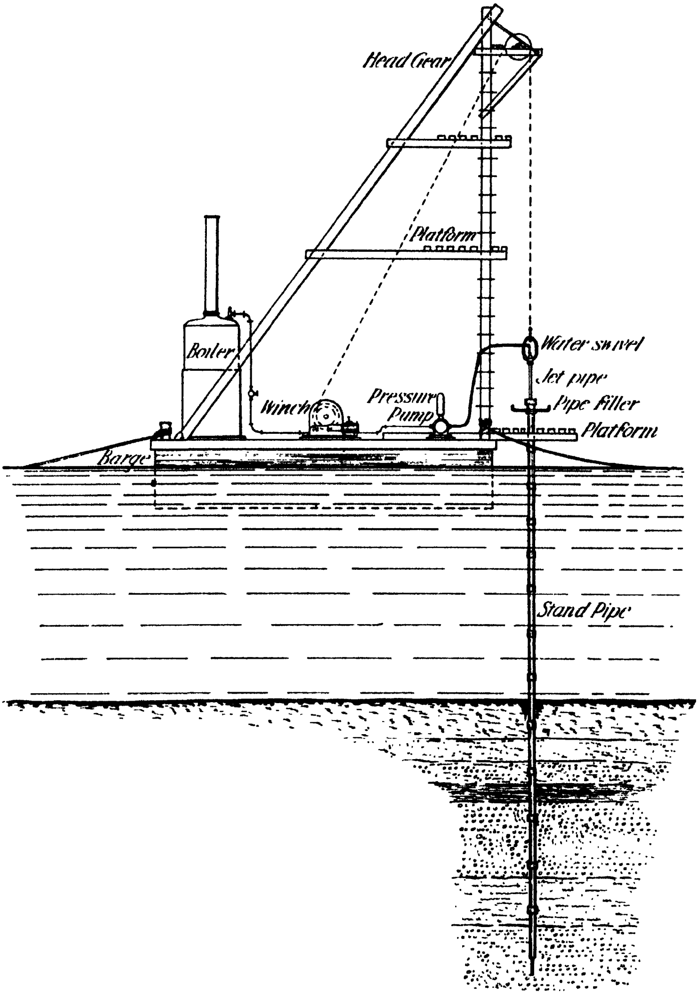


Fig. 115.—Boring Barge for Wash, and Percussive Boring.

drive the casing pipes into the bottom, the derrick and hoisting machinery are used to work a light falling weight or hammer for this purpose. If wash boring is carried out in tidal waters, the casing tubes require to be adjusted to suit the varying water level by screwing and unscrewing lengths as required. The barge moorings must also be regulated to keep it in proper position, and thus avoid throwing weight on the pipe column.

Percussive Boring under Water.—For percussive boring under water the outfit of the boring barge includes a steam boiler, power winch, headgear, and force pump, together with solid and hollow boring rods and chisels, and casing and driving pipes. The arrangement of the boring barge is the same as that shown on Fig. 115, which is adapted for either wash or percussive boring. In all cases of percussive boring under water, the casing or stand pipe is first lowered to the bottom and then sunk through the loose materials by using either solid or hollow chisels (Figs. 97 to 101), worked from the winch and derrick, until it is sealed into the rock or the firm ground. The *débris* may be removed by the sludge pump, or washed up by water jet. The driving pipes are forced down by a hammer worked from the winch, as shown on Fig. 139. In sinking through soft and hard beds of loose materials, wash and percussive boring may be combined with advantage When rock has been reached, percussive boring may be carried out in the usual way, the drilling tools being raised and dropped by the hoisting rope and winch and rotated by a hand tiller. In tidal waters the proper adjustment of casing or stand pipes and barge moorings must be made, as in wash boring. When the column of stand pipe is of considerable height above the bottom, it should be supported by four wire anchor stays, attached to it about the level of low water, the anchors being 200 to 300 lb. in weight (Fig. 119).

Shallow Percussive Borings under Water.—In prospecting a bottom for a quay wall or pier, where the foundations are comparatively shallow, or proving rock then over a considerable area, a smaller boring barge may be used, fitted up with one or more percussive drills, so that a single hole or several holes can be bored simultaneously. A boring barge of this description is shown on Fig. 116, and carries a boiler, power winch, force pump, and headgear. Each drill has an independent rope drum opposite to it, placed under the headgear, and the drums are keyed rigidly to one common drum shaft, which is driven from

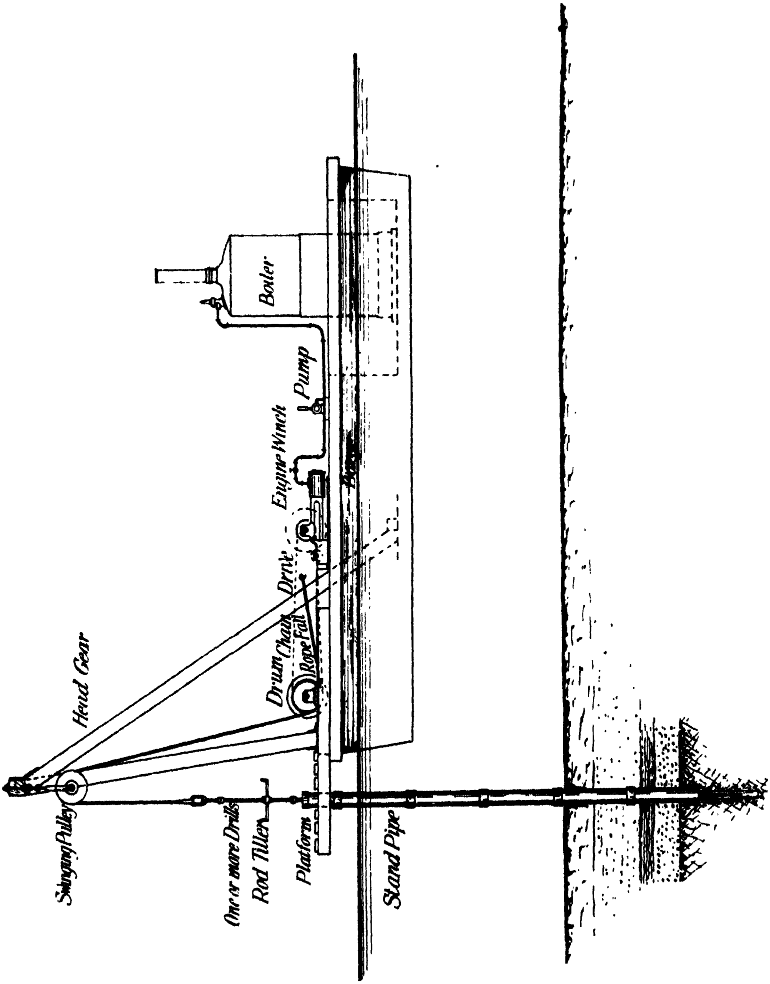


FIG. 116.—Multiple-drill Boring Barge, for Shallow Holes.

the winch by chain and sprocket gear. The drum shaft is run at a fixed speed continuously, and in one direction. Each line of boring rods is suspended by a manila rope, which passes over a swinging pulley at the top of the derrick, and the fall, or free end, is coiled with three turns round the drum. In boring, the rods are lifted about 2 ft. by tightening the rope on the revolving drum, and let fall suddenly by slackening the end of the rope, so as to deliver a percussive blow by gravity. This arrangement requires two men at each drill, one to tighten and slacken the drum rope, and one to work the tiller on the rods. The flexibility of this method permits holes of considerable depth to be bored, as the rods are not greatly affected by the movement of the barge, and if the barge is fitted with several drills, a considerable area can be tested in a short time. Large diameter casing pipes should be used with this plant to give clearance for the boring rods when the barge is ranging.

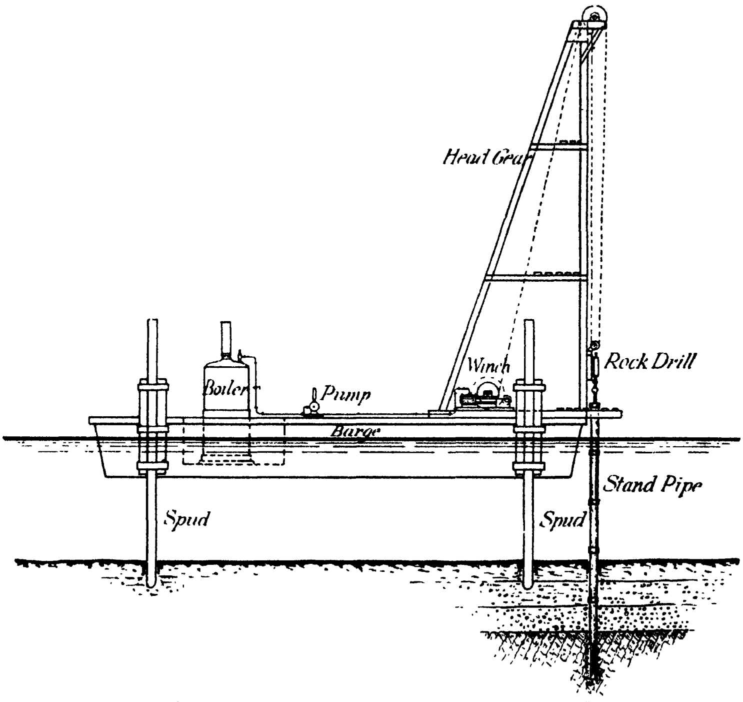


Fig. 117.—Spud Boring Barge, with Rock Drill, Side Elevation.

Steam Rock Drilling under Water.—If it is merely intended in shallow boring to prove a rock surface for a few feet, a steam rock-drill mounted on a barge may be used with speed and economy, provided that the barge is tolerably steady or is steadied upon subaqueous legs or "spuds." The drill and headgear may be mounted on a small carriage set on rails for traversing the barge, or on a frame similar to that of an ordinary pile driver. The length of the boring rods should not be more than about 30 ft., as greater lengths are too much for an ordinary rock-drill, with a

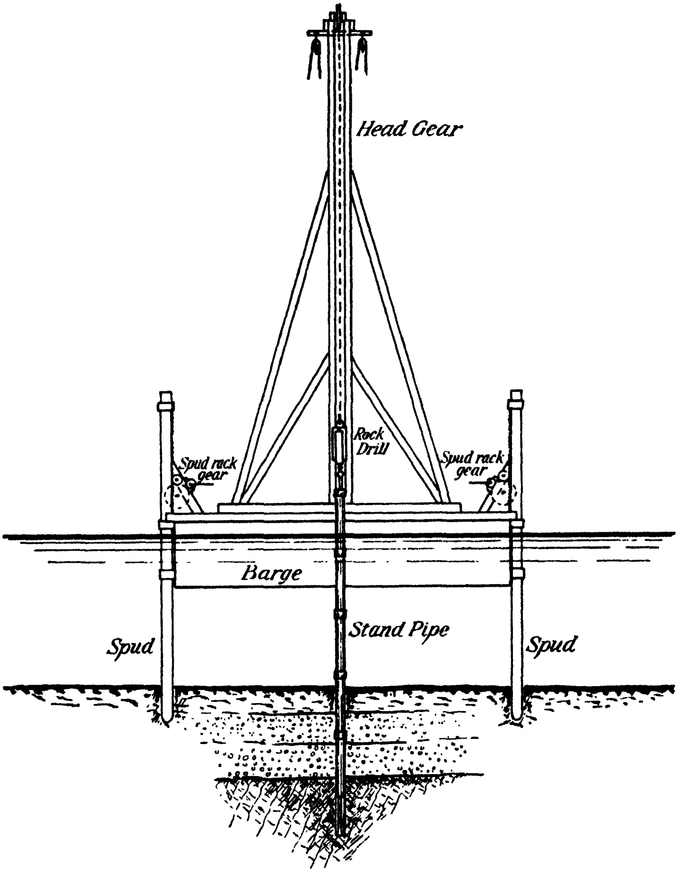


Fig. 118.—Spud Boring Barge, with Rock Drill, Front Elevation.

3-in. bit, to work effectively. In Figs. 117 and 118, which show the side and end elevations respectively of a plant of this kind, the drill is bolted to a heavy iron bedplate, which slides up and down between the guides of the frame, and keeps a steady pressure on the drill when at work. The bedplate is raised and lowered by a wire rope from the winch, which passes over the headgear pulley and round another pulley fixed to the bedplate. The feeding is done by gently manipulating the brake of the winch. A cross tree at the top of the headgear is provided with tackle for handling the rods, bits, and casing pipes. When a rock drill is used the hole should be cleaned out frequently during boring, as there is a tendency on the part of the rock drill to stick, owing to the more perfectly circular nature of the hole and the limited flexibility of the long, solid bits. The cleaning out can be done either by a sludge pump, or jet pipe worked from the barge. Large diameter case pipes should be used with this type of boring barge to give angle clearance when changing long bits.

Rotary Boring under Water.—Rotary boring under water requires a rigid platform for the drill. A freely floating barge is not, therefore, a suitable base from which to carry out rotary boring, unless either the barge is deprived of buoyancy, or the drill itself is mounted upon a fixed foundation. For rotary boring generally, the barge is converted into a steady platform by adjustable supports fitted to the hull, or by grounding it upon a specially prepared rigid base, as described further on. Owing, however, to the compactness and light weight of the combined diamond drill and engines used for test borings, the drilling apparatus can be placed, independently of the barge, on a small, rigid platform secured to the column of casing or stand pipes, which rests upon the subaqueous bottom. The drill is steamed from the barge, and many deep test holes have been made by this method. The floating plant described below (Fig. 119), for diamond drill boring is suitable for subaqueous rotary boring generally.

Diamond Drill Boring under Water.—Subaqueous diamond drill boring is usually preceded by wash and percussive drilling until the bore hole has reached hard strata. A diamond drill boring barge should therefore include all the necessary outfit for

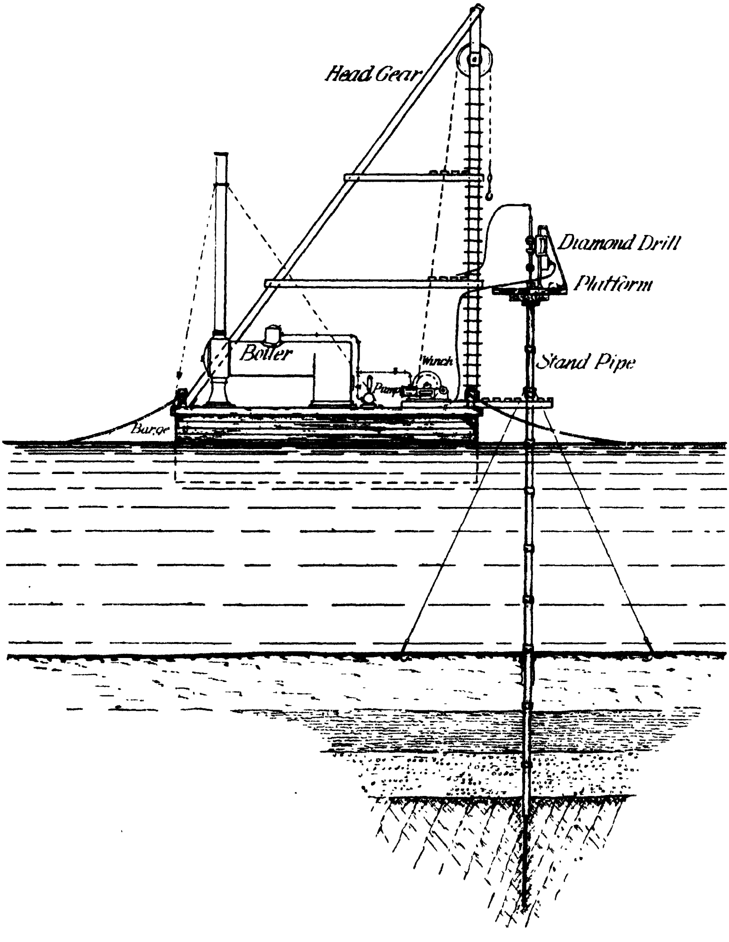


FIG. 119.—Boring Barge for Diamond Drilling.

these methods in addition to that strictly required for diamond boring. The boring barge for the combined systems, in the case of deep bore holes, is usually about 90 ft. long by 30 ft. wide, and carries the boiler, hoisting winch, pressure pump, headgear, and deck accommodation for crew and stores (Figs. 114, and 119). If wash and percussive boring are not necessary, or if they have been completed as preliminary work to the diamond drill boring, a smaller barge about 30 ft. long by 18 ft. wide can be used. This size of craft will then be sufficient to carry a steam boiler, pressure pump, winch and headgear, and the spare tool essential for diamond boring.

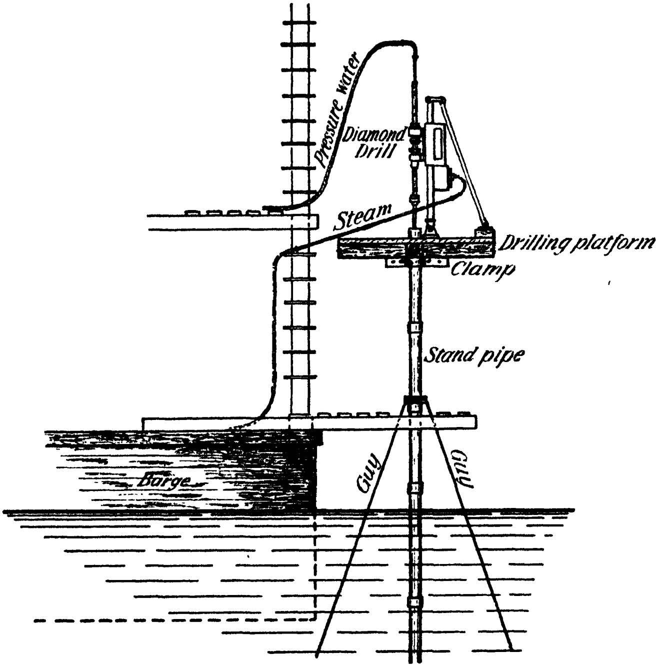


Fig. 120.—Diamond Drilling Platform on Stand Pipe.

As diamond drill boring must be carried out from a perfectly rigid base, the drill itself is set up on a timber platform clamped to the column of stand pipes only, but easily detachable therefrom in case of need (Figs. 119, and 120). The platform is kept as small as possible, being sufficient only to carry the drill and two operators. Steam is supplied to the drill engine, and high pressure water to the drill itself by means of flexible pipes led from the barge. The stand pipe column is first fixed firmly into the bottom by wash, and percussive boring, braced with four anchor stays, and is then ready for the diamond drill and platform. Diamond drill boring is carried out from this platform in the usual way, the boring rods and other parts being manipulated from the derrick and hoisting winch on the barge, independently of the drill. The barge itself is kept entirely clear of the pipe column, so as to avoid all risk of damage by collision or by undue pressure upon it, which might easily cause bending or overturning. Great care has to be exercised, therefore, in a tideway to keep the moorings of the craft in proper adjustment to avoid accidents of this kind. The boring crew consists of a drill operator and assistant, with three or four hands to manage the barge. The derrick or headgear is usually about 50 to 60 ft. high when there is a considerable range of tide, so that long lengths of boring rods can be handled at low water with less consequent disconnecting of the stand pipes.

Boring from a Temporarily Fixed Barge.—In many cases it is found convenient to secure the boring barge temporarily in a position above the highest water level, so as to give a steady platform for the drill. This is usually done in two ways, viz. :—

(*a*) By temporary supports.
(*b*) By special appliances on the boring barge.

(*a*) TEMPORARY SUPPORTS.—Supports of a more or less temporary character may be used where the water is not too deep and the variation of the surface level small, as in the case of non-tidal rivers generally, and shallow lakes. Supports of this kind may consist of heavy spars or piles resting upon, or driven into the river bed. When piles are used, they may be driven from the barge itself by using a driving hammer suspended from the headgear, and manipulated by the winch. The requisite number of piles are driven at a low water stage of the river or tide and are capped with cross logs, spiked down or fixed by iron dogs, so as to form a rough gridiron for the reception of the barge (Fig. 121). The cross logs are levelled and dressed roughly to give a uniform

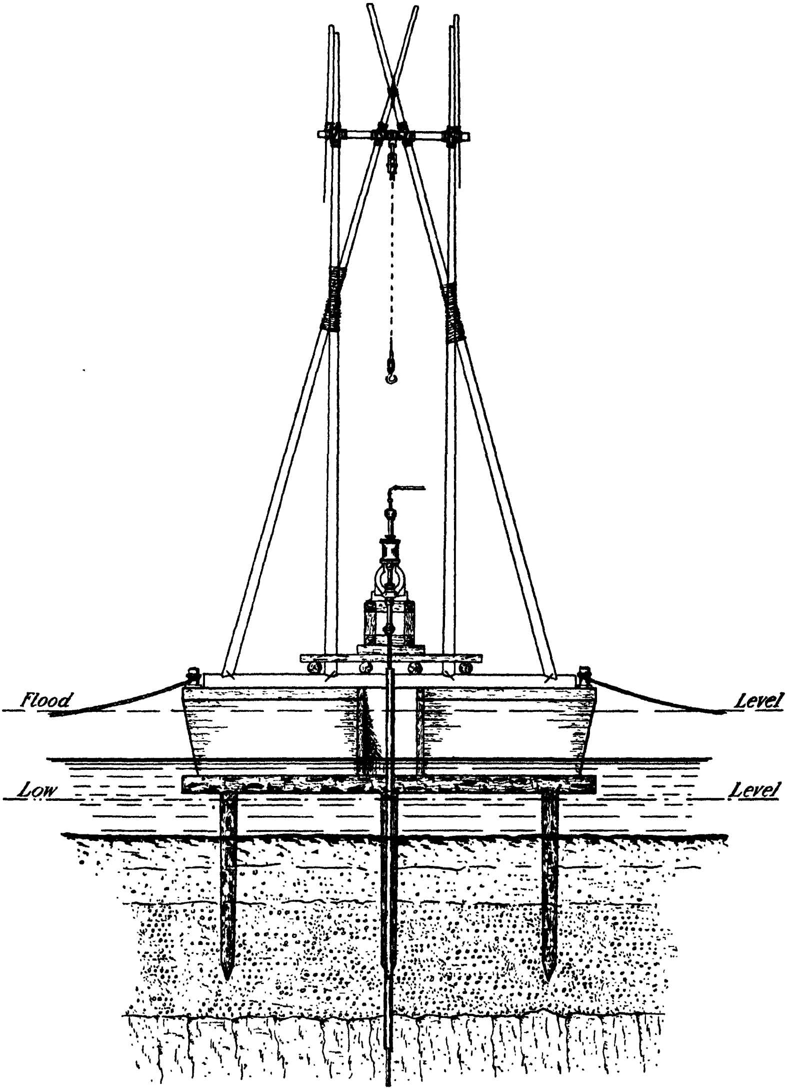


FIG. 121.—Boring Barge on Temporary Supports.

bearing surface, and the barge then floated into position at a suitable water level, and loaded with stones until it rests with sufficient dead weight upon the gridiron to prevent it being floated off at high water stages of the river or tide. In addition to temporary supports of this kind, moorings should always be run out for safety. When it is necessary to shift the barge, the stones are removed, so that it can be floated off the cross logs.

When the boring is near the bank a timber crib, similar to that shown on Fig. 131, can be built out from the shore, the barge floated on to it, and sunk in position on the crib by loading it with stones.

(*b*) SPECIAL APPLIANCES ON THE BARGE.—Boring barges, specially constructed for making test borings, have usually a steel hull to which permanent, adjustable, under-water legs are attached (Figs. 117 and 118). These legs or " spuds " consist of iron or timber columns, working in guide frames. The " spuds " are adjusted from the barge by means of heavy, worm and rack gear, operated by hand or power, and fixed at deck level to the guide frames, so as to bear a fraction of the weight of the craft, and thus steady it whilst boring is going on. As the water level varies, the " spuds " are raised or lowered accordingly. This appliance is particularly well suited to positions where the variation of water level is not great, and in specially designed barges, where ample power is provided for working the " spuds," by a small independent engine on each, boring can be done in 30 to 40 ft. of water. Rotary boring, with either diamond or steel crowns, can be done from " spud " barges, as well as percussive, and wash boring.

" Fixing " Boring Barge in Position.—The boring barge is brought into position over the site of the intended bore hole either by the intersection of signals or marks, which have been previously arranged on the shore for the work ; or by triangulating with one or more theodolites from a shore base ; or by sextant angles taken from the barge to predetermined shore objects, as explained in Chapter II. The exact position of the boring barge should be carefully fixed when the boring has been commenced, as there may be deviation from the bore hole as set out, owing to difficulties in mooring the barge exactly in place.

(2) Boring from Fixed Stagings

General Description.—Boring from fixed stagings is usually adopted where the current is too swift, as in a river, or the site is too much exposed, as on a flat sea shore, for floating plant to be used. Stagings can only be used in moderate depths of water, and where the bottom is satisfactory for such erections, as otherwise there is no choice left but floating plant. Under suitable conditions, fixed stagings are desirable, as any method of boring can be carried out from them.

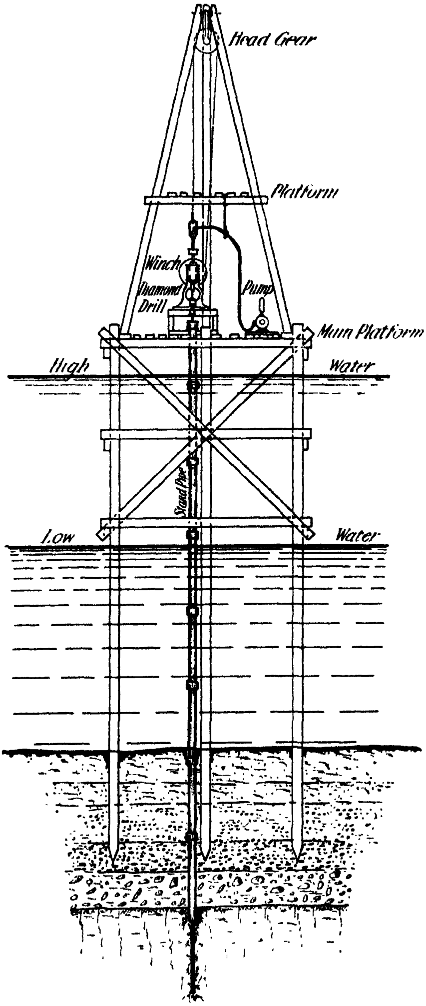


FIG. 122.—Isolated Staging, in Exposed Position.

Boring from fixed stagings may be done from :—

(*a*) Isolated stagings.
(*b*) Continuous stagings.

(*a*) ISOLATED STAGINGS.—Isolated stagings are used where the bore holes are far apart and more or less irregular in plan. They are constructed of timber piles, or heavy spars driven into, or resting upon the subaqueous bed to be bored, and properly braced and stiffened as the exigencies of the case demand. In tidal waters, much exposed to waves and strong currents, the stagings require to be of ample dimensions and strength, and are usually constructed of heavy uprights 13 to 14 in. round or square. In shallow rivers, on the other hand, the stagings may

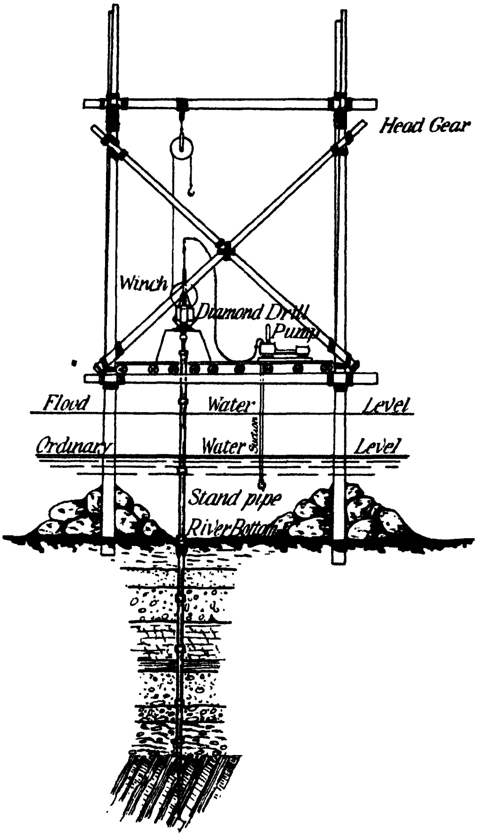


FIG. 123.—Isolated Staging in a River, Front Elevation.

be more of the nature of scaffolding, and entirely so in still waters. In tidal waters, it is essential that the drill and platform be placed well above the levels of extreme tides, so that work can be carried on without interruption. An isolated staging for an exposed situation in an estuary is shown on Fig. 122. It consists of a platform or deck, about 20 ft. long by 10 ft. wide, formed of six piles 14 in. by 14 in., driven to a hard bearing in the estuary bottom, and braced together by three horizontal braces with stiffening diagonals, 12 in. by 6 in. scantlings. The inter-

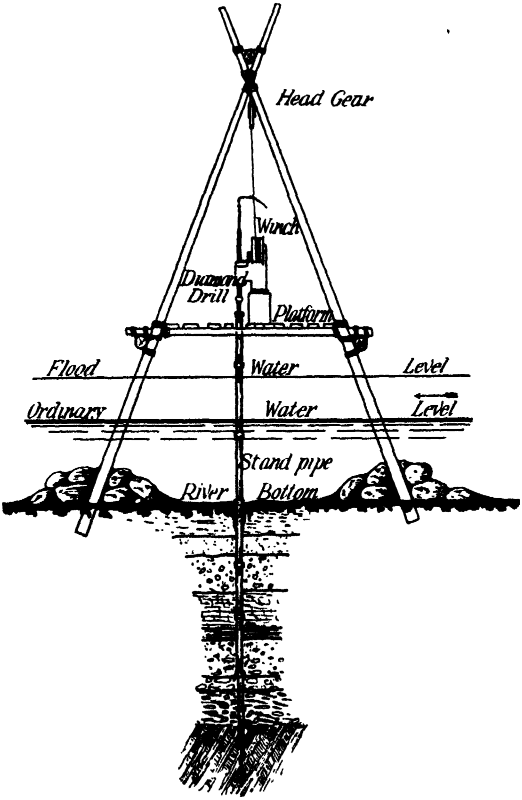


Fig. 124.—Isolated Staging in a River, Side Elevation.

section of the braces on the main piles are made with heavy bolts. The headgear, pressure pump, and combined drill and hoisting winch are placed on the platform, and steam is supplied from a boiler, placed on a barge anchored alongside, through flexible piping. A boat is used to convey the operators to and from the work.

An isolated staging for a river with a rapid current, but only about 5 ft. deep, is shown on Figs. 123 and 124. It consists of tapering spars, about 12 in. diameter at the lower end, braced together by light spars, the intersections being secured by rope lashings. To give greater stability to the pier, and to prevent scour, large stones are dumped round the lower ends of the main spars where they rest on the river bed. This type of staging is largely used in open country where natural timber is plentiful. In the case of scaffold stagings, the weight only of the boring apparatus, including the combined drill and winch, and the pump, is carried on the staging itself, the boiler being excluded on account of its weight, and the difficulty generally in placing it on the staging. Steam for running the drill and pump may be supplied from a boiler placed on the shore, the steam pipes being carried on a light gangway to the staging (Fig. 131), or on a platform suspended from a steel rope. In many cases the boiler can be conveniently placed on a barge moored close to the site, and the steam conveyed to the drill by means of a flexible pipe.

(*b*) CONTINUOUS STAGINGS.—Where bore holes are numerous and relatively close in line, it is more convenient to construct a continuous staging. A continuous staging facilitates the transport of the drills from point to point, and is suitable for carrying a continuous line of steam pipes from the boiler on shore, while greater latitude is allowed in the selection of sites for bore holes. Considerable economy and saving in time can also be effected by using several drills simultaneously on the work, especially when the borings are numerous. The usual method of constructing continuous stagings is to erect a number of isolated frames and connect them together with light gangways, sufficiently strong to

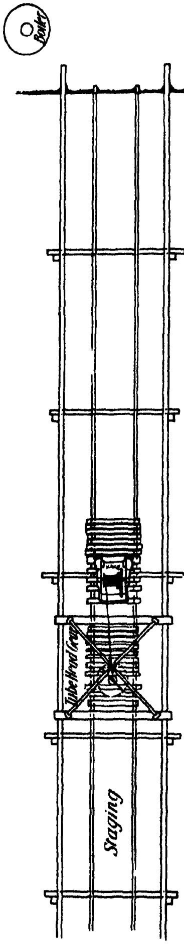


FIG. 125.—Continuous Staging in a Tideway, Plan.

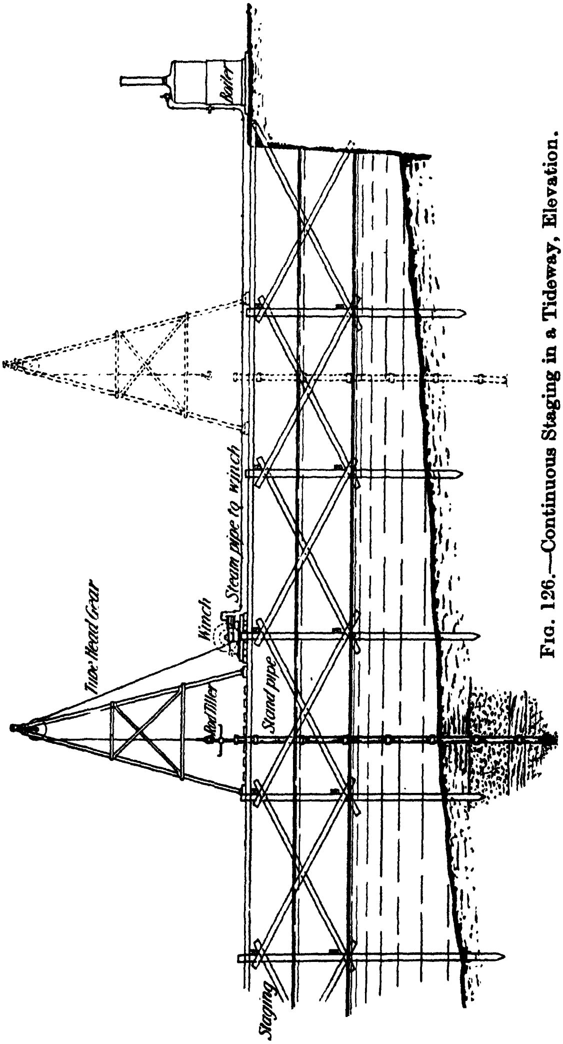


FIG. 126.—Continuous Staging in a Tideway, Elevation.

carry the boring plant without the boiler. In a tideway or exposed situation, the frames are formed of two or more piles, fairly hard driven, and stiffened with bracings in the same way as for isolated stagings. The running timbers of the gangway are laid across the frames, and the whole structure braced crosswise, thus making a series of continuous trestles, as shown on Figs. 125 and 126. Joints in work of this kind are made with bolts, 1 in. diameter.

In the case of a shallow river, the staging may be constructed of trestles formed of spars resting on the bed of the river, braced together with lighter spars, and the whole connected together with rope lashings. The gangways are made in a similar manner, but much lighter, as shown on Figs. 127 and 128. Where the current is rapid, additional stability is given to the trestles by dumping large stones round the bottom. Steam is conveyed from a boiler on shore by an iron steam pipe laid along the gangway, and the rods are manipulated by the winch on the drill itself.

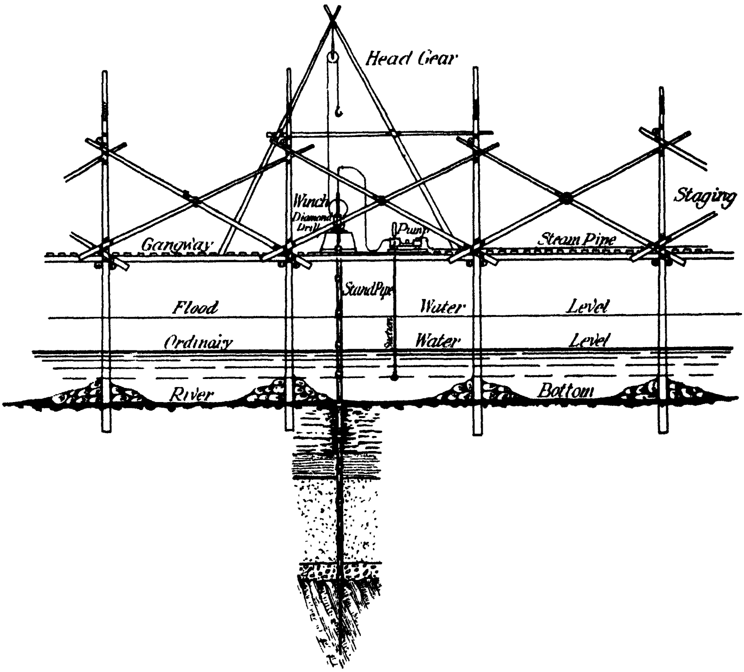


Fig. 127.—Continuous Staging in a River, Elevation.

Stagings of this kind are well adapted for pioneer work in a well wooded country where timber is generally cheap.

(3) **Boring from Shore Supports**

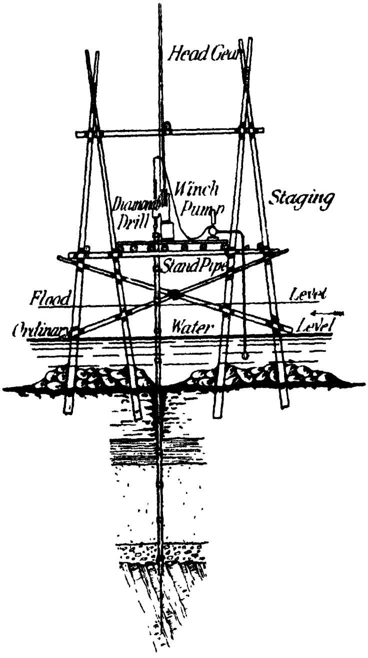


FIG. 128.—Continuous Staging in a River, Section.

General Description.—Boring from shore supports includes all cases where the boring plant for any system of boring can be carried directly on existing supports at the side of the water, or by short, artificial extensions of such supports. Generally speaking, extensions of shore supports are made by means of overhanging platforms, cribs, or short stagings, to enable the site of the boring to be reached. The simplest form of extension is an overhanging platform, loaded at the shore end to counterbalance the weight of drill and operators.

Shore Stagings. — When hand boring to shallow depths is carried out, it is necessary only to support the weight of the derrick, operators, and spare gear. The staging may then consist only of two logs placed about 5 ft. apart, counterbalanced with stones, and covered with planks to form a platform for the operators when travelling round with the tillers or the bracehead (Fig. 129). In cases where a longer platform is required, the staging may be of the same construction, but with two raking timbers additional, acting as cantilever supports from the shore. When the length of the staging necessitates further support, two logs or piles are generally placed upon or driven into the bottom, and the gangway of logs carried upon them and the shore rest (Fig. 130). In all such cases the boiler, if used, is placed on shore, and the steam conveyed to the drill by means of iron pipes. In pioneer work, a timber crib may be constructed on the shore, floated into position, sunk in place with stones, and connected to the shore by a light gangway (Fig. 131). In countries where the winters are severe, and thick ice forms, advantage is taken of the ice as a support for the boring plant. A hole is pierced in the ice with the drill sufficiently large to allow of freedom in placing the casing or stand pipe on the bottom, and boring is then carried out as on shore. When the cold is intense the pres-

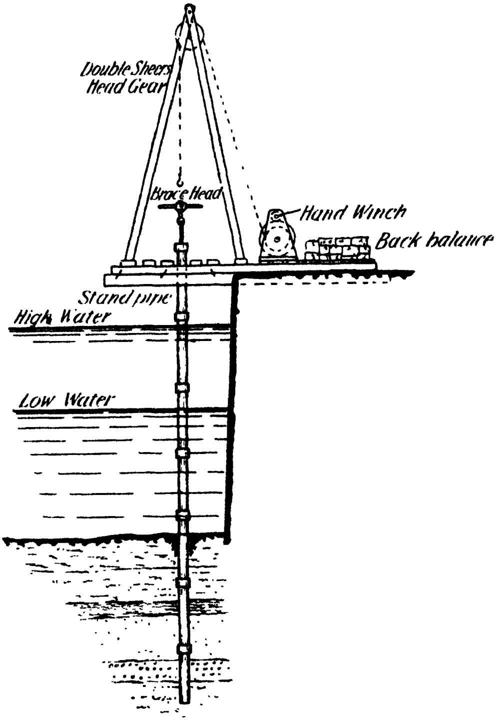


Fig. 129.—Hand Boring, Shore Support.

sure water may require to be mixed with glycerine, or heated by turning the exhaust steam from the drill engine into it.

Samples from Borings under Water.—Samples of borings from a subaqueous bottom are taken, and recorded in the same way as for borings on land.

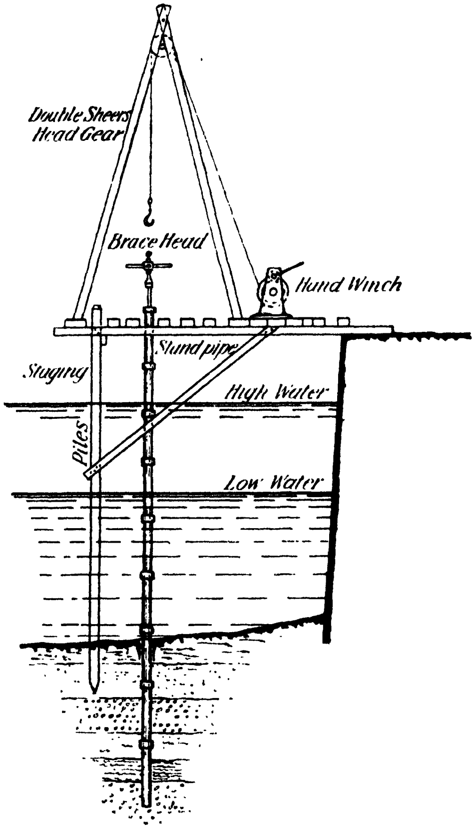


FIG. 130.—Hand Boring, Short Shore Staging.

Setting Out Borings under Water.—Bore holes under water may be set out in the same manner as described in Chapter II.

Soundings.—In all cases where borings of any kind are made under water, soundings must be taken, over the site of each

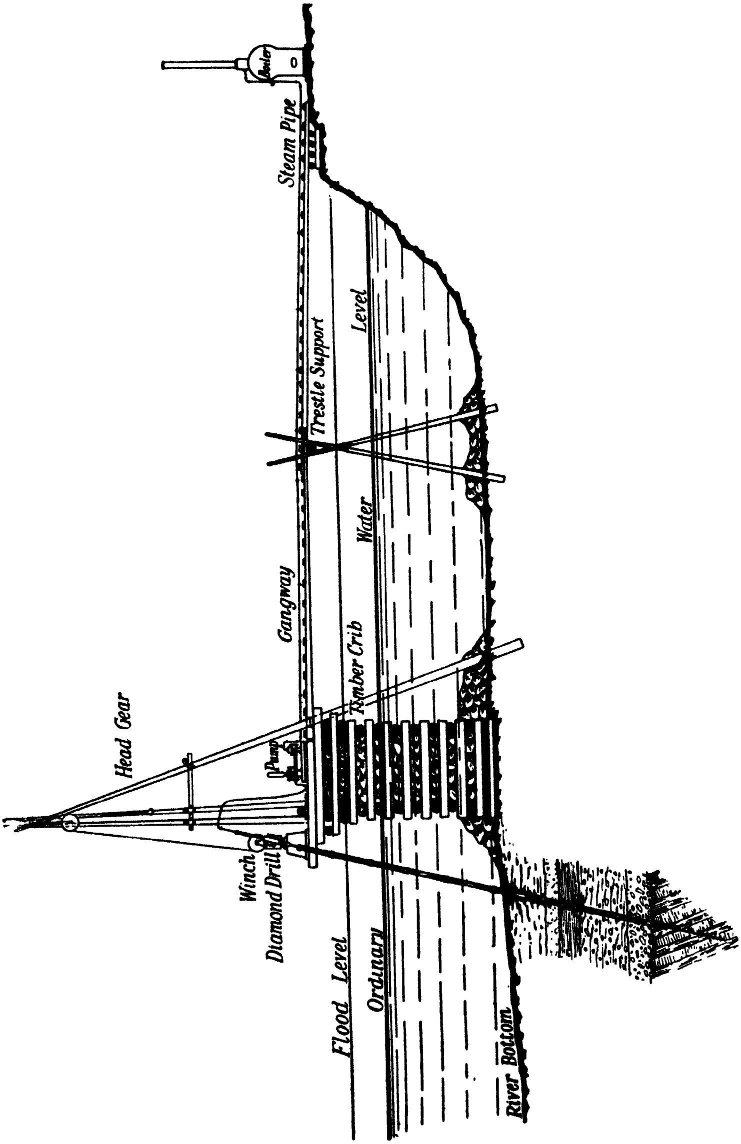


Fig. 131.—Boring from a Timber Crib.

boring, and if it is intended to construct a cross section, or sections of the bottom under examination, complete lines of soundings must be taken to include all the bore holes. The methods of sounding, and reduction of soundings to a datum are explained in Chapter II.

Tide Gauge.—When boring under water, a tide gauge should be set up in every case, not only for sounding purposes, but also as a necessary guide to the operators when borings are being made. With attention to the tide gauge, arrangements can be made as to the use of suitable lengths of case pipes and boring rods, and proper adjustment of the barge moorings, while warning is also given of any unusual rise in the water level indicative of approaching floods, or of extra high tides.

Plotting Borings made under Water.—Borings taken under water may be plotted in the manner described for probings, and percussive borings in Chapters II and III.

CHAPTER VI

II. BORING (*continued*)

SINKING OF BORE HOLES

General Considerations.—Great care has to be exercised in sinking test borings through difficult ground, and when they are deep a high degree of skill and resourcefulness is necessary to overcome the many obstacles encountered. The most difficult part of the work in sinking a deep bore hole is in penetrating a great thickness of loose materials of widely varying character which may overlie the solid rock. It is accomplished by sinking lining tubes by means of wash, and percussive boring in the manner already described, but the exigencies of deep boring through varied superficial deposits call for many modifications of the methods and tools applicable to the more simple and straightforward conditions with which engineers generally are familiar. Difficulties with deep lining pipes arise very largely from overdriving, so that they cannot be withdrawn when required during the boring operations, either through excessive skin friction, or from damage to the pipes themselves by bending or buckling them, and cases occur where a bore hole has to be abandoned on account of the diameter of the commencing pipe proving too small to permit of the use within it of smaller pipes necessary to reach the rock surface. Good judgment, therefore, is necessary in the selection of the proper classes and sizes of lining pipes, and of the methods used to sink them. Accidents may also arise to boring rods and tools, often from want of care and experience. The recovery of lost and damaged parts of a boring outfit is always a matter of delay, and boring operations may be brought to a complete standstill for long periods thereby.

A bore hole may even have to be abandoned as the result of a simple accident of this kind, unless exceptional skill and resourcefulness are applied, together with perseverance, in finding a remedy. The following is a brief description of the methods and tools generally used in sinking both shallow and deep bore holes :—

Lining Bore Holes.—Steel or iron tubes are used to line bore holes. They are known generally as "lining tubes," and are divided into two classes, viz. :—

(1) Casing pipes.
(2) Driving pipes.

Casing pipes are of light make, and are intended mainly to give support to the sides of a bore hole in soft and loose materials, while driving pipes are heavy to withstand being forced down, often under severe pressure, in hard and compact strata.

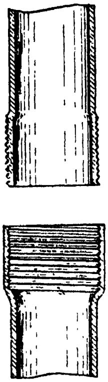


FIG. 132.—Cressed and Swelled Joint.

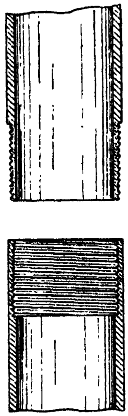


FIG. 133.—Flush Joint.

Casing Pipes.

(1) CASING PIPES. — When the ground is of such a nature that the lining tube will follow down with the drill, either by its own weight or with light driving, or by washing, casing pipes are sufficient to line the bore hole. They are commonly light, weldless, steel tubes, commonly 4 to 6 in. external diameter, and about $\frac{1}{8}$ to $\frac{3}{16}$ in. thick respectively. The usual lengths are 10 ft. for deep, and 5 ft. for shallow bore holes, with a proportion of shorter lengths 4, 3, and 2 ft. long. The tubes are connected together by screwed joints with V threads, and may be swelled and cressed (Fig. 132) or flush jointed (Fig. 133). In deep bore holes, where telescopic pipes are necessary, the diameters of the larger tubes may be from 8 to 10 in., or even more, according to the number of diminishing pipes required (Fig. 144). Casing pipes may

be sunk by rotating them with a pipe tiller, and this operation can be assisted by gentle driving with a wooden mallet, in which a driving head, made of a piece of tube about 6 in. long and flanged at the top, is used to protect the screw threads (Fig. 71). If a water jet is available, the process of sinking is facilitated by washing out the materials from under the foot of the pipe. Care should be taken to keep the casing pipes quite plumb in sinking, otherwise the chisel works with difficulty, and there will be trouble in withdrawing them. In rotary boring, the inside diameter of the smallest lining pipe should not be less than ½ in. more than the maximum diameter of the crown.

Fig. 134.—Outside Coupling Joint.

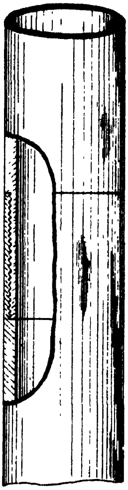


Fig. 135.—Flush Joint.

Fig. 136.—Flush Coupling Joint.

Driving Pipes.

(2) Driving Pipes.—In hard and stony ground, or compacted beds of shingle, weldless steel driving pipes must be used. They are of a much heavier section than casing pipes, with joints specially made to take the shocks of forceful driving. Where the pipes are of one diameter throughout and of no great length,

the outside coupling joint is generally used, but where the driving pipe requires to be frequently withdrawn a flush-joint is adopted. In deep bore holes, the lining pipes must be kept free to permit of blasting away obstructions, and have thus to be frequently withdrawn for some distance out of danger, while in telescopic holes (Fig. 144), the flush-joint permits of a commencement being made with a smaller diameter casing pipe, as no allowance has then to be made for outside couplings. Flush-jointed pipes are, therefore, most suitable for deep holes. An outside-coupling joint is shown on Fig. 134. The tube and socket are screwed so that no threads are left exposed, the bottom of the coupling bearing hard on the pipe itself, and the top end having a slight recess for easy entry. When the joint is made, the machined ends of the tube butt hard upon each other, and the strain of driving is thus taken directly by the tubes. A flush-joint is shown on Fig. 135, in which case the threads are cut partly on the outside and partly on the inside diameters of the tubes out of the thickness of the metal. The minimum thickness of pipe with this kind of joint is $\frac{1}{4}$ in. for 4 in. and $\frac{7}{16}$ in. for 12 in. external diameter. The pipe ends are machined, so that when the joints are made they are perfectly flush, both outside and inside, and butt hard. A flush-coupling joint is shown on Fig. 136. This joint is made by introducing a coupling between two lengths of tube. The coupling is screwed at both ends and, when the joint is made, is flush with the inside and the outside of the tubes respectively, the latter bearing hard upon the shoulders of the coupling. The screw threads of driving pipe joints are usually made of V shape, machine cut, but in diamond boring square-cut threads are adopted, eight to an inch. The ordinary pipe lengths used are 10 ft. long, with a proportion of shorter pieces 5, 3, and 2 ft. long. These latter are useful as top pieces, as it is inconvenient to have long lengths standing above ground.

The leading length of driving pipe is armed with a cast steel shoe to protect it from injury, and to facilitate cutting through difficult ground, while a forged steel driving flange or cap is screwed on to the top length to prevent injury when driving. Two forms of driving head and shoe are shown on Figs. 137 and 138. The tubes are driven down by a cast iron hammer or ram, weighing 300 lb. for light, and 500 lb. for heavy driving, and having a vertical hole or slot in the centre through which the boring rods may pass freely. The hammer is worked from the winch and head gear in a similar way to that of pile driving, and may be used with or without the boring rods (Fig. 139).

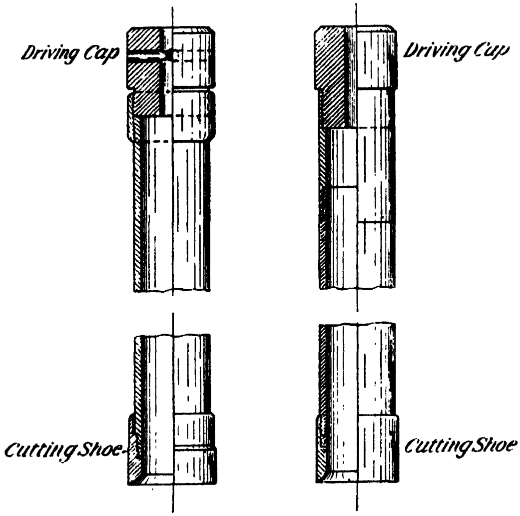


Fig. 137.—Outside Coupling Pipe.

Fig. 138.—Inside Coupling Pipe.

Driving Caps, and Cutting Shoes.

Sinking Driving Pipes.—The sinking of driving pipes through any soft ground overlying more compact and fragmentary beds presents no unusual difficulties, the same methods being used as in sinking casing tubes. When ground is reached, however, composed of materials which refuse to be displaced or washed out, such as compact shingle, loose stones and boulders, recourse must be had to chisels or cutters to break them up. If these tools are of the solid type, the obstructions are chopped up and the *débris* removed with the sludge pump, or washed up by a jet if such be available, and the conditions favourable. When rotary boring is used, the ground is broken up by the hollow chisels shown on Figs. 97 to 101, which are attached to the hollow boring rods, and worked up and down by the winch. The *débris* is washed up to the surface by the pressure water, or the bore hole may be cleared with the assistance of the sludge pump, when the velocity of the water is much reduced by the use of large lining pipes. When the bore hole has been cleared, the pipes should be driven down gently as far as possible, and without delay, and the chopping and jetting process repeated when necessary. To avoid the loss of time in removing the chisels, before driving is begun, chopping, jetting, and driving may be carried out together, in which case the *débris* is removed by washing out at a high pressure (Fig. 139). When the driving pipe practically refuses to descend after chopping and jetting, the obstacle may either be a large boulder or solid rock. In such cases it is important that no further attempt should be made to force the driving pipe down for fear of injuring it by collapsing the end, or deflecting it from the

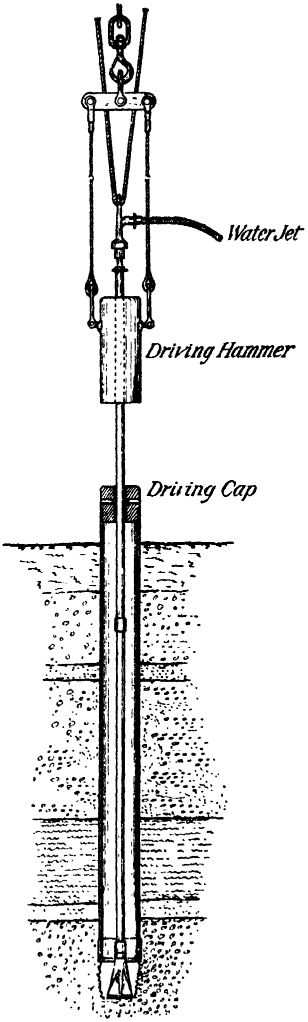


FIG. 139.—Sinking Driving Pipes.

vertical by introducing a bend in the pipe. A percussive drill works with difficulty in a bent pipe, and rotary drills cannot be worked at all. If driving is persisted in with a bent pipe, the accumulated resistance becomes so great that further progress is impossible, and the deformed tubes must be withdrawn or destroyed by blasting, always a difficult matter, or the bore hole abandoned. The obstacle should be drilled into by either percussive or rotary boring, as the only satisfactory test. The drill will pass through a large boulder, and solid rock should be proved for a depth of 20 to 30 ft. before it is accepted as such.

Blasting of Obstructions.—For blasting purposes, dynamite, blasting gelignite, or other such high grade explosive is used, fired by an electric exploder. The usual blasting charge is from 3 to 5 lb. of N.G. dynamite, but charges up to 10 lb. may be found necessary in face of a difficult obstruction. In preparing the way for a blast, the obstruction is penetrated by drilling sufficiently far to get the explosive placed well in advance of the driving pipe. When the hole is drilled and cleaned out, no time should be lost in getting a line of thin casing pipe lowered to the bottom of the hole, as the inrun of sand or loose materials may close it up, and thus militate against the effectiveness of the shot by introducing a cushion between it and the obstruction. The usual size of pipe for this purpose in a deep hole is from 2½ to 4 in. diameter, but if an ordinary jet pipe has been used, it may be left in the hole to place the shot in position. The explosive cartridges are securely lashed to the wires of the electric exploder in the form of circular bundles, packed in a waterproof casing, sufficiently small to allow them to pass freely down the pipe, with at least two detonators in a small shot, placed at different points in the bundles, and a greater number in large charges to guard against misfires. Another and safer method in deep, wet holes is to pack the whole charge of dynamite into a tin canister of a diameter suitable for the pipe, along with the detonators and waterproof casing, as shown on Fig. 140. When lowering the charge, the distance must be carefully measured off on the sus-

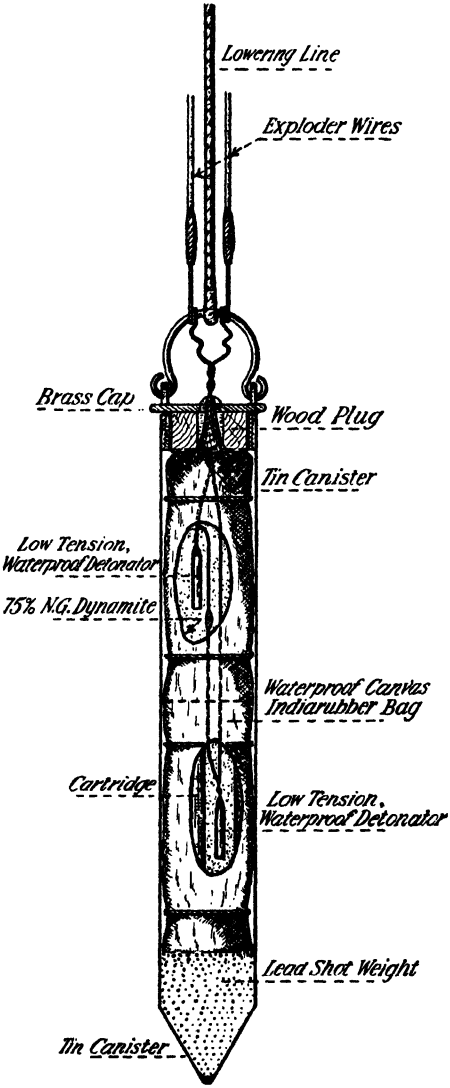


FIG. 140.—High-explosive Charge.

pending line, or the exploder wires to ensure that it has reached the proper position. Before the charge is exploded, the driving pipe must be withdrawn 5 to 10 ft. clear of it, as otherwise the force of the explosion tends to distort and rag the end, so that succeeding tubes cannot pass through, and the drill itself may be damaged by the imperfect pipe. The importance of keeping the driving pipe always free for easy withdrawal is thus evident, particularly in deep bore holes where blasting is frequently required. When the charge has been exploded, the driving pipe should at once be forced down, as the displaced materials tend to fall back into the cavity formed by the shot. If the obstruction has been disposed of, the pipe will descend freely, but, otherwise, only a few inches, and the process of chopping, jetting, and blasting must be repeated.

Enlarging Bore Holes.—When a percussive bore hole has been sunk for some distance in soft materials, and the need for lining is apparent by the sides caving in, the hole must be enlarged to permit of the descent of the casing pipes, which are, of course, greater in diameter than the bit or chisel. A special tool, termed the " reamer," is used for this purpose, consisting of a square rod to which is riveted two, or four saw-edged, spring blades, bent in the form of an elliptical bow (Fig. 141). The reamer is screwed to the end of the boring rods, and gently rotated in the same way as a drill, and the trimmings from the hole are removed as required by the sludge pump, or the shell auger (Figs. 72 and 73). When a sufficient depth of the bore hole has been enlarged, the reamer is withdrawn and the first length of tubing put in. To reach the remainder of the bore hole, the reamer has to be forced through the tubes already in the ground, but the steel blades are sufficiently flexible to allow of this temporary compression, and expand to their full diameter again when clear of the bottom of the lining tubes. The maximum diameter of the reamer should be rather greater than the outside diameter of the particular size of casing pipe in use. Reaming may also be done with this tool in percussive boring to free the casing pipe, if already in the bore hole, when difficult to get down, but a special form of reaming chisel is more generally used, as shown on Fig. 142. This chisel is eccentric in form, with one straight side and two cutting edges,

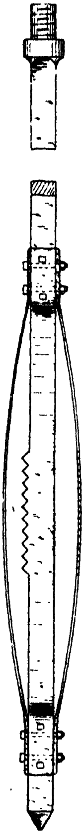


FIG. 141.—Spring Reamer.

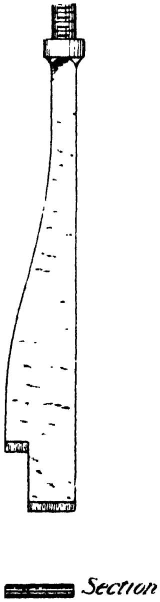


FIG. 142.—Chisel Reamer.

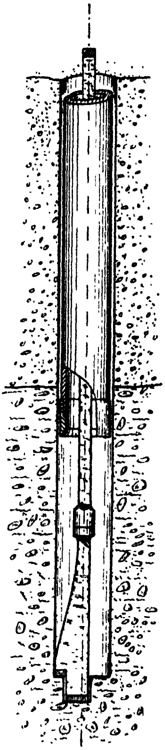


FIG. 143.—Reaming Lining Pipes.

and the width of blade is limited by the space available to get it down the casing pipe. When clear of the foot of the pipe, the chisel, when worked perpendicularly in the centre of the bore hole, cuts over an area circumscribed by its long radius, and thus outside the diameter of the lining tubes in practice (Fig. 143). The casing pipe should be made to follow down with the reamer, and the latter withdrawn only when it is necessary to clear the hole of *débris*. The spring reamer is suitable for loose ground only, but the chisel reamer may be used both in hard ground and rock.

In rotary boring, when it is necessary to ream a lined hole in rock, the reaming is done by a special diamond crown, or a steel cutter, as the case may be. The operation is the same as in ordinary boring with these tools, and the *débris* is altogether washed up to the surface by the pressure water, or partly removed in a calyx core-box in the usual way. In such cases of reaming, the hole reamed is of less diameter than the lining tube, and is meant to take a smaller pipe.

Sealing Lining Pipes.—When the driving pipe has reached the rock surface, a tight joint must be made to prevent the influx of sand and light materials into any further extension of the bore hole, and in the case of rotary boring to prevent the escape of pressure water into the surrounding strata (Figs. 89, and 109). The joint may be made by using a reaming chisel (Fig. 143), or by chopping up the rock with solid or hollow chisels (Figs. 97 to 101), and driving the pipe down. If in shallow holes a tight joint has not been made, the reaming should be extended, the hole thoroughly cleaned out, and neat Portland cement in thin linen bags lowered to the bottom, sufficient to fill the reamed hole and the first few feet of the driving pipe. The pipe should then be driven as far as it will go, and the cement bags immediately broken up and rammed by a few blows of a cross-bit drill. When the cement has set hard, it may be drilled through until the rock is again reached. Another method of making the joint tight is to lower the cement in a plastic condition in a sludge pump, fitted with a disc valve to which a rod is attached, projecting downwards below the foot of the pump. The sludge pump is connected to the boring rods and, on reaching the bottom of the bore hole, is worked gently up and down, thus raising the valve by means of the rod, and so allowing the cement to escape. When sufficient cement has been lowered in this way, the lining pipes are driven down, and the cement allowed to set hard. In rotary boring, the lining pipes may be lifted for some distance, the hole reamed, and liquid cement forced down under pressure, either through the hollow rods, or preferably through a special tube, after which the lining pipes are immediately driven down as far as they will go, and the cement allowed to set hard. In all of these operations it is important to measure the depth of the bore hole carefully before the cement is lowered, so that the exact conditions may be known for regulating the quantities of cement properly.

Deep Bore Holes with Telescopic Linings.—In the case of borings through thick deposits of loose materials, the lining of the bore hole must be carried out by tubes gradually diminishing in diameter. This is termed "telescopic lining" (Fig. 144). In starting a bore hole of this kind, the first part of the lining may be done with ordinary casing pipes, so long as the ground is soft, but when the limits of this method have been reached all subsequent lining must be with heavy driving tubes, armed with a cutting shoe at the foot. When the depth of the strata is considerable, the diameter of the commencing tube should be large, as a boring may have to be abandoned before completion owing to the impossibility of getting in the requisite number of smaller tubes to reach the desired depth. The actual length of lining pipe which may be driven before a change to a smaller diameter is made, depends on the nature of the ground and the power available to pull up the line of piping. Lining pipes which are overdriven, or jammed amongst stones, are liable to part at joints when a heavy lifting strain is put upon them. In soft ground, a length of about 100 ft. or more can usually be sunk, and by carefully preparing the way in hard ground by blasting in advance, lengths of about 60 to 80 ft. may be driven. On this basis a calculation of the necessary diameter of the first pipe may be made. Thus a prospective diamond core boring, 2 in. diameter and about 250 ft. deep, might be lined out with pipes having a commencing diameter of 7 in. inside, an intermediate of 5 in., and a finishing diameter of 3 in. through the loose materials. The selection of a commencing diameter of 7 in. would thus leave a margin for further variation of the intermediate diameters, should that be found necessary. In a telescopic bore hole, each diameter of piping reaches to the surface through the other concentric pipes, and the resistance, both to driving and withdrawing, is that only of its actual depth in the ground (Fig. 144). The bottom length requires to be driven for some short distance into the solid rock without rotating it, the recess being made by reaming out either with a chisel reamer, or by any of the hollow chisels used in rotary boring.

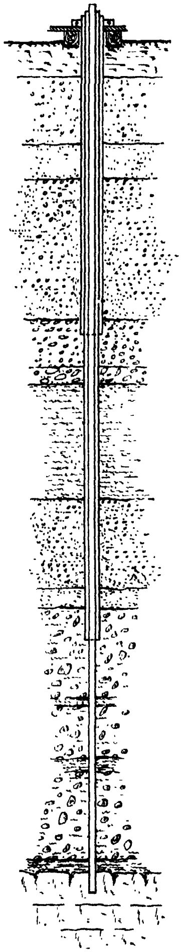


FIG. 144.—Telescopic Bore Hole.

Withdrawing Lining Pipes, Shallow Holes.—In shallow bore holes, the lining tubes are withdrawn by fixing a pipe clamp (Fig. 67), to the top tube, and attaching it in turn to the hoisting rope of the winch by a short sling. When strain is put upon the hoisting rope, the tubes are rotated with the pipe tiller (Fig. 66), and further strain may be put upon them by hand levers applied under the pipe clamp. The top tube should be tapped smartly with a wooden mallet to free the pipe line, if there is difficulty in starting it when under strain. If the lining is short, and in loose ground, an iron plug or "swedge" may be used with success (Fig. 145). The swedge is attached to the end of the boring rods, and lowered to the point required in the casing pipes, when rough, gritty sand is thrown into them, and, by jamming the plug, creates sufficient friction to enable a grip to be made, and a considerable amount of strain to be applied through the hoisting rope. This may be supplemented by using the pipe tiller, and hand levers as before.

When lining tubes are difficult to draw, a special tool, termed a "spring-dart," is used, which consists of a length of solid, boring rod, to which is bolted two bent springs with dart-shaped ends

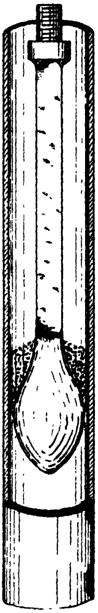


Fig. 145.—Swedge.

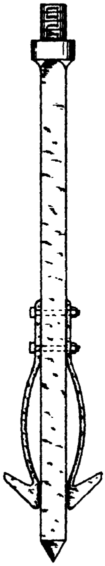


Fig. 146.—Spring Dart.

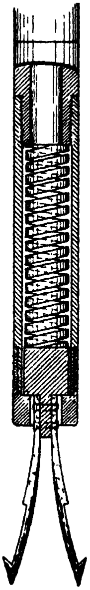


Fig. 147.—Helical Spring Dart.

(Fig. 146). Immediately before the spring-dart is used, the bottom of the hole is cleaned out, so as to allow the tool to operate freely under the bottom of the pipes. The spring-dart is attached to the boring rods, and forced down the casing pipe until it passes out at the bottom, when, being free from side pressure, the darts are thrown out to their full extent by the springs. The underside of the tube can thus be caught when strain is put upon the hoisting rope, and with the assistance of the pipe tiller the tubes can be raised. A more modern form of spring-dart, generally used in rotary boring, is shown on Fig. 147. It consists of a cylinder with a head or piston to which the darts are riveted. The piston is controlled by a helical spring, and when the tool is forced down the lining pipes the spring is compressed, but on reaching the bottom the darts are forced out to their full extent by its pressure. In place of the winch and hoisting rope, the lifting power may be supplied by means of a hollow jack, which permits of the tubes passing freely through its centre (Fig. 148). A pipe clamp is fixed to the tube above the jack and bears upon a loose, hollow collar, which rests upon the jack head. By rotating the screw clockwise, the tubes are made to move upwards a distance equal to its pitch for each revolution of the handles. A hollow, hydraulic jack of the same type, operated by a hand force pump, is used for large casing pipes. When there is much difficulty in removing casing pipes, it is better to leave them in the ground, as the expense incurred in their removal will then be greater generally than the cost of the tubes themselves.

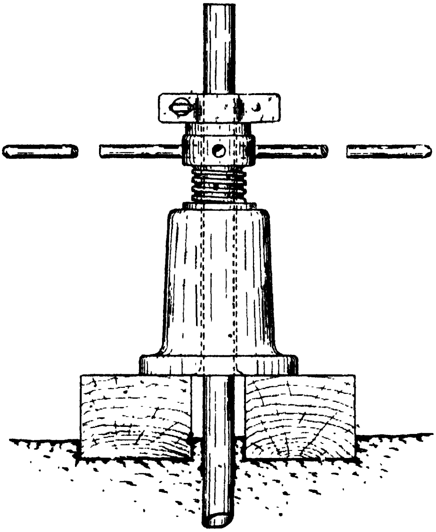


FIG. 148.—Hollow Screw Jack.

Withdrawing Lining Pipes, Deep Holes.—In the case of deep bore holes, the actual recovery of the lining pipes themselves is not so important a matter as the fact that they have to be partly withdrawn from time to time, in the course of boring, to allow of the use of explosives. In difficult ground, therefore, lining tubes should always be kept free by blasting, and not forced by severe driving. Deep lining tubes are usually withdrawn by the hoisting rope of the power winch, which is attached to a heavy clamp on the top tube, and as the resistance to pulling up is nearly as great as that of driving down, the length of a line of pipes should be so fixed that their resistance is not greater than the capacity of the winch. When long pipes are difficult to start, their upward movement may be initiated by applying force in a series of jerks or blows, in which case a hollow, ring weight with side lugs is slipped over the top tube, and a heavy pipe clamp fixed above it. The hoisting rope is attached to the weight by the lugs, and the clamp struck on the underside by a series of upward blows, the reverse of the operation of driving, until the pipe line is free. In boring under water, the same measures are adopted, or by heaving on the hoisting rope until the barge is well down in the water, then suddenly releasing the winch brake, and, as the barge is in the act of rising, suddenly applying the brake again. This throws a quick and powerful jerk upon the pipe, which may be repeated with care as often as may be necessary to release the lining pipes.

Accidents when Sinking Bore Holes

The recovery of damaged or lost parts of the outfit from a bore hole is generally known as "fishing," and the following are some of the methods and tools used to this end :—

Impression Cup.—As all fishing is carried out in the dark, it is necessary that the engineer in charge of boring operations should have at all times a clear and concise record of the state of the bore hole as regards depth, linings, rods, and tools in use, as well as that of the character of the strata. The state of matters at the bottom of the bore hole, or the point of accident, may be ascertained by lowering an "impression cup" in which an impression or imprint of the objects in the way is more or less clearly made. This tool consists of a hollow cylinder attached to the end of the boring rods, and into the bottom end of which a wooden plug is driven, leaving a space about 6 in. long for a solid plug of bees'-wax, or firm soap of a consistency to receive and retain an imprint (Fig. 149). From the data thus obtained, the proper kind of fishing tool can be selected for the work of recovery. In course of fishing, it is necessary to lower the impression tube from time to time, in order to ascertain any change in the conditions of the bore hole.

FIG. 149.

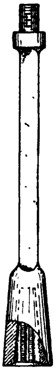


FIG. 153.

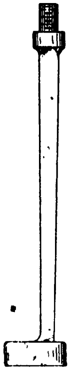


FIG. 150.

FIG. 151.

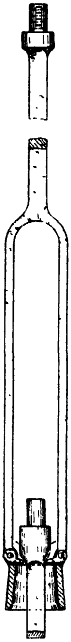


FIG. 152.

FIG. 154.

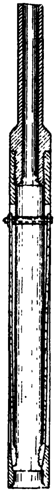


FIG. 155.

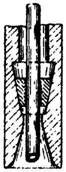


FIG. 158.

FIG. 156.

FIG. 157.

FIG. 149.—Impression Cup.
FIG. 150.—Crow's Foot.
FIG. 151.—Crow's Foot Plan.
FIG. 152.—Bell Box.
FIG. 153.—Bell Screw.
FIG. 154.—Slip Socket, Elevation.
Fig. 155.—Slip Socket, Section.
FIG. 156.—Slip Socket, Spring Tongs, Side.
FIG. 157.—Slip Socket, Spring Tongs, Front.
FIG. 158.—Principle of Gripping Tools.

Solid Rods.—In the case of boring rods of the solid type, the common fishing tools are the "crow's-foot" (Figs. 150 and 151), and the " bell-box " (Fig. 152), either of which can be screwed to the end of a line of boring rods and lowered into the bore hole. These appliances are suitable for tools which have broken above a coupling. The crow's-foot is rotated until its fork becomes engaged with the shank of the broken rod, and is then pulled up until the coupling rests upon the fork, when the rods can be lifted to the surface. The bell-box is lowered on to the broken rod to a point below the coupling. The bottom hinged flaps open upwards to admit of the coupling passing through them, but close on the neck thereafter, so that when the bell-box is raised the coupling rests upon them, and takes the weight of the broken line of boring rods. When solid rods have broken so that a coupling cannot be engaged by the foregoing tools, a " bell-screw " is used (Fig. 153). It consists of a tapered, steel, screw die within the cone, and is used to cut a screw thread upon the end of the broken rod, whereby the lost rods can be raised. Another form of fishing tool which has a general application, and is suitable for either solid or hollow rods, is the " slip-socket " (Figs. 154 to 157). It consists of a barrel with a cone end, inside of which are a pair of spring tongs, with hard steel palms. The palms are wedge-shaped, and slide up or down in wedge-shaped recesses in the barrel, and the faces are strongly roughened, like a file, for gripping purposes. Thus when an object is encountered as the slip-socket is lowered, the palms or wedges move upwards and permit it to enter, but when the tool is raised they slip down the inclined recesses and exercise a powerful vice-like grip upon the article enclosed, on the principle shown on Fig. 158.

Hollow Rods.—In the case of hollow boring rods and tools, screw taps of various kinds are used to recover lost parts. These taps are screwed to the line of boring rods as required, and the rods rotated until the tap has threaded itself securely into the inside, or on to the outside of the broken rod, as the case may be. A rod tap is shown on Fig. 159, a coupling tap, smaller in diameter, on Fig. 160, and a hollow tap for engaging the outside of a rod on Fig. 161. If the break in the rods is not clean, a " rose " bit is used to pare or mill it down, so that the rod tap may be inserted. A "rose" bit has a projecting, tapered, guide spindle for entering the interior, or a bell-mouth for guiding it on to the exterior of the rod.

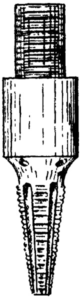


Fig. 159.—Rod Tap.

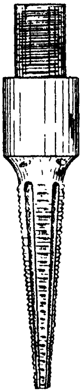


Fig. 160.—Coupling Tap.

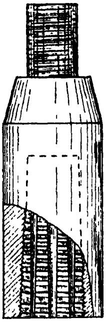


Fig. 161.—Hollow Tap.

Similar taps, but of larger dimensions, are used for recovering lining tubes.

Lost Diamonds.—Lost diamonds from the boring crown may be recovered by attaching an impression cup to the boring rods, which are then lowered to the bottom of the bore hole and worked gently up and down. This action causes the loose materials lying at the bottom to be pressed into and to adhere to the wax or soap plug, and amongst which the lost diamond is often included. If lost diamonds, or other small objects, cannot be recovered by this means, or by suitable recovering tools, the bore hole may be filled with cement for some distance above the lost articles, and the rock reamered out for its whole depth by a larger crown, down to a point well below the level of the lost object. A core is then taken from the cement filling, in which the missing article may be found embedded.

Lining Pipes.—Damaged casing pipes may be withdrawn from shallow bore holes by using the ordinary withdrawing tools. In deep bore holes, the pulling out of damaged lining pipes is a much more serious matter, as the point at which an accident takes place may lie at a considerable depth, and necessitate pulling up long lines of pipes. If the lining pipes have parted at a joint, the upper section is withdrawn, and a recovering tap or die (Fig. 159), lowered at the end of the boring rods, and rotated until it has effected a proper union with the lower section, when it may be pulled up, or a "pipe-spear" may be used for this purpose (Fig. 162). The pipe or casing spear consists of two hard, steel, sliding wedges for a small, and four for a large tool of this kind, which are free to move up or down upon inclined plane recesses cut in the solid steel cylinder. The wedges are connected by a through pin, which works in a vertical slot cut in the recesses, and the exposed faces of the wedges are roughened by a series of parallel indentations, shaped like saw teeth, with the points upwards. When the pipe spear is lowered down the lining pipe at the end of the boring rods, the wedges move upwards and give the necessary clearance for its passage, but when raised the wedges fall downwards and give a powerful grip by wedging themselves tightly against the inside of the pipe. In

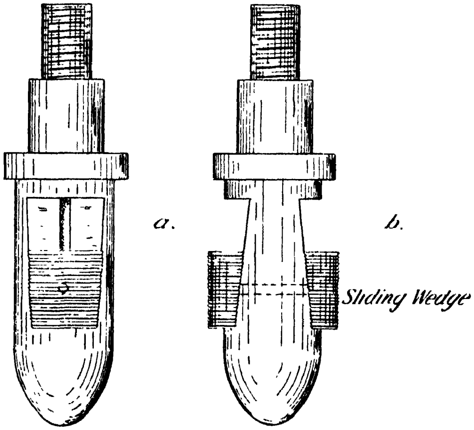


FIG. 162.—Pipe Spear. (a) Front View; (b) Side View.

the case of badly bent lining pipes, which have resisted all efforts to pull them out, the matter of their recovery or dispersion is one of extreme difficulty. It is usual to attempt their recovery by cutting the line of pipes just above the bend with a "casing cutter," which consists essentially of two or more horizontal, steel cutting blades, contained in slots within a bar or tube, and capable of inward and outward movement. It is attached to the line of boring rods, and lowered to the required point in the lining pipe, the cutting being done by rotating the rods. A common, small casing cutter is shown on Fig. 163, having two blades actuated through linkage by the resistance of the attached spindle and spring when jammed in the pipe.

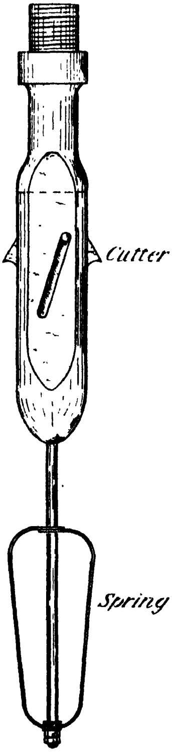


FIG. 163.—Pipe Cutter.

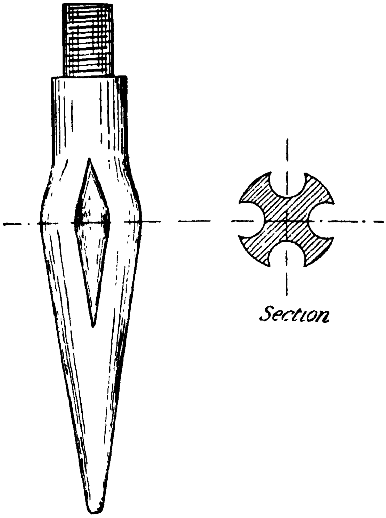


FIG. 164.—Pipe-expanding Swedge.

The upper, and straight section of the lining pipe is pulled out when cut, and the bent end engaged with a recovering tap, or a pipe spear as before. Should the bent pipe not be recoverable by this means, it must be blasted clear of the true line of the bore hole, when a new line of pipes may be got down. Lining pipes which have become collapsed at the bottom, as in over-driving amongst stones or boulders, or accidentally deformed by blasting, may be sufficiently enlarged again to admit of the passage of a smaller size lining by using a special form of "swedge." It is shown on Fig. 164, and a beginning is made with one of small diameter, followed by others of greater diameter. Lining pipes which have become so firmly fixed that the usual means of withdrawing them prove useless, must be cut into sections by the casing cutter, and lifted by means of a recovering tap, or a casing spear.

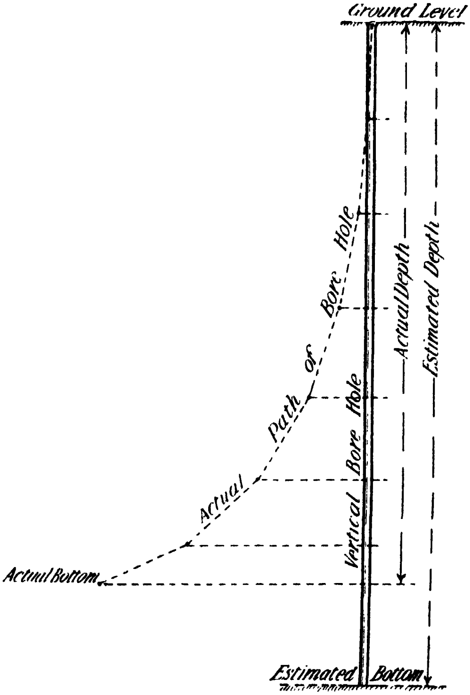


FIG. 165.—Path of a Deep Bore Hole.

Deviations of Bore Holes.—Rotary bore holes have a decided tendency to deviate from the true vertical after about the first 100 ft. of depth. The deviation then comprises the two factors of slope and direction. Deviations are greater in boring through hard rocks composed of inclined beds of widely differing degrees of hardness, than in horizontally bedded rocks of a more or less uniform hardness, due to the drill following the lines of least resistance. Some observations of diamond borings through hard rock give the average deviation at about 5 degrees from the vertical at a depth of 500 ft., and it is found to be roughly proportional to the depth. In important, deep, test bore holes, it becomes necessary to measure the deviations by taking observations at every 100 ft. bored, but in many such cases the vertical deviation only is recorded when the horizontal direction is not a matter of importance. The path of a deep bore hole is, when looked at as a vertical section, generally that of a compound curve, and the deeper the bore hole, therefore, the more the strata are cut at a flatter angle to a horizontal datum (Fig. 165). The actual distance bored does not thus represent either the true thickness of the beds pierced or their actual level beneath the surface of the ground, and hence the need for correction by surveying the deviations.

Surveying Deviations.—Special instruments of great delicacy are used for measuring the deviations of bore holes, and there are five or six methods in vogue, the greater number of which depend upon the use of a fixing agent in the form of hydrofluoric acid, and liquid gelatine or wax, placed in special phials, and lowered to the required points in the bore hole. The simple hydrofluoric method is used for determining deviations from the vertical only by etching a horizontal line on the glass tube, the angle between this line, or the plane within it, and the axis of the phial being the dip or slope of the bore hole, and is measured by placing the phial in a specially designed clinometer. The gelatine or molten wax method registers the dip by allowing the molten liquid to solidify in the bore hole, thereby fixing a delicate plummet contained in the phial in the position which it had assumed in the bore hole, and the horizontal or deflection angle by locking a delicate magnetic compass in its north and south magnetic direction in the congealed liquid at the same time. The dip is measured by placing the phial in a specially made clinometer and bringing the plummet to the vertical, and the deflection by setting the needle to the magnetic north and south at the same time, when the conditions obtaining in the bore hole at the time of solidification of the liquid are reproduced. In more recent instruments of this kind, the means of measuring dip and deflection are combined by using a compass of the mariner's type, having a fine silver mirror attached to the top of the needle. The needle and mirror adjust themselves freely in the liquid to the conditions of the bore hole, and are fixed in position when the former is congealed. The dip can then be measured from the mirror, and the direction from the compass. Details of the instruments and methods used in surveying and plotting the deviations of bore holes are given in most modern treatises on mining, and should be consulted for further information, particularly in regard to deep bore holes.

CHAPTER VII

III.—TEST PITS AND SHAFTS

TEST pits and shafts are used for the examination of comparatively shallow foundations, and afford within their limits the most satisfactory evidence as to the actual nature of the strata. They also give facilities for carrying out practical tests of the bearing and compression powers of the strata, and of their behaviour when exposed in this way to atmospheric conditions.

General Features of Test Pits.—Test pits as a rule are sunk through soft materials, and thus require to be artificially supported by timber or iron frames to prevent the sides from caving in. The minimum size of a shallow test pit is usually from 5 to 6 ft. square, this space being necessary to allow two or three men to excavate and fill the skip or bucket by which the excavated materials are removed, or to work a boring tool inside the pit should it be necessary. When a number of test pits have to be sunk they should be kept strictly of one size and design, as it is then possible generally to draw and use the timbers and supports over again. The sites selected for test pits should be at important points in a scheme of foundations of constructional works.

Test pits may be constructed with :—

(1) Timber supports.
(2) Iron supports.
(3) Timber and iron supports combined.

(1) **Test Pits With Timber Supports**

There are three methods usually adopted in constructing test pits with timber, viz. :—

(*a*) With runners or sheeting timbers.

(*b*) With poling boards.

(*c*) With runners and poling boards.

The first (*a*), is used for loose or wet ground; the second (*b*), for stiff and firm ground; and the third (*c*), where there is both loose and firm ground. The quantity of timber actually used for supporting the sides of the pits by any of these methods, will depend on the degree of firmness of the soil and the amount of water met with.

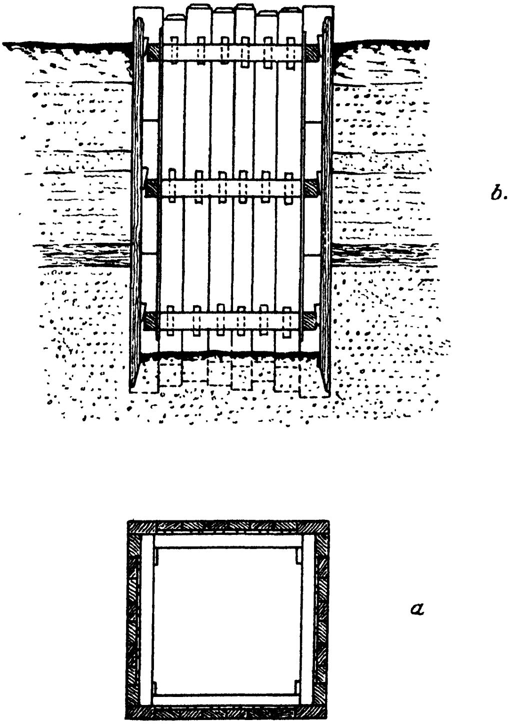


FIG. 166.—Test Pit, with One Setting of Runners. (*a*) Plan; (*b*) Section.

(*a*) PITS WITH RUNNERS.—The general method of constructing a shallow test pit in loose ground by means of one set of "runners" is shown on Fig. 166. The runners form the four sides of the pit, and are usually of sawn white wood from 1½ to

2 in. thick, by about 16 ft. long, and 7 to 8 in. in width. The points are roughly bevelled off with an axe or adze to facilitate driving, while the heads are ringed with a light iron band, 1 in. wide and ¼ in. thick, to prevent splitting when being driven (Fig. 167). To support the timbers against earth pressure, they are braced internally with "walings" or "rangers," usually about 9 in. by 3 in. scantling, or about 6 in. diameter, butted hard to each other in the form of a frame, and placed about 4 ft. centres apart vertically (Fig. 166). The runners are brought to a bearing on the walings by hard wood wedges. To permit of this wedging, the corner vertical or face timbers are 1 in. more in thickness than the runners, and in short lengths, equal to the vertical distances apart of the walings, so that a set of walings and face timbers can be put in place in advance of the runners to act as guides when the latter are being driven.

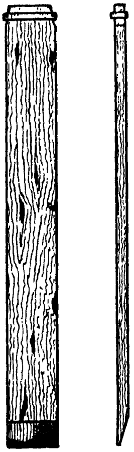


FIG. 167.—Runner for Test Pit.

Pits with Double Setting of Runners.—When test pits are of considerable depth, say, 40 ft., it is necessary to "double set" the timbers, in which case two, or more sets of runners are used to reach the bottom. The construction of a test pit of this kind, with two settings of timber is shown on Fig. 168, and with three settings of timbers on Fig. 169, the latter having a depth of about 35 ft. In cases where double setting is required, the commencing size of the pit must be such that at the finish there is about 5 ft. clear at the bottom. In Fig. 169 the commencing dimensions are 10 ft. by 10 ft., and the successive reductions by runners and walings leave it about 5 ft. by 5 ft. at the bottom. In double setting, the bottom waling frame of the first setting requires to be made with larger timbers than those above it, so as to give the necessary clearance for driving the next set of runners, and this applies also to all additional settings, as in pits or shafts with three, four, and more settings (Fig. 169).

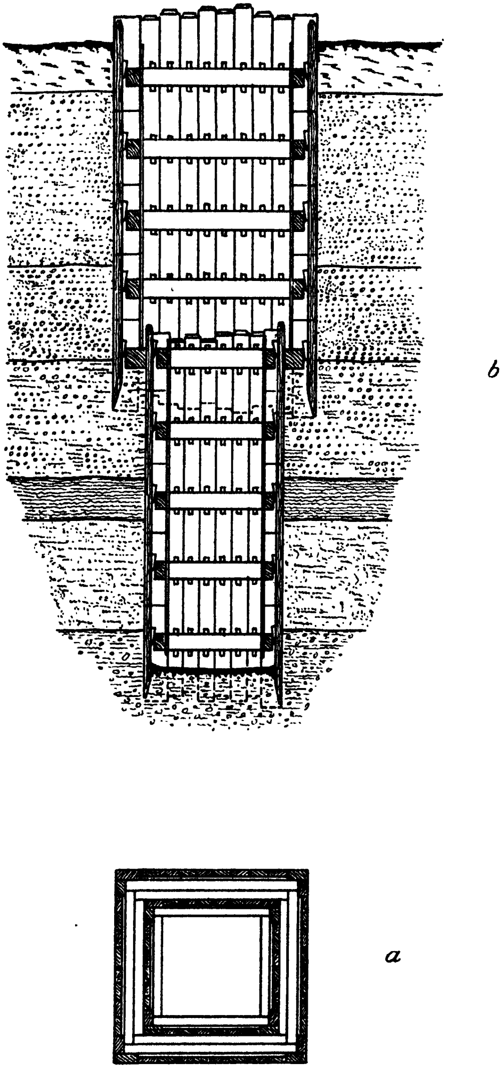


FIG. 168.—Test Pit with Double-Setting of Runners. (*a*) Plan; (*b*) Section.

Procedure in Sinking with Runners.—In sinking a test pit or shaft with runners, the ground is excavated for about 2 ft. in depth below the surface, and of sufficient dimensions to allow of the corner timbers or face pieces being put in, together with the walings or rangers forming the first internal frame. The long

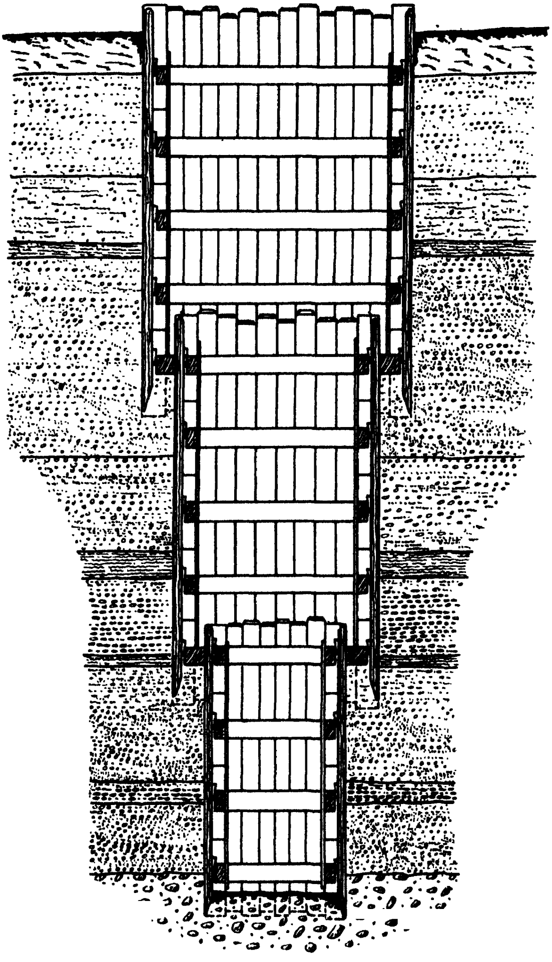


Fig. 169.—Test Pit, with Three Settings of Runners.

walings are placed first against the face pieces, and the shorter walings or stretchers driven hard between them, so as to form a

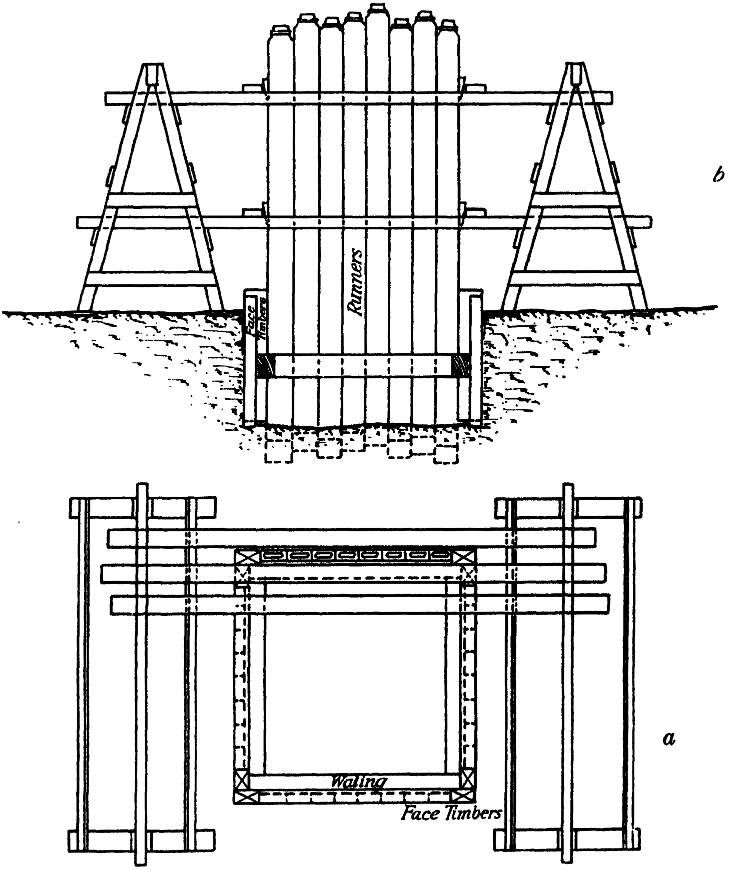


FIG. 170.—Method of Commencing a Test Pit.
(a) Plan. (b) Elevation.

rigid frame. The runners are then inserted in the space left behind the frame, and driven gently down for some distance into the ground. At the commencement of the sheeting operations, the runners stand a long way above the surface, and are supported by temporary timber stagings formed of trestles and planks (Fig. 170), which also serve as a platform for the men when driving the runners with hand mallets (Fig. 171). As the soil is taken out the runners are driven further down so as to be always near the level of the excavation within the pit, and are temporarily wedged off the walings at each operation. In bad ground, however, the runners require to be advanced below the level of the excavation, and it may be necessary to caulk the joints with oakum, or pack the runners from behind with straw when there is much water and sand coming into the pit. As the runners are driven down new walings are placed to support and guide them. Care must be exercised to keep the runners straight, and the pit plumb and square. Obstructions in the way of the runners, such as boulders, must be dug out or cut off by boring them with plug drills. When large boulders are met, small charges of explosives may be judiciously used to break them up.

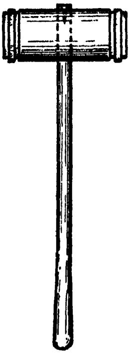


FIG. 171.—Wooden Hand-Mallet.

Removal of Excavated Materials.—In the early stages of excavation the materials removed may be thrown out directly to the surface with shovels through a gap formed by leaving two or three runners out of one or more of the sides of the pit, if the ground is comparatively firm. If the ground is soft, the timbering of the four sides has to be placed complete, and the materials may then be removed in ordinary buckets attached to ropes, hauled up to the surface by hand, or in two lifts by shovelling them on to an intermediate platform, about halfway down the pit, and from thence to the top again, until a depth of 8 to 10 ft. has been reached. If the pit is to be of greater depth than this, a double-handled windlass and endless rope should be erected on a platform over the centre for dealing with the excavated materials, so arranged that as the empty bucket or kibble descends the full one is brought up by two men turning the handles (Fig. 172).

The materials removed from the pit should be stored close at hand for examination, and for refilling the hole, as is generally necessary. The windlass proves very serviceable for handling timber when pits of double and treble settings are sunk, and for withdrawing and hoisting it when the pits are being filled in again.

Unwatering of Pit.—When the quantity of water in a pit is small it may be dealt with by bailing out with a bucket attached to a hand rope, or with buckets worked from the windlass. When the water is more troublesome recourse must be had to pumping of some kind. An ordinary hand pump will suffice to lift from depths of about 20 ft., and a hand force pump will raise water to about 30 ft. with a suction pipe about 15 ft. long. In important pits it may be necessary to employ a small pulsometer, or stream force pump to keep them dry. In all cases where water is found

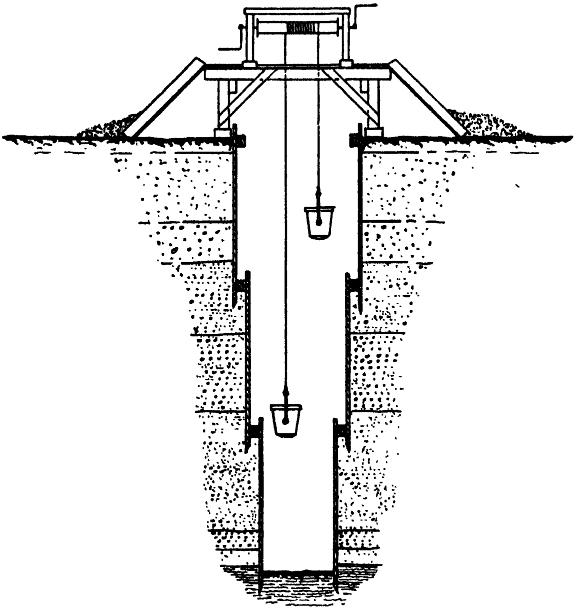


Fig. 172.—Sinking a Test Pit.

in the pit in any quantity, a proper sump must be formed to which the water can be drained, and the sump must be kept in advance of the sheeting. When, however, the amount of water is great, excessive pumping may lead to serious collapses of the strata and timbering, and other means must be devised to check the water. If the water proceeds from a thin seam, say, of sand, it can be checked by driving tongued and grooved sheet piles in front of the wet places, and sealing the space at the junction between the runners and the sheet piles with clay or concrete. The sheet piles must be thicker than the runners to allow of the grooves being formed. The usual thickness is 3½ to 4 in., with ½ in. grooves for iron tongues of flat bar, 3 in. wide by ⅜ in. thick,

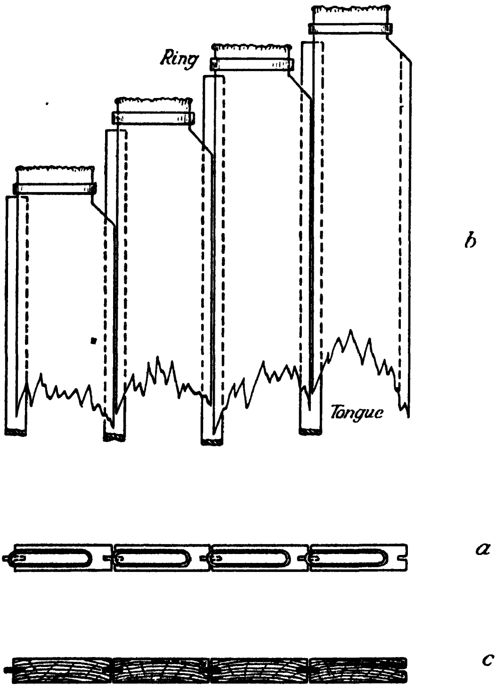


Fig. 173.—Iron Tongued and Grooved Sheet Piles. (*a*) Plan ; (*b*) Elevation ; (*c*) Section.

or $\frac{7}{8}$ in. grooves for $\frac{3}{4}$ in. pitch pine or hard wood tongues. Iron tongues take up less space in the piles and are very suitable where timbers have to be drawn and used over again, as well as being less liable to break in driving. The bars should be well greased before fitting to the grooves, to preserve them and to facilitate withdrawal (Fig. 173). When the pit is very wet the best method is to continue the lower part with steel sheet piles, as shown on Fig. 191, and in the worst of places it may be necessary to put down a deep shaft constructed entirely of long steel sheet piles, with two or more settings, as hereinafter described.

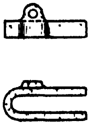


FIG. 175.—Runner Clamp.

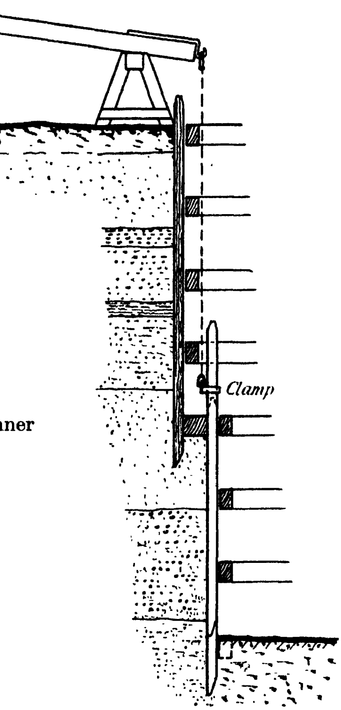


FIG. 174.—Drawing Timbers from a Test Pit.

Drawing Timber, and Refilling Pit.—If a test pit is not required for any permanent part of the works, the timber is withdrawn and the hole filled up again. The timber should be carefully removed so as not to injure it, especially when it is required for other pits. To withdraw the timber the bottom of the pit is filled up with the excavated soil, thoroughly rammed and consolidated to the level of the lowest set of walings, which are then removed preparatory to filling up to the next set. When a pit has been opened out for some time there is considerable pressure on the walings, and it is somewhat difficult to knock them apart without injury. In such cases two long screw jacks, placed crosswise in the pit, are used to ease the pressure while the stretchers or short pieces are being taken out, or service stretchers with wedges, or with a short screw jack at one end may be employed for this purpose. As each set of walings is removed the runners are pulled up a corresponding amount, care being taken that in bad ground the points are not lifted above the level of the refilling at any time. The runners may be withdrawn by means of a hand lever and iron clamp (Figs. 174 and 175), or by screws hung from temporary cross supports. The heads of the runners require to be wedged apart to permit of the clamp or sling (Fig. 175), being attached, and if one runner can be safely drawn up a considerable distance the wedging apart of the heads greatly facilitates the removal of the remaining runners thereafter. When the runners have been under earth pressure for some time they are difficult to start, and upward strain should be applied in a series of jerks, the runner being struck simultaneously on the flat side with a heavy mallet or hammer. This has the effect of freeing the runner of materials adhering to it, and so reducing skin friction. When the timber has been removed it should be carefully laid aside in selected lots for further use, and runners and walings repaired where necessary.

(*b*) Pits with Poling Boards.—Poling boards are generally used in pits where the ground is comparatively firm, as in good clay. The chief difference in this method of timbering a pit from that of runners is in the use of short timbers or "poling boards," as compared with long runners (Fig. 176). The poling boards are usually about 4 ft. long, 6 to 12 in. wide, and 1 to 1½ in. thick, and the walings and stretchers about 10½ in. wide by 5 in. thick. These waling frames are spaced about 4 ft. centres, and are supported vertically, one from the other, by struts or "puncheons," about 4 to 5 in. square, placed between the frames, and connected

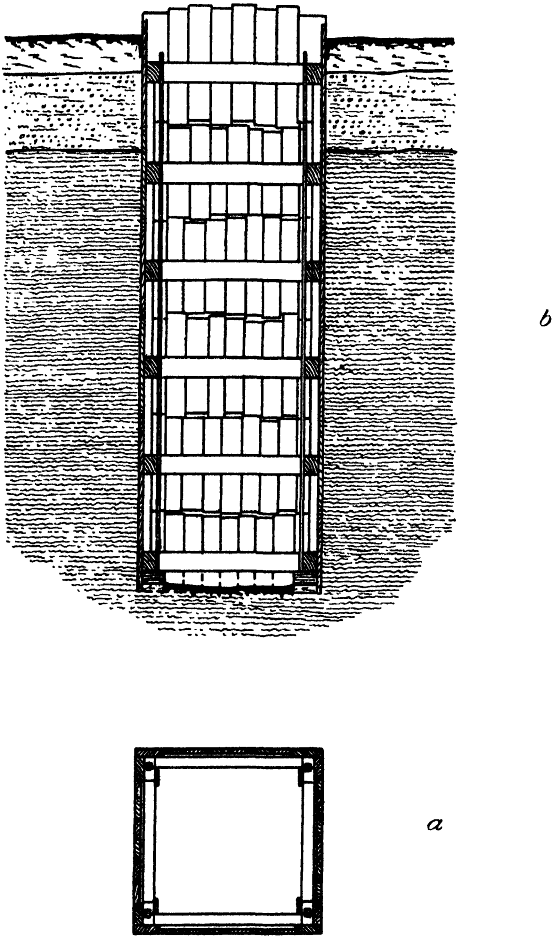


Fig. 176.—Test Pit, with Poling Boards. (*a*) Plan. (*b*) Section.

to them by covering pieces, about 1 in. thick, securely spiked to the walings. The corner poling boards or face pieces are usually made about 1 in. thicker than the ordinary poling boards to give a good bearing to the frames, and to allow for wedging up the poling boards. When poling boards are used extensively in a deep pit or shaft, they are generally carried right down to the bottom without break or intake, as is necessary in the case of runners, but the waling frames are placed closer together to support the thinner and shorter linings. When a pit exceeds 25 to 30 ft. in depth, the centres of the frames are gradually reduced from 4 ft. at the top to about 3 ft. centres, and terminate at about 2½ ft. centres at the bottom, when the depth is about 40 ft. below the surface.

Procedure in Sinking with Poling Boards.—The ground is first opened out to a depth of about 3 ft. and the face boards and first waling frame securely put in place. Poling boards are then driven down behind the walings to a stand a little above ground level, and wedged in place off the walings. In the kind of ground where poling boards are used it is not necessary as a rule to put in the poling boards close together at the commencement of the pit, and every second board or so may be left out. The pit is further excavated to the level of the second waling frame, which is then placed in position and a new set of poling boards driven down behind. If the ground is at all inclined to run, only part of the excavation below the frame is taken out to allow a few boards to be placed at a time. In this way the pit is gradually extended downwards until the desired depth is obtained. In the case of poling boards, they are driven into place from within the pit by a hand mallet, and so do not require the staging necessary in commencing a pit supported by runners.

Removal of Excavated Materials.—The excavated materials may, in the early stage of sinking, be thrown out by hand shovel to the surface, either by single or double handling, until the pit reaches a depth of about 8 ft., when a bucket or hand windlass should be used, as explained in sinking with runners.

Unwatering of Pit.—Bailing will usually keep down the water in a pit supported with poling boards, or a small hand pump. If the water cannot be dealt with by simple means, some other method, such as runners or sheet piles, must be employed to carry on the sinking, when the methods of unwatering before explained are applicable.

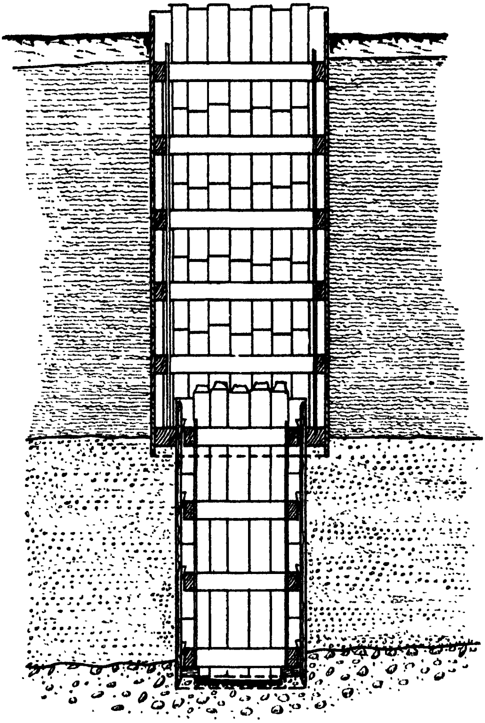


FIG. 177.—Test Pit, with Poling Boards and Runners.

Drawing Timber and Refilling Pit.—The withdrawing of the timbering may be carried out much in the manner explained for pits supported with runners. The excavated materials should be refilled up to the waling frames before they are knocked out and the poling boards withdrawn.

(*c*) PITS WITH RUNNERS AND POLING BOARDS.—The adoption of runners and poling boards for supporting a test pit or shaft is generally the result of variations in the strata, to which either of these methods is particularly adapted. A test pit in loose or bad ground may be commenced with runners, and be terminated with poling boards, or, and what is more usual, a beginning may be made in good ground with poling boards, but the subsequent influx of water or badness of the strata may make it necessary to employ runners at the latter end.

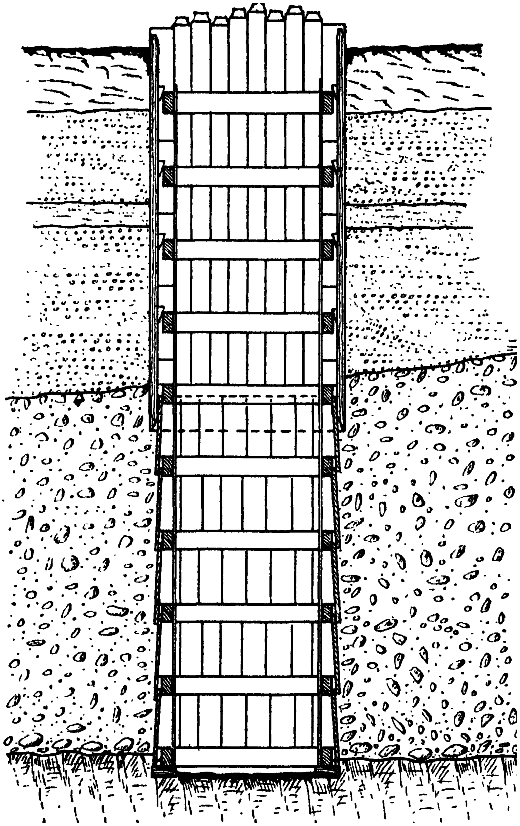


FIG. 178.—Test Pit, with Runners and Inclined Poling Boards.

Methods of Construction.—When a pit is commenced with poling boards in good ground, such as firm clay, which is found eventually to overlie bad ground, runners must be used for the remainder of the sinking, in the manner shown on Fig. 177. In this case, the last frame of walings supporting the poling boards requires to be increased in thickness by 2 to 3 in. to allow of clearance when driving the runners. This arrangement contracts the size of the pit by rather more than the combined thickness of the two walings and runners each way. If it is desired to maintain the width of a pit commenced by runners which reach good ground, inclined poling boards may be used as shown on Fig. 178. In this instance, the runners are brought to a bearing on the timbers of the last frame by inserting four boards or "tucking" pieces, about 6 in. wide and 1 in. thick, between them and the walings. The pit is then excavated to the bottom of the next frame, and poling boards pushed up from below into the groove thus provided for them on the top frame, the bottom ends being secured in position by the second frame and tucking pieces (Fig. 179). In this way the pit is excavated and shored until the bottom is reached, when a cill of 12 by 6 in. timber is laid to carry the weight of the superincumbent timbering. Each

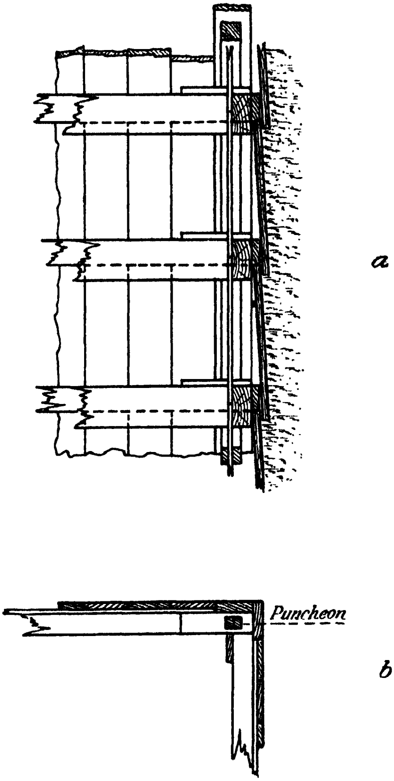


FIG. 179.—Method of Construction with Inclined Poling Boards. (*a*) Vertical Section. (*b*) Plan.

frame is supported at the corners by vertical struts or puncheons, as before described for pits supported by poling boards. A runner pit may have become so contracted by successive settings that it is necessary to finish it with inclined poling boards. Other cases will occur where runners are used alternately with poling boards, or *vice versâ,* as good or bad layers of strata are encountered (Figs. 178 and 190).

The methods of unwatering these pits and withdrawing timbers are much the same as already described.

(2) **Test Pits With Iron Supports**

Steel Sheet Piles.—The introduction and perfecting of interlocking steel piles has placed a valuable means at the disposal of the engineer for constructing deep test pits or shafts in bad ground. The outstanding features of steel piles are their superiority in penetrating soils to great depths, which would damage timber piles, their strength, and watertightness. The continuous interlocking of the piles gives great strength and rigidity to the structure, thus reducing the need for heavy and frequent internal bracings, and offers an effective barrier to the passage of water, so that the leakage to be dealt with is minimised thereby. Owing

Fig. 180.—United States.

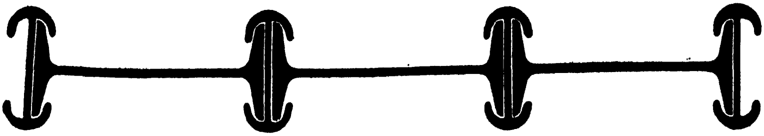


Fig. 181.—Universal Joist.

Fig. 182.—Lackawanna.

Figs. 180—182.—Forms of Steel Sheet Piling.

to the continuous grip which one pile has with another, there is much less risk of the steel piles being forced apart at the points, and thus out of line, as compared with timber runners and sheet piles. In this way bad ground can be negotiated with advantage. For test pits, steel piles can be used over again many times if carefully handled, and this is particularly valuable where the pits are of a standard size.

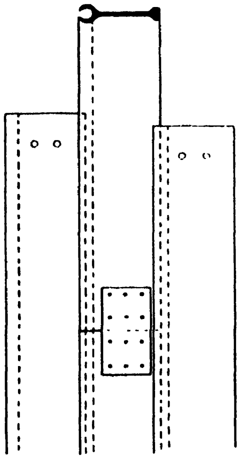


FIG. 183.—Jointing of Steel Sheet Piles.

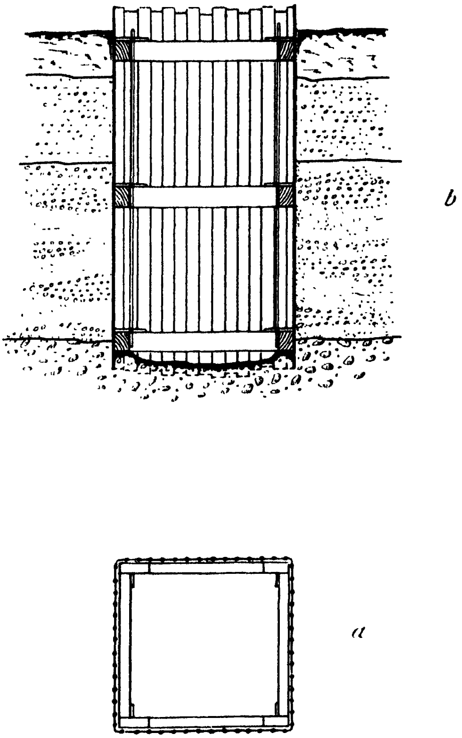


FIG. 184.—Test Pit with One Setting of Steel Piles. (*a*) Plan; (*b*) Section.

Forms of Steel Sheet Piles.—There are many forms of steel sheet piles manufactured, typical forms being shown on Figs. 180 to 182. These sections are rolled from the solid, and do not require building up and riveting together of several parts. They are commonly used in lengths of about 30 ft., but are made up to about 50 ft. long, and if extensions to short or to long piles are required, additional pieces can be connected to those already driven by means of fish-plates bolted or riveted up on the site (Fig. 183).

Test Pits of Steel Piles.—The method of constructing a shallow test pit, about 12 ft. deep, with steel sheet piles is shown on Fig. 184. The piles are 6 in., by 11 lb. per foot, and 14 ft. long. The walings or rangers are 10 in. by 5 in. timbers, placed about 6 ft. centres vertically, and supported by 4 in. by 4 in. puncheons in the usual way. A test pit, about 40 ft. deep, with double setting of steel piles through bad ground, is shown on Fig. 192. In this case the intake must be sufficient to allow of the second setting of piles being driven with a power hammer, and it may be necessary to seal it with concrete to exclude water. A third

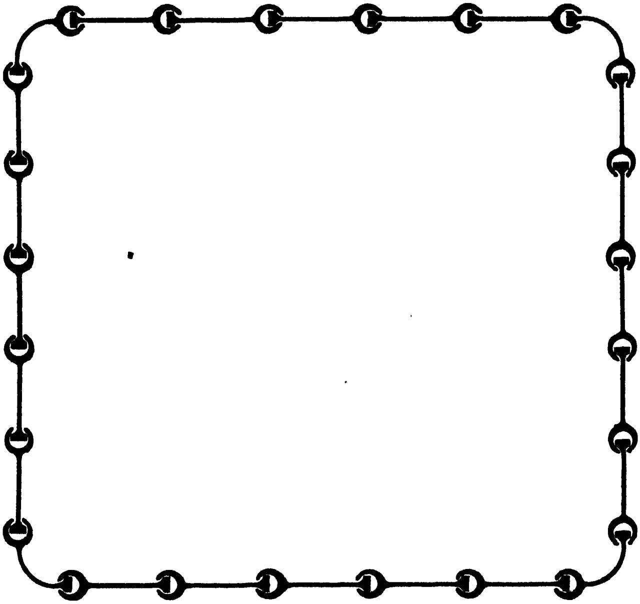


FIG. 185.—Plan of a Test Pit with Steel Sheet Piles.

setting, or more, of piles may be driven in the same way, but owing to the increased size of the pit at commencement necessary to allow of finishing at about 5 ft. square, it is better to use long piles to begin with, in the case of a deep pit or shaft, or join up additional lengths to shorter piles with riveted or bolted fish-plates. When steel piles are extended by fish-plates, long and short piles should be used to commence with so as to break bond at the joints (Fig. 183). The method of constructing the four sides and corners of an interlocked steel pile shaft or pit, is shown on Fig. 185.

In constructing test pits up to about 12 ft. deep, the usual size of steel piles is from 6 to 7 in. wide, and weighing from 11 to 12 lb. per lineal foot. These can be conveniently handled by two men, and are suitable for hand driving. For pits up to about 20 ft. deep, steel piles, about 9 in. wide and weighing 16 to 20 lb. per lineal foot, are suitable, and above this depth piles about 12 in. wide, and weighing from 35 to 45 lb. per lineal foot, are used, according to the nature of the ground. The heavier classes of steel piling generally require to be power driven.

Procedure in Sinking with Steel Piles.—In the case of a shallow test pit, say 12 ft. deep, and constructed with steel piles 6 in. wide, the procedure in sinking is similar to that already described for sinking with timber runners, as in ordinary ground the piles can be driven with a hand mallet or sledge hammer. The ground should be excavated as far as practicable, and the waling frame placed in position as a first guide for the piles. A leading pile should then be driven down firmly to act as a guide for the others, which are then threaded on, and care must be exercised to arrange the piles before driving so as to interlock and close properly at the four corners (Fig. 185). The piles must be driven plumb and in fair line, as otherwise there will be trouble when withdrawing them. In deep test pits or shafts, constructed with double settings or long, continuous piles, it is necessary to use a power hammer to drive the piles (Fig. 193). In commencing a deep pit, one pile is set up and driven rigidly into the ground, perfectly plumb in every direction to form a true guide for the remaining piles. The first of these piles should be driven down a short distance as the others are threaded on, until the whole area of the pit is enclosed by the sheet piling at a practically uniform depth for a start. Driving should then be carried out so as to keep the points of the piles as much as possible together, as in this way there is less chance of individual piles being forced out of line by obstructions owing to the continuous support derived from the interlocking. As the piles are driven down, the interior of the pit is excavated and the internal timber bracing put in. Each frame is wedged off the piles at intervals to secure it in position, but the wedges must be slackened when an individual pile is being driven, and support given by wedging against a driven pile. When a piling hammer is used, the heads of the steel piles should be protected by a special cap or "dolly" to prevent them being damaged, and particularly so if the piles are to be withdrawn and used over again. A cap, suitable for 6-in. piles, is shown on Fig. 186. For light steel piling, a ram weighing about ½ ton is suitable where the piles cannot be driven by a mallet or sledge hammer, the arrangement being similar to that shown on Fig. 187. Heavy steel piling is best driven by a steam, or other power hammer, weighing from 1 to 2 tons, either of the direct-acting or double-acting type, worked from a portable piling frame, or, in the case of the double-acting hammer, by suspending it from a crane or suitable headgear (Fig. 193). When sinking requires to be done by hand, a winch, drop hammer, and portable piling frame may be used to handle and drive the piles, but in such cases it is better to use short piles and join on additional lengths with fish-plates (Fig. 183), both for convenience in handling, and to keep the pile heads above ground throughout the

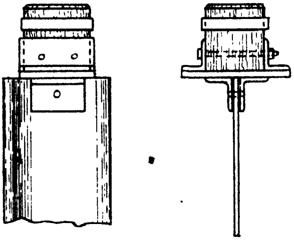


FIG. 186.—Driving Cap for Steel Sheet Piles.

sinking operations. The portable piling frame is pinched along the platform of planks on which it rests by crowbars, round the pit from pile to pile as required, rollers being inserted under the frame when necessary to move it for a few feet. The most difficult materials for steel piles to penetrate are compact ballast, or shingle, and driving should be done with short blows, so as to allow them to slowly search a way through the stratum. Before the piles are placed in position, the locking edges should be well coated with soft soap or waggon grease to facilitate withdrawal.

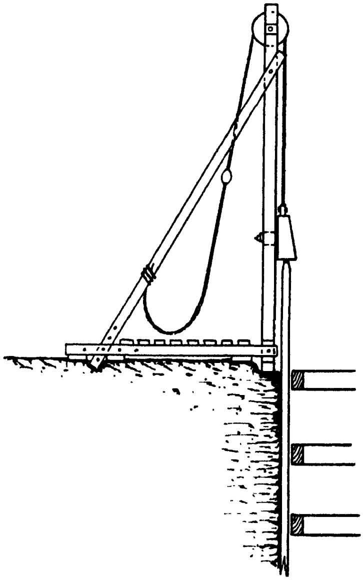


Fig. 187.—Hand Piling Engine for Runners, and Sheet Piles.

Removal of Excavated Materials.—The materials may be removed from shallow pits in the manner described for those constructed with timber runners. In the case of deep pits, however, some form of hoisting power is necessary to deal with the increased lift. This may be provided by using a crane (Fig. 192), or the piling frame and winch, but otherwise a special headgear must be erected.

Unwatering of Pit. — Trial pits constructed of steel sheet piles are, as a rule, fairly watertight, and leakage through the joints tends to be taken up in time by the infiltration of fine materials from the surrounding strata. Shallow pits may, therefore, be dealt with by means of bailing or an ordinary hand pump, and deep pits by a small force pump or a pulsometer.

Drawing Sheet Piles, and Refilling Pit.—Steel sheet piling is comparatively easy to draw, provided that it has been driven straight and plumb. Every care should, therefore, be exercised in driving steel piles which are to be pulled out again. In shallow pits, the piles can be conveniently withdrawn by means of a hand lever, consisting of a log resting on a block fulcrum, placed near the edge of the pit. Steel sheet piles are provided with a hole in the web near the head to which the shackle of the lifting chain at the end of the log lever can be readily connected (Fig. 188). Longer and heavier piles can be drawn in the same way by securing a rope tackle to the long end of the log lever, and attaching the hoisting rope of the piling winch, or crane to the free end or fall of the tackle rope. The piles may also be drawn by means of a suitably arranged tackle worked directly by a winch, or crane; or by a special " pile extractor " ; or by reversing the steam or pneumatic hammer; or hand, or hydraulic jacks may be used. The arrangement with hand jacks is shown on Fig. 189. The jacks are placed one on each side of the pile to be drawn, resting upon the adjacent piles, and supporting a hollow bridging girder, from which is hung an adjustable lifting screw. The screw is connected to the pile head by means of a link and shackle, and then adjusted by the top nut until there is strain upon the pile, when it can be lifted by operating the jacks. Jacks are usually employed to start piling which has become stiff, and on one pile being slackened or withdrawn the others come more or less easily,

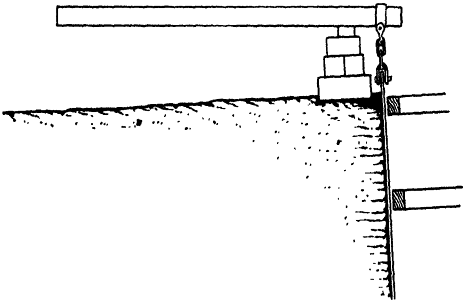


FIG. 188.—Drawing Steel Piles with Log Lever.

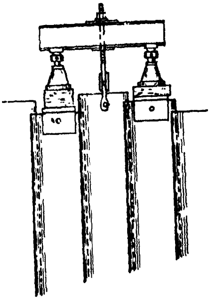


FIG. 189.—Drawing Steel Piles with Screw Jacks.

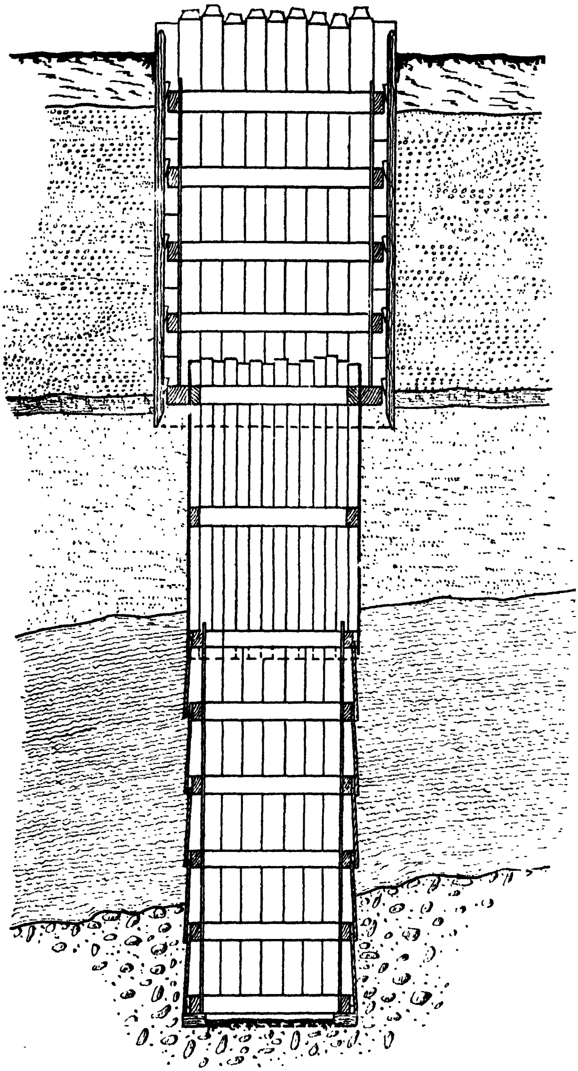


FIG. 190.—Test Pit, with Runners, Steel Piles, and Inclined Poling Boards.

and can then be handled better by tackle or by lever. If the piling has stood undisturbed for a considerable time, the locking joints may become more or less attached to each other, especially in

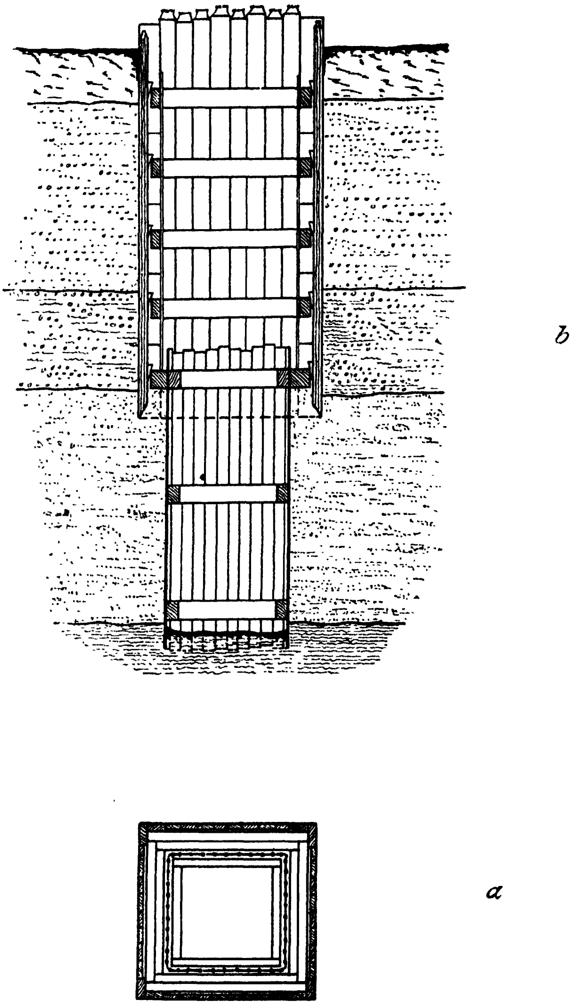


Fig. 191.—Test Pit, with Runners and One Sotting of Steel Piles. (*a*) Plan ; (*b*) Section.

wet ground. In that case it is advisable to go over the piles with the ram and drive them down about ½ in. so as to free the joints.

In refilling the pit, the materials may be lowered in a skip or kibble to the bottom by the hoisting machinery, or shovelled off a high platform over the heads of the piles. The materials thus thrown back should be thoroughly consolidated up to the nearest waling frame before it is slackened and removed.

(3) **Test Pits with Timber and Iron Supports Combined**

Timber and iron supports for test pits may often be combined with advantage where the strata are found to be composed of good and bad beds.

Pits with Timbering and Steel Piles.—Steel piles may be used in a timbered pit to enable sinking to be done through an intermediate piece of bad ground, after which the remainder of the pit can be completed with timber work, as shown on Fig. 190, or a timbered pit may be completed on reaching bad ground by using steel piles in the lower section, as shown on Fig. 191. In many cases a pit, begun and carried through bad ground with steel piles, may be completed by timbering the remainder when good ground has been reached, as shown on Fig. 192. The foregoing methods described for carrying out each particular class of work, are severally applicable to pits which are a combination of them.

Boring from Test Pits.—In cases of doubt as to the depth to which a test pit will have to be finally sunk in order to prove a selected stratum for a foundation, such as rock, a percussive bore hole may be put down from the bottom of the pit as then excavated. The information gained from the boring will form a guide as to the method of sinking which should be adopted in order to reach the required depth with a pit of workable size.

Plant Required for Test Pits.—For timbered pits, the only plant required is a hand windlass (Fig. 172), for removing the excavated materials, and handling the timbers. Wooden mallets or mauls (Fig. 171), serve to drive the runners, or a light hand piling ram (Fig. 187). If a number of test pits are to be opened on a line, but at considerable distances apart, a light steam travelling crane, of about 1½ to 2 tons lifting capacity will prove of great

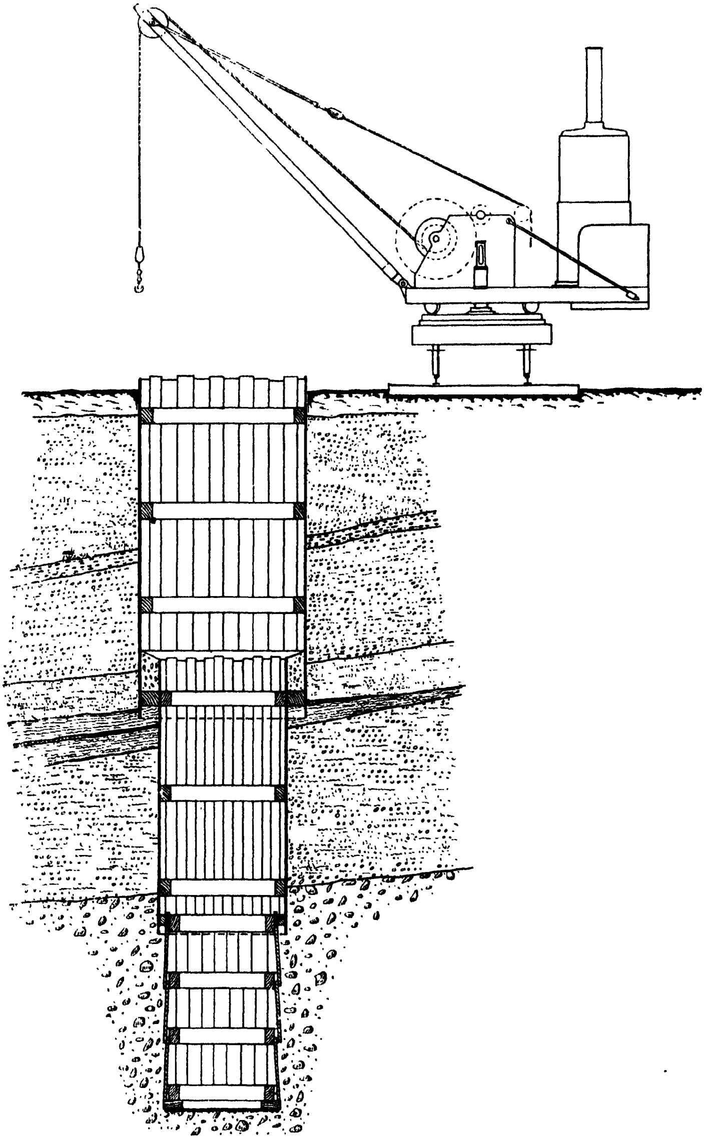


FIG. 192.—Test Pit, with Double Setting of Steel Piles, completed with Inclined Poling Boards.

service (Fig. 192), and for pits in close proximity to each other a steam derrick crane (Fig. 193). In deep pits and shafts, where heavy steel piles are used, a piling engine and portable piling frame are necessary, or a double-acting hammer suspended from a crane or headgear (Fig. 193), and where hand power alone is available in such cases, a winch, portable piling frame, and drop hammer. For removing excavated materials and refilling pits, buckets, kibbles, and skips are required, and for dealing with boulders and obstructions, drills and explosives. Drainage of the pit calls for bailing buckets, and hand or power pumps. To

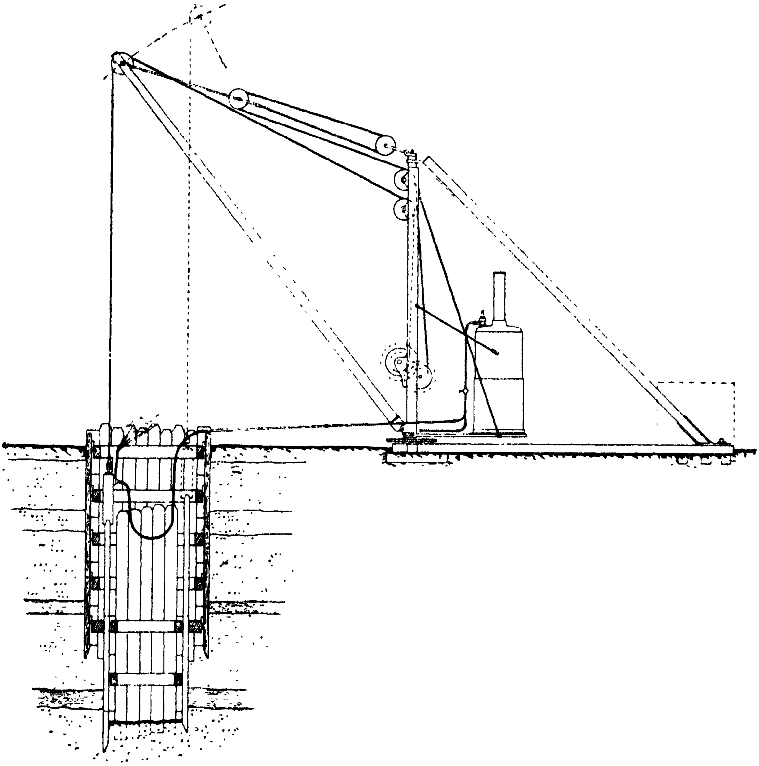


FIG. 193.—Driving Runners with a Double-acting Steam Hammer.

withdraw timbers and piles, levers, tackles, winches, and jacks worked by hand or by power are necessary.

Samples from Test Pits.—Samples from test pits and shafts are selected from the strata as they are opened out, and are best stored in boxes for reference, as shown on Fig. 83. The depths at which samples are taken must be measured, and the various thicknesses of strata passed through recorded. Any visible inclination of a stratum should be carefully measured at the four sides of the pit, so as to give some indication of its true dip. The depth at which water normally stands must be noted, together with the quantity of water dealt with per hour.

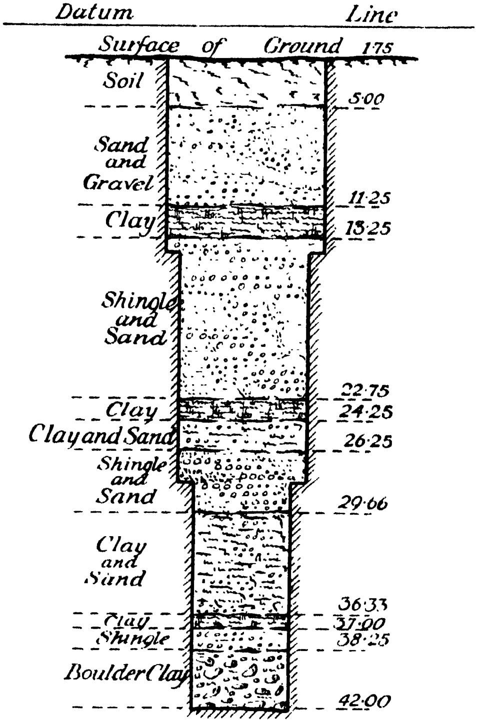


Fig. 194.—Section of Strata from Test Pit.

Plotting Results of Trial Pits.—In plotting the various strata passed through in a test pit, it is best to draw the vertical section of the pit to scale, so as to include the area actually examined. In pits where the strata show marked inclinations, two sections should be made to show the dip. An example of plotting results of a test pit is given on Fig. 194.

Test Borings and Trial Pits: Applications

General Considerations.—No general rule can be given as to the numbers and positions of test borings and trial pits which should be put down when examining in detail a route or site of works, but it may be stated generally that works of an important and costly nature, and at considerable depths below the surface, require more numerous borings and pits, placed in well considered positions, than works of a more superficial and inexpensive kind. For instance, in the case of an ordinary shallow sewer it would be obviously out of proportion to the cost and importance of the undertaking to overload it with a series of numerous borings and pits, whereas a large, storage reservoir dam, or the piers of an important bridge, require the utmost care to be exercised in proving the foundation strata. In the first case, probably a boring or shallow pit here and there would be sufficient, whereas, in the latter, numerous deep and carefully placed borings and pits are necessary.

It is possible to give here only a few examples of the usual lay-out of test borings and pits as applied to constructional works.

Water and Sewerage Works.—In the case of large water and sewerage works, borings should be put down at every point where constructional work of any importance is to be carried out, such as tunnels, aqueducts, junction chambers, overflows, valve chambers, outfalls, syphons, reservoirs, filter beds, and such like. Also where the pipe or sewer line passes in cutting near existing works which will require to be underset or supported from below in any way. In the open country, borings may be put down on the centre line of the work at anything from 300 ft. to ½ mile apart. The discovery of rock or hard deposits at any particular point above the intended level of the pipes or sewers, will necessitate closer spacing of the borings to locate its exact limits and character, and the same applies to any waterlogged or specially soft strata. In general, the original intentions as regards the positions and numbers of borings must be departed from where any boring indicates that it is desirable to investigate a particular area more closely.

Railways.—Over lines of railway, borings require to be put down on the sites of tunnels, viaducts, bridges, culverts, retaining walls, covered ways, and other important constructional works. In addition, the strata also require to be proved where high embankments occur in order to form some idea of their bearing powers. Important viaducts and bridges require particular attention, special borings and test pits being put down on the sites of the piers and abutments. In addition to borings and test pits, important tunnels may require one or more deep shafts to be sunk to formation level, which can be utilised afterwards for constructional, or ventilation purposes. Where the railway passes near to existing works requiring underpinning or support, borings should be put down to prove the ground, and where buildings are in the vicinity of cuttings, and stand on slippery strata, extra borings are necessary. In the open country, prospective cuttings and embankments should be tested by borings, especially on side sloping ground, and if rock is encountered on the one hand, or treacherous ground on the other, such areas require closer investigation by a greater number of borings and probably a few test pits. Where the line follows a generally level surface, occasional borings only are required, but special attention must be given to marshy and sodden ground.

Impounding Dams.—Dams for impounding water are usually thrown across a valley, and the highest importance is attached to the soundness and tightness of the foundations. In the case of important dams, borings and test pits are largely used together, as giving the best indication of the nature of the strata, including dip, strike, faults, and other geological information affecting the stability and watertightness of the foundations. The pits or shafts are usually sunk on the centre line of the tongue trench at distances of 100 to 300 ft. apart, and supplemented by intermediate borings. When the base of the dam is broad, as in the case of earth dams, borings are usually made on each side of the centre line of the tongue trench to prove the ground over the area occupied by the base of the dam.

Docks, and Quays.—In the case of docks and quays, borings are usually made on the lines of the dock or quay walls at distances of from 100 to 300 ft. apart, but over the sites occupied by gateways, or entrances they are arranged much closer, as it is there that the most costly, as well as the most important, part of the work lies. Where the foundations of quay walls of considerable length have to reach great depths, valuable information can be got by sinking exploratory shafts here and there in the form of built iron or concrete wells, and subsequently incorporating them into the general work of construction. When the proposed foundations are largely of piles, it is good practice to drive a few test piles, from 100 to 200 ft. apart, or where desirable, and to supplement them with borings. Exploratory shafts and test piles are a valuable means of proving the ground, and should be used, when applicable, in all important dock work schemes where the ground is doubtful, as from the experience and information thus gained the terms of a contract can be made more definite, and the difficulties of the foundation work largely anticipated.

Piers, Breakwaters, and Sea Barriers.—In the case of most piers and breakwaters, it is not possible to make borings except from fixed stagings, or from floating plant. The borings are made on the centre line of the proposed work at a distance usually of from 100 to 300 ft. apart. If the pier or breakwater is of considerable width, and is intended to be carried down to some good bearing stratum, such as solid rock, the borings should be arranged in two, or three lines parallel to the centre line of the pier, so as to cover the extreme limits of the foundations of the structure and thoroughly prove the bottom on which it rests, with a view to safeguarding against scour. As test borings for sea works can only be made in most cases when the state of the sea and weather are suitable, they may occupy several seasons in the case of a long pier or breakwater.

CHAPTER VIII

TESTING GROUND FOR BEARING AND COMPRESSION

General Considerations.—Tests of the bearing capacity and compressibility of soils form an essential part of a thorough examination of ground intended to carry important foundations. Owing to the fact that all soils are compressible, it is not enough merely to ascertain their bearing powers, but also the extent to which settlements will take place under definite loads imposed upon them for a considerable time. A foundation subsoil may safely carry a given load in so far as merely sustaining it is concerned, but the settlements due to compression might be so great or so unequal as to cause serious damage to the permanent structure. The safe loading of soils for settlement is a matter of experience and experiment, and the practical object, therefore, in making tests of bearing and compression is to discover to what extent settlements under known loads will take place, and thus obtain reliable data from which the design and proportions of the foundations can be fixed, so as to avoid undue or unequal settlement or subsidence of the superimposed structure.

Classification of Tests.—The nature of foundations generally is such that they are constructed either in ground which is opened out for the purpose and made directly accessible thereby, as in open excavations and trenches, or in closed ground which is reached indirectly through some special means, such as piles, deep shafts, or caissons. The tests of bearing and compression may, therefore, be classified as :—

(1) Direct tests.
(2) Indirect tests.

(1) Direct Tests

General Methods of Testing.—The manner of applying a test load to the ground for bearing and compression will depend largely on circumstances, as facilities for carrying out tests by a particular method in some cases may be absent in others. Where ground is open and unconfined, and the stratum to be tested lies near the surface, direct loading of a base or slab of suitable area for the conditions is usually adopted. In deep foundations, however, loading in this way soon becomes unwieldy and often impossible, particularly when the bearing capacity of the soil is high, and a smaller base becomes necessary in order to reduce the dimensions and total weight of the test load. The size of base generally adopted in experimental tests with a small area is 12 in. square, or 13·55 in. diameter, giving an area of 1 square foot, the standard unit worked to in practice. Bearing and compression tests made on a large area are to be preferred generally to those made on a small one, and, indeed, full size tests of foundation soils are the nearest approach to the actual conditions obtaining in each particular case, were it always possible to carry them out on such a scale. There seems to be no doubt, however, that carefully conducted tests made on an area of 1 square ft. give reliable practical results, and can usually be pushed far enough, without inconvenience, to ascertain the breaking down point of the bearing resistance of a soil. They have also the merit of not overstating the values of bearing and compression, and thus cover many unknown factors which enter into this difficult question. Whatever method of testing is used, the bearing slab or base must be placed directly on the soil to be tested.

Large Area Tests.—When ground is opened out, as in shallow foundations, tests of bearing and compression can be made in a simple way by placing a stiff slab of some practically undeformable material, such as cast iron or concrete, directly upon the stratum to be tested, and loading it gradually. The dimensions of the slab will depend upon the bearing capacity of the soil, and should be sufficient to permit of a load equal to about twice the assumed safe bearing load being placed upon it. For practical purposes, the slab should not be less than 4 ft. square, so that it can be loaded properly. The materials comprising the test load should be built up regularly and symmetrically upon the base to ensure uniform distribution of load, and they should not project

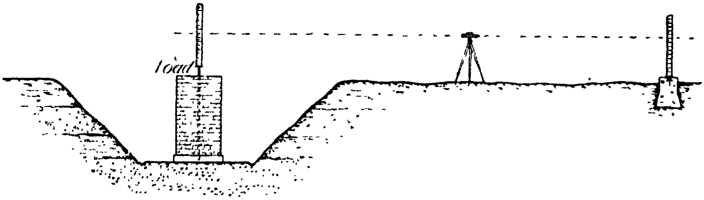


FIG. 195.—Open Ground, Load Test.

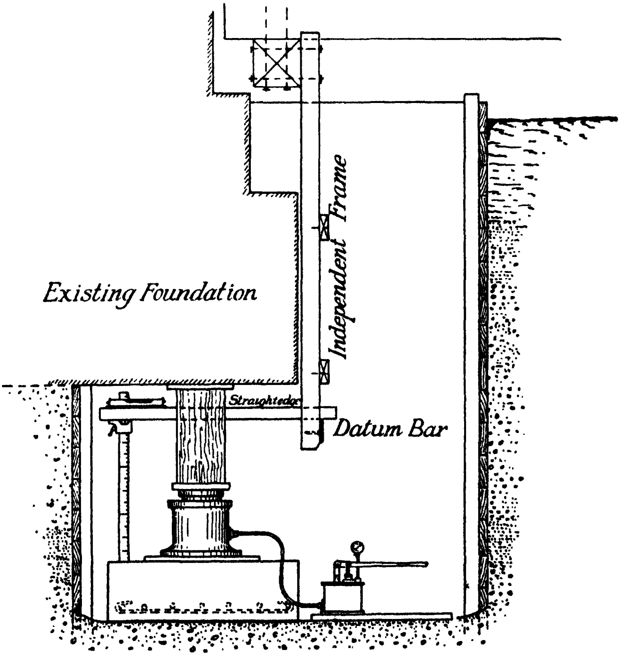


FIG. 196.—Load Test, with Hydraulic Jack.

over any of the edges of the slab. For the purpose of reading the settlements, a stiff iron rod, or a tube, should be firmly sunk in the centre of the base, so as to be always visible, and of sufficient length to reach above the highest point of the load when necessary (Fig. 195). Before placing the base in position, the site should be cleared and made quite level, and provision made for the exclusion of, or quick draining away of surface water. Deeper foundation soils may be loaded by sinking a small shaft or trench to the level of the stratum under test, and placing a strong block of concrete, reinforced with steel if necessary, on the bottom, upon which the load may be built up. On confined sites this arrangement is not possible, and where a suitable reaction can be obtained the load may be imposed upon the slab by means of a hydraulic jack, a method which is frequently used in the underpinning work of heavy buildings (Fig. 196). In such cases the reading of the pressure gauge in pounds per square inch, multiplied by the area of the ram, gives the total amount of the

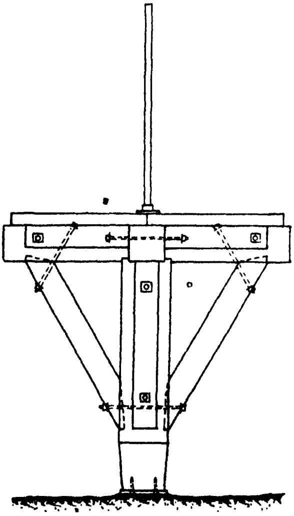


FIG. 197.—Load Platform, Elevation.

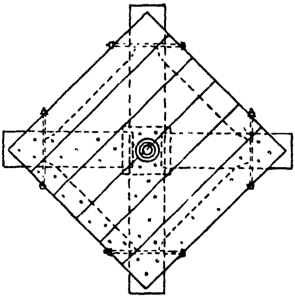


FIG. 198.—Load Platform, Plan.

load on the slab at any time, less a deduction of 10 per cent. for friction of the apparatus. The power of the jack must be sufficient to impose the maximum load per square foot for which the test is to be made.

Standard Area Tests.—Where the foregoing methods of testing cannot be applied, on account of the large amount of test load required, or of the difficulties in handling it, the bearing area of the load base is usually, but not always, restricted to 1 square foot, and a specially arranged load platform constructed. A convenient design is that shown on Figs. 197 and 198, which consists of a timber centre post, about 12½ in. square, on which is formed a horizontal platform about 4 ft. square, supported on four cross beams about 10 in. square, stiffened by inclined struts about 5 in. square. The cross beams are packed up level and flush, and laid with 4-in. planks to form the platform on which the test load is placed. A stiff, steel base plate, 1 in. thick and exactly 1 ft. square, is screwed to the bottom of the centre post, which latter is then tapered off so as not to project over the plate

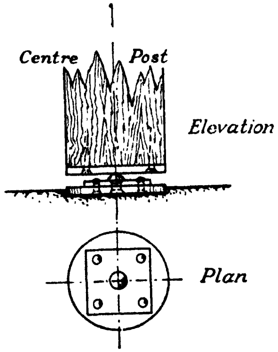


FIG. 199.—Bearing Plate with Pivot.

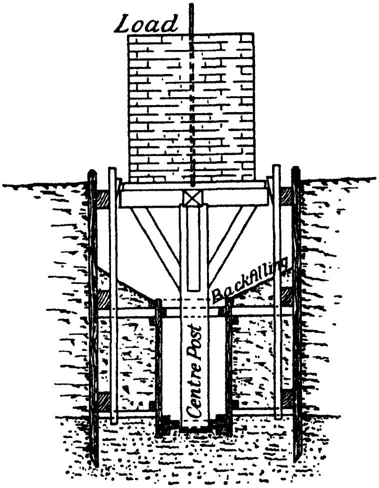


FIG. 200.—Load Test, with Back-filled Inner Casing.

in any direction. Another form of bearing plate and centre post for a similar load platform is shown on Fig. 199, in which the post bears upon a detached plate through a cup-headed pin, the intention being to maintain a central pressure on the plate in the event of the load platform canting slightly. The bearing plate is circular, 1 in. thick and 13·55 in. diameter, to give an area of 1 square foot, and has a stiffening plate on top. The centre post may be round, or square shaped, and is fitted with a plate, 1 in. thick, screwed on to the end. A rigid iron rod, or a tube, is securely fixed in a vertical position to the centre of the platform for the purpose of taking settlement readings by level, and long enough to be always visible above the load if required. When loose materials are used for the test load, such as stones, a rough box or crib, secured to the platform framing, is necessary to retain them. If the ground under test is inclined to rise or " arch," as in some clays, the centre post may be confined by an inner

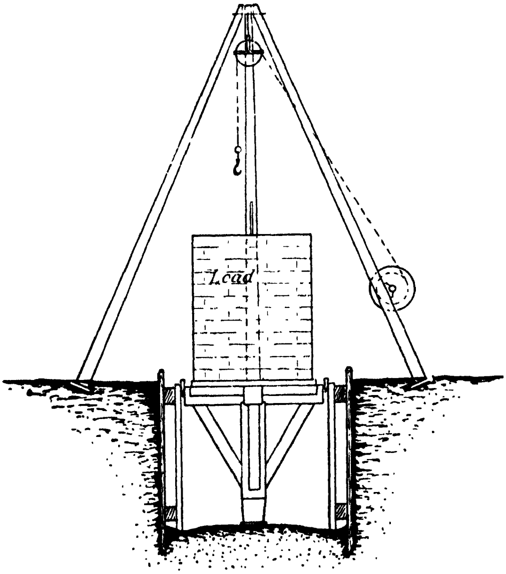


FIG. 201.—Shallow Foundation, Load Test.

casing, back-filled with earth, consolidated to the degree of the natural soil, round the space between it and the sides of the pit (Fig. 200). When the bearing plate is circular (Fig. 199), the inner casing may be a vitrified fireclay pipe, or a metal, or a timber tube. In applying a test by this method to shallow foundations, a timbered pit, about 8 ft. square, is sunk to the required depth, and the load platform is steadied and kept in a vertical position within it by upright runners secured to the walings, sufficient clearance being left at the sides to insert greased wedges loosely between them and the cross beams of the platform (Fig. 201). In deeper foundations a timbered, or timber and iron lined pit is sunk to the level of the stratum to be tested, and the load platform supported in a similar way (Fig. 202). The load platform is carefully adjusted so as to be truly horizontal and vertical before any load is applied.

Materials for Test Loads.—The usual materials for test loads are bags of sand, squared stones, bricks, bars of pig iron, steel billets, and railway rails. In the case of bricks and stones, they may be bedded with dry sand to keep them uniform and level, while pig iron bars, steel billets, and rails may be levelled with strips of timber, which will also allow of their being conveniently slung and handled. All materials forming the test loads should be built up carefully and symmetrically, so as to ensure a uniform distribution of load. A light tripod and hand winch are very useful for loading and unloading the materials (Fig. 201). It is essential for the accuracy of the tests that the load platform itself and all of the materials composing the load should be correctly weighed before being placed in position, so that the exact weight carried by the ground is known at any stage of testing.

Test Loads.—In making a test, the safe load which the soil is intended to carry per unit of area is usually applied at once to the base, by building it up steadily, and, after a period of rest, is gradually increased by increments to about twice that amount, with periods of rest between. It is important in all tests of this kind that an interval of time should elapse after the assumed safe bearing load has been applied, and between successive loadings thereafter, as the largest settlements frequently take place during the period over which the test load is left undisturbed, time being required for the soil to readjust itself to a state of stable equilibrium when heavily loaded. The usual periods of rest for partial loads are from two to three days, and the final load is generally left undisturbed for four to eight days, or even longer should that be necessary for the soil to recover its equilibrium and the settlement to cease. If settlement is still going on at the end of an intermediate two to three days' period, no further load should be added until it has practically ceased, as it may happen that the soil is then approaching the yield point, or its equivalent. During the test, the settlements are measured at stated intervals of six, twelve, or twenty-four hours, but readings at other time intervals may be taken when necessary, and always when each stage of the loading has been completed. When the load base has been placed in position, it should be carefully levelled immediately before any load is applied to it.

Measurement of Settlements.—Settlements of the test loads are measured, whenever possible, by accurate levelling with a tripod level. The levels should be referred to a substantial datum peg, or bench mark cut in the solid, placed conveniently near at hand, but not so close as to be affected by the testing operations, and the level itself set up in a position equidistant from the bench mark and the test load (Fig. 195). The readings should be taken upon the iron rod in the centre of the load platform (Fig. 197), and be made at one sight for each set of records without shifting the instrument. An accurate method of taking the readings is by marking the various intersections of the cross hairs of the level upon a light, smooth-dressed lathe with a sharp pencil or knife when it is held respectively upon the bench mark and the iron rod on the load platform, the reading on the iron rod, with reference to the bench mark, made just before loading is begun, being taken as the datum from which to plot the settlements. The actual differences in level can then be scaled off with a decimal scale, and the lathe kept for reference if necessary. In deep foundations it is usually more accurate, as well as more convenient, to measure the settlements by direct means. This may be done by securing one end of a steel band to the load platform by a small eye-bolt and shackle, and passing the other over a small frictionless, supporting drum or pulley at the top of the pit (Fig. 202). The free end of the band is loaded with a small weight securely clamped to it, so as to give a constant tension in the band, and a fine steel or brass pointer is fixed by screws to the

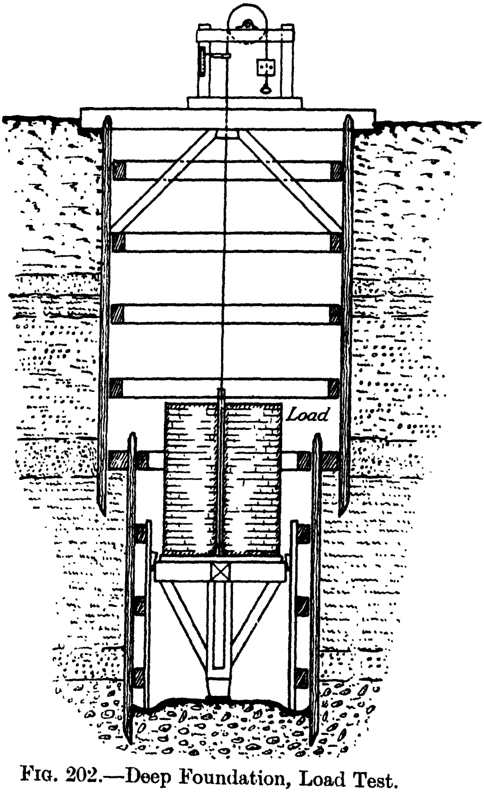


FIG. 202.—Deep Foundation, Load Test.

SOIL TEST

Particulars of Test.	Date.	Time.		Total Load,			Settlement. In.	Time Settlement. In.	Total Settlement. In.	Remarks.
		H.	M.	T.	C.	Q.				
Hard, dry clay, 10 ft. below surface, thick bed. Exposed in pit.	June 10th,	10 a.m.		3	0	2	0·22	—	—	Loading completed. Weight of platform included in total load.
	June 11th,	,,			,,		0·30	0·08	0·30	
	June 12th,	,,			,,		0·30	0·00	—	No settlement.
Bearing plate 12 in. by 12 in. Inner casing back-filled, and lightly rammed.	June 12th,	11	15 a.m.	5	6	1	0·54	—	—	Loading completed.
	June 13th,	,,			,,		0·58	0·04	0·60	
	June 14th,	,,			,,		0·60	0·02	—	Slight settlement.

. . . . etc.

band on the attached side at a convenient height. Against the pointer is a metal decimal scale, rigidly screwed to an independent upright, upon which the variations in level arising from settlements can be read off in accordance with the movement of the pointer (Fig. 203).

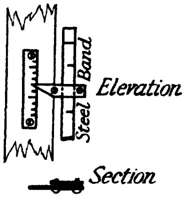


Fig. 203.—Pointer and Scale.

Record of Settlements.—The record of settlements may be kept in the manner shown on p. 216.

Plotting of Settlements.—Settlements are usually plotted from the field book in graph form to exaggerated scales, which enables the results of a test for bearing and compression to be followed easily. The relationship between load, settlement, and time is shown on Fig. 204, for a test on a thick bed of hard, dry clay, of which the above are a few particulars. The settlements of the test loads during their respective periods of rest are shown on Fig. 205. The relationship of load to settlement is shown on Fig. 206, and can be plotted from the two preceding figures, the horizontal parts of the curve being the time settlements over the periods of rest given in Fig. 205. The yield point of the soil, or

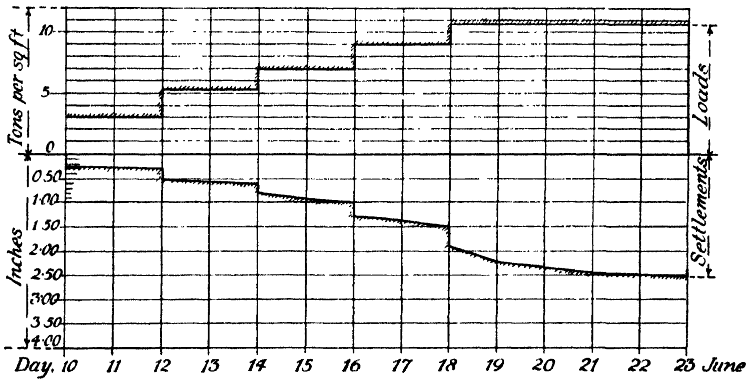


Fig. 204.—Load, Settlement, and Time Test.

its equivalent, may be taken in this case as being in the vicinity of 7 tons per square foot, as the settlement is in proportion to the load up to this point, and increases disproportionately thereafter. It is usual in practice not to exceed a safe bearing load per square foot of from one-half to two-thirds the yield point load, provided the settlement is reasonable at these amounts with respect to the character of the permanent load or structure.

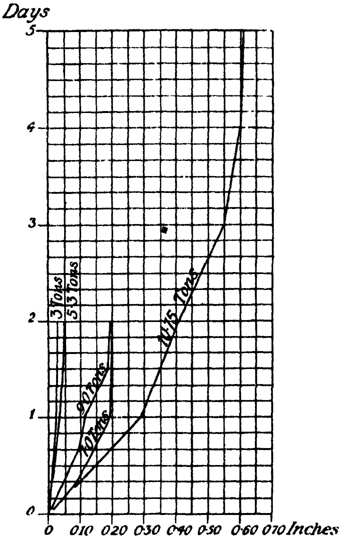


FIG. 205.—Time Settlements, in Periods of Rest.

Assuming the yield point of the soil in this instance to be 7 tons per square foot, the safe load may be taken at one-half that amount, or 3½ tons per square foot, the corresponding settlement being about ⅜ in. In practice, the safe bearing load on hard, dry clay is usually taken at 3 to 3½ tons per square foot, and the test appears to justify these figures in so far as bearing capacity is concerned, with the addition of showing that the settlement in this particular case would be reasonable within these limits.

Effects of Weather.—Tests of open ground should be protected from the undue effects of weather, as temperature, frost, and wet may change the condition of the exposed ground, and the results become misleading. Arrangements should be made, if necessary, to cover in the site and apparatus, and the means of clearing the site quickly of surface water, either by natural falls or pumping, should always be provided. If it is thought that undue atmospheric conditions are affecting the ground under test, loading should be stopped until the normal conditions are restored.

When, however, the soil is such that it is liable to become much changed in character under varying atmospheric conditions, it should be left naturally exposed for a sufficiently long period to permit of the development and study of any inherent tendencies in this respect, and with the maximum test load imposed upon it during that time. A test of this kind may show that a soil, which had good bearing and compression values for foundation purposes when newly opened out, steadily deteriorates in these respects when subject to the influences of weather, and may be expected to give a large settlement continuously for a long time under the maximum test load in such cases.

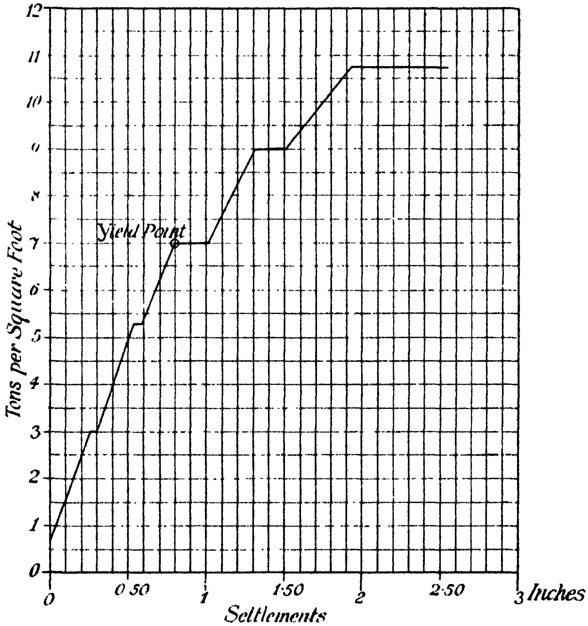


FIG. 206.—Ratio of Load to Settlement.

(2) Indirect Tests

General Considerations.—Tests of closed in or covered ground for bearing and compression belong more or less to foundations of the deep type, where a suitable stratum for founding upon is reached by piercing the ground from above. Preliminary information as to the depth at which such a stratum lies may be obtained from test borings, and arrangements made accordingly for the bearing and compression tests.

The most usual means of piercing ground closed in are :—

(*a*) Test piles.
(*b*) Exploratory tubes.
(*c*) Exploratory cylinders and caissons.

(*a*) TEST PILES

Test Piles.—Information as to the bearing capacity of the ground can be got from the behaviour of piles during driving, and as to both bearing and compression by actually subjecting the piles to a direct test load after being driven. There are many formulæ for obtaining the theoretical bearing capacities of piles from their final penetration, under a known weight and fall of hammer. These formulæ, however, take no account either of the actual nature and depth of the ground penetrated, or of the increase in bearing capacity which usually succeeds a period of rest following upon driving, and it is, therefore, more reliable and satisfactory generally to carry out static tests in order to arrive at the actual bearing capacities of piles, than to trust to any formula.

Tests for piles may therefore be divided into :—

(1) Driving tests.
(2) Loading tests.

(1) *Driving Tests*

Conditions of Testing.—Test piles should be driven whenever possible under the same general conditions as will obtain in the permanent foundation work, as otherwise the results may be to some extent misleading. If it is intended to excavate the ground to some depth below the surface for the permanent foundations, and drive piles from the bottom of the cutting, the conditions of the test pile should be made identical. This may be done by opening out a short slope-sided trench (Fig. 207), or by sinking a timbered pit to the same depth as the permanent work (Fig. 208). When it is intended to drive permanent piles in groups, the test piles should be a similar group if possible, or a part group of not less than four piles (Figs. 221, and 222), pitched at not less than 3 ft. centres, as pile clusters usually give different results as compared with single piles. In general, the piles under test should be of the same materials, forms, and dimensions, and be driven in the same manner as is the intention regarding the permanent work.

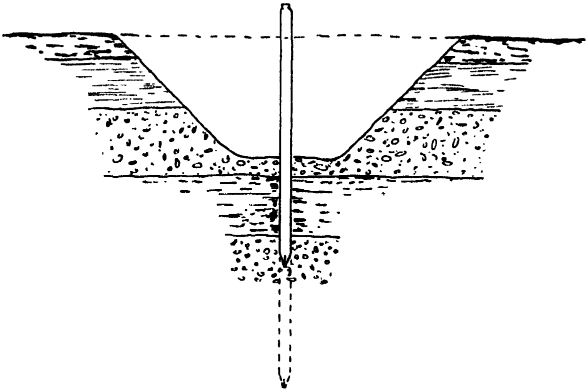


Fig. 207.—Test Pile Driven in Open Trench.

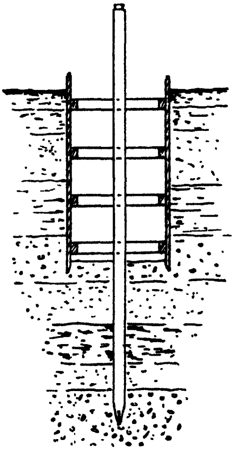


Fig. 208.—Test Pile Driven in Timbered Pit.

Driving Appliances.—The appliances required for driving test piles may consist of a hand, or power hammer, piling frame or headgear, and hand, or power winch. In cases where test piles have to be driven in a considerable depth of water, it may be necessary to erect a temporary staging to carry the piling plant, or to use a barge for that purpose if more convenient. The only form of piling hammer which will give reliable results in driving test piles of large section to a hard bearing, is that of the drop type, having a free fall, or stroke in the case of a single, direct-acting power hammer. Standard sizes of piling hammers are made with falling weights of from 10 to 15 and 20 cwts. for the lighter classes of piling, and from 20 to 60 cwts. for the heavier kinds, the intermediate sizes advancing by 10 cwts. each in weight. For specially large reinforced concrete piles, however, hammers ranging from 70 to 80 cwts. have been used. In practice, the weight of the hammer for any particular piling work is selected from the standard sizes as nearly as possible equal to the weight of the pile, preference being given to a rather heavier than to a lighter hammer when the pile weight falls between the two nearest standard sizes. The drop, or stroke as the case may be, varies from 3 to 6 ft., but a drop of about 4 ft. is good practice. The general tendency in practical work is to reduce the drop for the heavier classes of hammer. In driving through different kinds of strata, however, the drop may be regulated to suit the conditions, resistant materials being given a shorter drop than loose or free materials for successful penetration.

Procedure in Driving.—In driving test piles, the piling frame should be set up perfectly straight and plumb, and be rigidly secured upon stiff supports to prevent movement, as it is important that a test pile should be properly guided and kept in definite position from beginning to end of driving. When the pile has been pitched and secured in place, driving should be commenced gently until it has fairly entered the ground, after which the full energy of the hammer may be used. When penetration observations are being taken, it is desirable to keep the drop of the hammer uniform over the periods in which they are made, say of twenty blows, any alteration, if required, being made at the beginning of a fresh period. During driving, the pile must be carefully watched as to its condition for soundness. Timber pile heads are usually protected by an iron driving hoop or ring, but, despite this precaution, the timber often shows signs of splitting, in which case the damaged part should be cut off, and the pile head re-ringed. Timber piles which show signs of splitting in the body should not be driven further, but be replaced with a new pile. The use of a " dolly " or " punching piece," to drive down a test timber pile should be avoided. Should it be found, in course of driving, that the test pile is too short to reach a satisfactory bearing, it should be lengthened by splicing on a piece. A good typical splice for a 13 in. square pile is shown on Fig. 209, and may be applied proportionately to other sizes of piles. If the permanent foundation piles are driven in the final stages with a dolly, allowance must be made for the loss of energy thereby, and harder driving is required, as compared with the solid test pile. Reinforced concrete piles are nearly always driven with a dolly or helmet to protect the head. A large amount of the driving energy of the hammer is absorbed if they are of unsatisfactory design, and long, solid, timber dollys, or soft-packed helmets are the worst in this respect. A short helmet or cushion of English oak, about 12 in. long, and of the same dimensions as the pile head, secured by an iron band 8 in. deep by 1½ in. thick, shrunk on to the timber, is most efficient, or a dolly similar in principle. Reinforced concrete piles should not be "dollied" down on account of shortness, but may be lengthened by stripping the top end for about 4 ft. and joining on a new length equal in all respects to the original head. A lengthened

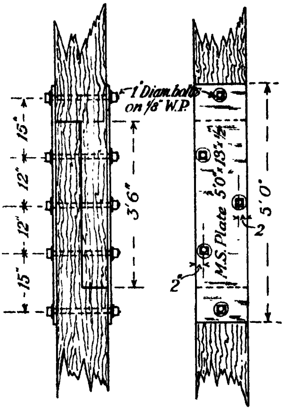


FIG. 209.—Splice for Timber Piles.

reinforced concrete pile must be allowed to harden properly before driving is resumed, and it is convenient, therefore, to use a reliable quick-hardening cement for this purpose, and minimise the delay thus caused to periods of from seven to ten days. The last series of penetration blows, for arriving at the final set of a reinforced concrete pile, should be delivered upon the unprotected head, without helmet or cushion.

Set of Test Piles.—As the result of experience, certain general deductions have been made as to the safe bearing capacity of piles with regard to the amount of penetration found in the final stages of driving, under the more or less standardised weights and falls of hammers. The total amount by which a pile penetrates the ground during the last ten or twenty blows of the hammer is termed the "final set," which is generally expressed as inches of penetration for ten or twenty blows, or as blows per foot of penetration, if the final set is taken over the last foot of penetration. In the case of timber piles from 12 to 14 in. square, driven with a standard hammer and fall, through average loose ground to a hard bearing upon a firm stratum at, say, 30 to 40 ft. below the surface, and with a final set of 1 in. for the last ten blows, delivered without the intervention of a dolly, the safe loads may be taken at 20 tons on the smallest up to 30 tons on the greatest size, without undue settlements. Concrete piles similarly driven, and through like strata, will carry estimated safe loads of 35 tons for 12 in. square up to 65 tons for 16 in. square piles, with final sets of 1 in. and ½ in. respectively for the last ten blows, delivered upon the unprotected pile head, without undue settlements. The bearing capacities of piles which depend for their resistance upon skin friction and end bearing, are much more difficult to summarise, owing to the widely different variations and physical properties of the soft strata in such cases. It has been found in practice that piles of this kind, 30 to 40 ft. long, driven in average soft ground, will carry safely loads of about 15 to 20 tons for 12 in. square and 14 in. square piles respectively, driven with standard hammers and falls, with a penetration of about ½ in.

per blow for each of the last ten blows, without undue settlements. Under test load, piles of this class would probably develop, after a period of rest, much higher bearing capacities, and it is obvious that any uncertainty as to this can only be satisfactorily disposed of by applying a static test load. The foregoing practical figures, however, may be used as a preliminary guide when fixing the dimensions of the test piles, hardness of driving, and the probable amount of the test load to be provided for in the first instance. The safe load on any pile, considered as a column, according to its physical conditions, should not exceed the safe compressive stress of the material used, a restriction which requires to be kept in mind when fixing safe bearing loads and applying test loads.

Obstructions in Driving Test Piles.—When a test pile meets with a hard obstruction, such as a large boulder, it will generally be indicated by a heavy rebound or " bounce " of the hammer. Should the obstruction be sunken timber, the pile will rebound and the hammer also. A fair and persistent attempt should always be made to penetrate or displace an obstruction, but when it becomes evident that the pile is receiving damage a fresh test pile should be put down nearby. The successful driving of a second test pile in the immediate vicinity will prove the obstruction met with in the first instance to be local. On the other hand, repeated failure to drive several out of other succeeding test piles is an indication of boulders, or some such obstruction in the ground. If borings have not already been made on the site, several should now be put down to disclose as far as possible the nature of the strata. The data obtained from the test pile driving and borings may then be sufficient to enable a decision to be made as to the proper design of a piled foundation to meet the conditions, or the adoption of some other type of foundation. When the results of driving test piles show that a proportion of boulders only exists in the strata, and that a piled foundation is generally suitable, one test pile at least should be carried past the obstructions. This may be done by putting down a lined percussive bore hole, and breaking up the obstructions by explosives, as explained in Chapter VI. The test pile should then be driven on the site of the boring as soon as the latter is completed, and a careful record made of its behaviour in penetrating the displaced strata. Such information is valuable in preparing a specification for piled foundation work where boulders or other obstructions have been proved to exist, and the data obtained in driving the test piles in such cases form a good guide for the execution of the permanent pile work.

Overdriven Test Piles.—In seeking to drive a test pile to a hard bearing, it is quite possible to overdrive it and thus obtain misleading results. In the case of timber piles, overdriving usually causes " brooming," or bursting of the pile, which most frequently takes place at the foot, often forcing the shoe into the heart of the timber, as shown on Fig. 210. A fruitful cause of damage is persistent driving on or amongst boulders, or into compact shingle (Figs. 210, and 211). A concrete pile, when overdriven in a highly resistant strata, tends to crack and scale, and the foot may be severely damaged, thus reducing its bearing capacity,


FIG. 210.—" Broomed " Timber Pile.

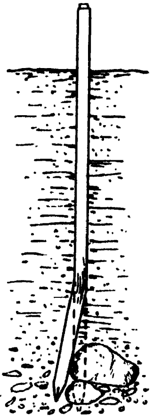


FIG. 211.—Timber Pile Damaged Amongst Boulders.

while persistent driving amongst boulders may cause such a serious deflection from the vertical in a long pile as to impair its strength. In all such cases, after a pile has been driven to a considerable depth, and has apparently approached the assigned limits of final set in a normal manner (Fig. 216), any gradual yielding or increase of set should be regarded with suspicion, particularly if the pile has a marked rebound, in the case of timber piles. A load test of a broomed, or damaged timber pile would probably indicate its condition by increasingly large settlements, if such a load were applied gradually up to at least twice the apparent safe load, and by a considerable recovery when the load was removed. It is obvious, in this respect, that driving one test pile only is not in itself a sufficient guarantee for accepting the results therefrom as being reliable, and several piles should, therefore, be driven in carefully selected positions before any decision is made as to the value of the data obtained. When several test piles are driven, it is instructive to withdraw one of the hardest driven for examination.

Withdrawing Piles for Examination.—The most complete and satisfactory finish to a pile driving test is to withdraw one or more of the piles and ascertain their actual condition, with a view to the safe construction of the permanent foundations, as the evidence thus obtained may lead to a revisal of the foundation design, or alteration of details in the piles themselves should they be found to be damaged. As a rule, test piles can be withdrawn by simple appliances, the loaded log lever being a common means for this purpose (Fig. 212). The log lever may be worked by hand by means of a rope attached to the long arm, through which a jerky strain is applied, or by the hoisting winch applied in a similar way. Another method is to use a multiple rope tackle worked directly from the piling frame and winch, a start being given to the pile by two lifting jacks, one on each side, placed on stiff timber supports on the ground, and operating against two cleats bolted to the sides of the pile, or against iron clamps in the case of a concrete pile. When a test pile has been driven from a barge in water of some considerable depth, the buoyancy of the barge may be used by forcibly displacing the latter against the resistance of the pile. The chain from the hoisting winch is made fast round the pile as low as possible, and the barge hove well down by winding the chain upon the winch. The strain is suddenly released, and, as the barge rises, the winch brake is suddenly applied, bringing a powerful jerk upon the pile, and this is repeated until the pile has started, when it can usually be lifted out with the winch. The principal difficulty always in withdrawing a pile is to start it, and the most effective means to that end is a sudden jerk repeated frequently. If a test pile is difficult to draw, its removal is greatly simplified if it can be enclosed within a timbered pit, and the materials excavated as far down as possible before a lifting strain is applied (Fig. 208). If piles are withdrawn by means of hydraulic lifting jacks, the frictional resistance can be closely measured by applying pressure gradually, and the data thus obtained are of great practical value in estimating the bearing powers of piles depending for resistance on skin friction.

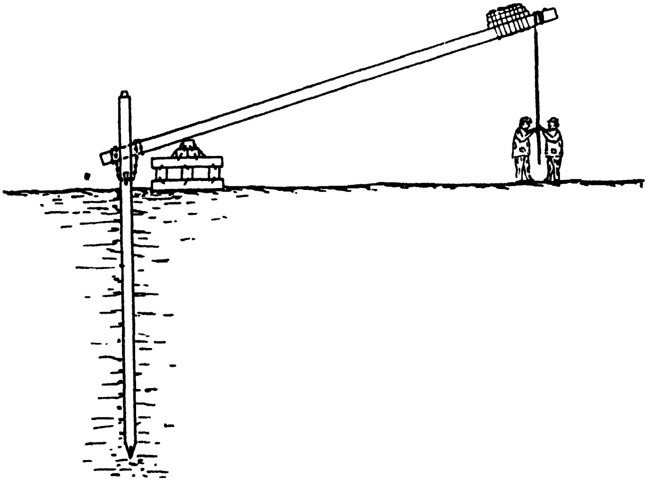


FIG. 212.—Withdrawing Test Pile with Log Lever.

Redriving Test Piles.—The bearing capacity of piles is increased after a period of rest following upon driving, and is most marked in piles which have been driven through soft ground. Test piles which have shown a doubtful final set may be retested in this respect by redriving after an interval of at least ten days. The number of blows should be limited to about twenty in the first instance, delivered under exactly the same conditions as obtained in the first case, and the set carefully noted. The experiment may be continued, if desired, but is likely to reproduce only the former results when the ground becomes once more thoroughly shaken by the vibration of continuous driving. If, as the result of such a retest, the amount of the final set is decidedly reduced, as compared with that of the former observation, a higher safe bearing load may be assigned to the pile, particularly if confirmed by a loading test applied again after a period of rest.

Recording Penetrations.—The movements of a test pile under driving should be carefully measured with a tripod level, set up at such a distance away from the pile as to ensure that it will not be disturbed by the shock of the piling hammer, and a levelling staff, or a 12-ft. graded rod. A convenient way of measuring the penetrations is to cut a reference mark on the pile at a fixed distance from the point of the shoe, and so arranged that when driving is begun the staff reading is nearly zero (Fig. 213). By this arrangement the pile can be followed down for the length of the staff, and if this mark becomes inconvenient to read a new one should be cut further up the pile at a fixed number of feet above it. In taking the readings, a carpenter's level is held at the reference mark on the pile, and the staff or rod set upon it with the face directed towards the observer (Fig. 214). Readings should not be taken on the top of the pile, owing to its liability to be damaged during driving. All levels should be referred to a permanent bench mark nearby, placed so that it can be read along with the pile at one sight. When the preliminary driving necessary to enter the pile into the ground has been done, the penetration readings should be taken at every twenty blows of the hammer, and ten blows, if so desired, for the final record, and the level turned back on to the bench mark between each set of records to check its correctness. It is important that blows of uniform falls should be given throughout the test, particularly so when the final set of the pile is being taken. The driving should be carried out with deliberation and care, but should be completed if possible without a stop. The test pile should be carefully examined from time to time during the driving operations to see that it is sound, and its behaviour under the hammer carefully noted and recorded. A short time before the final set is taken, the pile head should be cut off and re-ringed, if it is not in a sound condition, so that the full energy of the hammer may be conserved for that occasion.

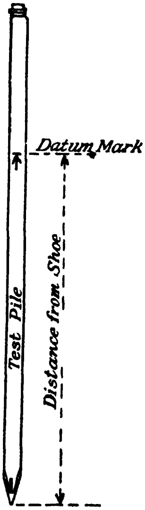


Fig. 213.—Marking Pile for Penetration.

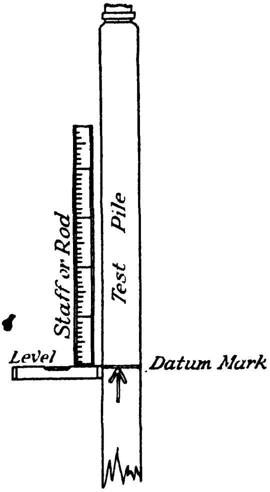


Fig. 214.—Reading of Penetrations.

Field Book.—The field book may be kept as below, the following particulars being those of a test pile as found at the final stages of driving into firm shingle :—

PILE TEST

Test Pile No. 5.	Hammer Cylinder.	Fall.		Number of Blows.	Readings on Pile.		Time.		Penetration.		Blows per Foot of Penetration.	Remarks.
	Cwt. Qr.	Ft.	In.		Ft.	In.	H.	M.	Ft.	In.		
12½ in. by 12½ in. by 42 ft. long, pitch pine, 40-lb. shoe.	20 0 Single-acting, steam hammer. Total Weight 25 cwt.	4	0	20	7	5½	10	15 a.m.	1	2½	17	Pile head in good condition.
		,,		20	8	2				8½	28	
		,,		20	8	8				6	40	
		,,		20	8	11				3	80	
		,,		20	9	2				3	80	Hammer bouncing.
		,,		20	9	5½				3½	69	,, ,,
		,,		20	9	9				3½	69	,, ,,
		,,		20	9	11				2	120	,, ,,
		,,		20	10	1				2	120	,, ,,
		,,		20	10	2¾	10	37 a.m.		1¾	137	Stopped driving.

Plotting Results.—The results obtained from driving a test pile may be plotted in diagram form for convenience of study, as shown on Figs. 215, and 216. The particulars given therein are those obtained from the driving of a pitch pine test pile, 12½ in. square and 42 ft. long, with a single-acting steam hammer, the cylinder or moving part of which weighed 20 cwt., through the strata shown on Fig. 216. The general record of the driving is presented in graph form on Fig. 215, and gives the total penetra-

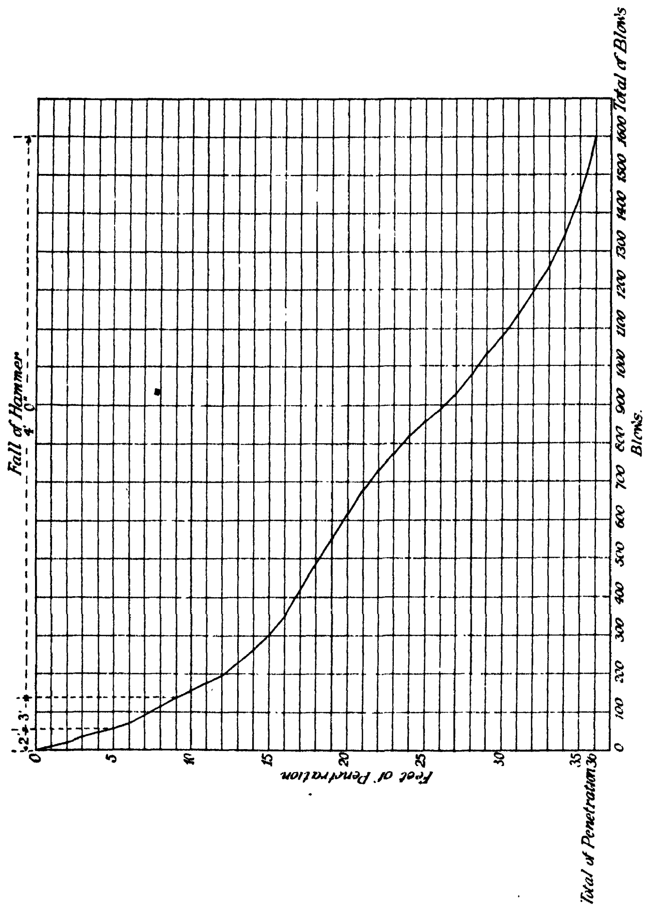


FIG. 215.—Record of Driving a Test Pile.

tion and the total number of blows to reach the final set. The graph drawn on Fig. 216 shows blows per foot of penetration

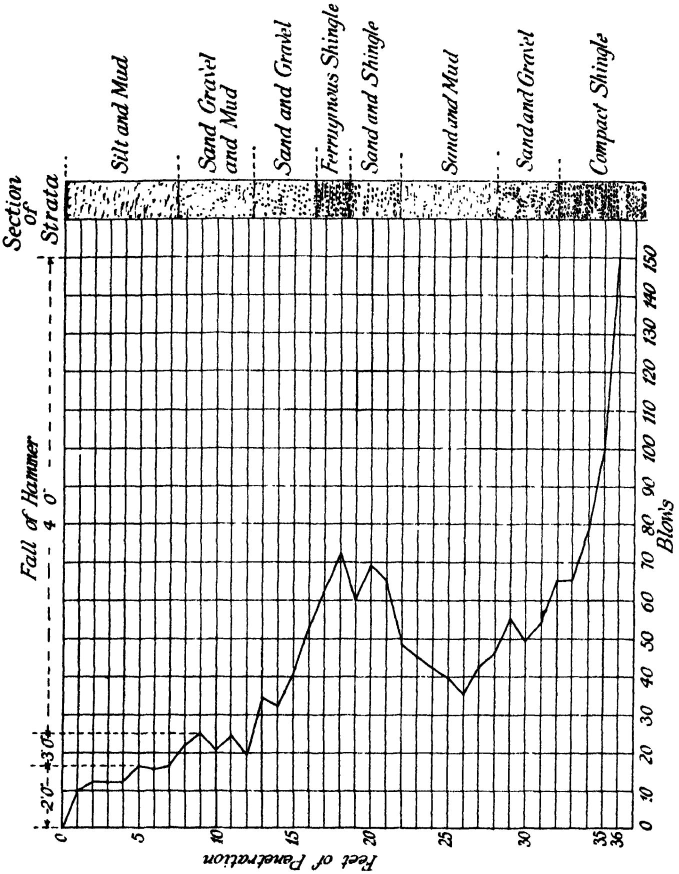


FIG. 216.—Test Pile, Blows per Foot of Penetration.

throughout the descent of the pile, and is based upon the data of Fig. 215. From Fig. 216 it will be seen that the hardness of the driving rose to about seventy blows per foot of penetration in piercing the layer of ferruginous sand and shingle, and fell again to thirty-five blows per foot in the succeeding softer strata. Near the end of the test, the resistance gradually rose from fifty blows per foot to 150 blows per foot at the final set, when the pile had penetrated some distance into the shingle bed. On being withdrawn, the pile was found to be in good condition, and the results were considered satisfactory.

In preparing drawings of the permanent foundation work, the positions of the test piles should be indicated upon the plan with the reference numbers attached, as "Test Pile No. 5," and the sections should show the depths to which the various test piles have penetrated.

(2) *Loading Tests*

General Considerations.—When piles are allowed to stand for some time after driving, their bearing capacities are usually increased, due to the reconsolidation of the ground around them,

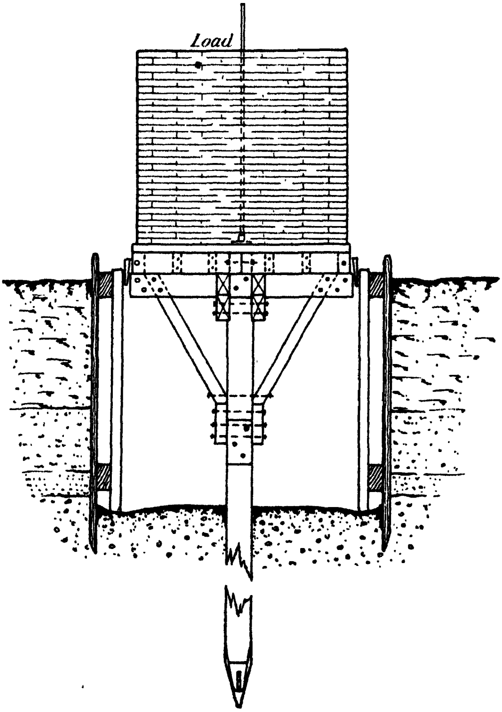


FIG. 217.—Load Test of Timber Pile. Elevation.

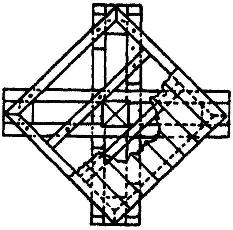


FIG. 218.—Load Test of Timber Pile. Plan.

and increase of skin friction thereby. Loading tests, which have for their object the measurement of settlements and relative bearing powers, should not therefore be made until a period of rest has intervened after driving. In practice, the minimum period is ten days, but longer periods are desirable if circumstances permit. In many cases piles rise and keep on rising for some time after being driven, and it is desirable to defer loading tests until this movement has ceased.

Loading of Single Piles.—The test load may be applied to a single timber pile by cutting away all damaged timber, and constructing a timber loading platform upon the head, as shown on Figs. 217, and 218. A concrete pile may be loaded in a similar manner by means of a platform of rolled steel joists, laid upon a small reinforced concrete base or capital formed on the pile head itself (Figs. 219, and 220).

Loading of Grouped Piles.—After driving, the heads of timber piles should be cut off level, so as to remove all timber damaged in driving, and give a solid bearing for the load platform. The load platform is made by laying timber cills on the prepared pile heads, and planking them over flush and level with strong planks. The cills should be slightly notched, and well fitted to the pile heads, to which they may be secured by iron dogs (Figs. 221, and 222). In the case of grouped concrete piles, a special reinforced concrete load platform of sufficient rigidity may be constructed upon the pile heads themselves (Fig. 223), or a small platform or capital may be formed upon each pile head independently, and the gaps spanned by rolled joists in grille fashion (Fig. 224). To enable readings of settlements to be taken, a rigid iron rod or a tube should be firmly secured to the centre of the load platform, and project above the highest point of the load when required.

Control of Large Test Loads.—When large test loads are applied to piles, there is considerable danger to life and limb if the mass is not properly controlled against collapse from want of balancing. In such cases the load platform is carried temporarily upon hard

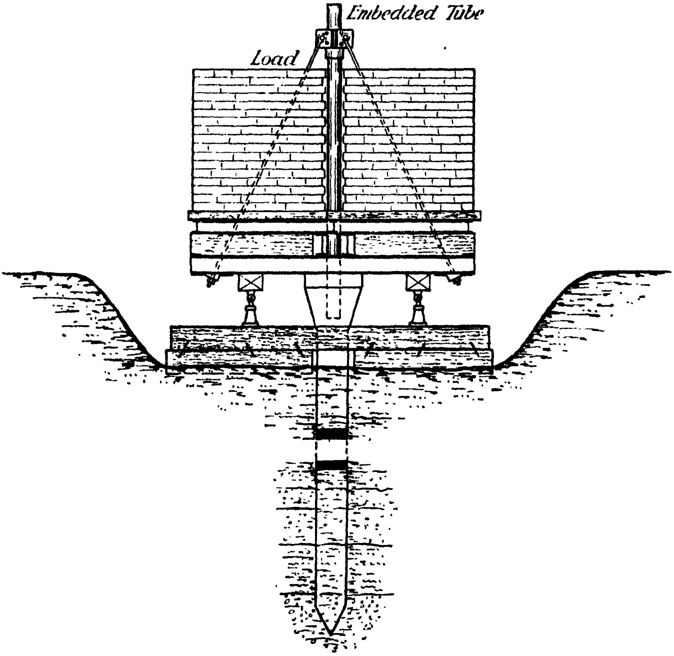


FIG. 219.—Load Test of Concrete Pile, Elevation.

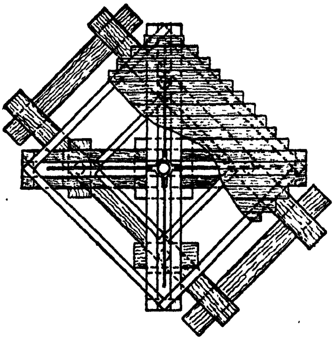


FIG. 220.—Load Test of Concrete Pile, Plan.

wood wedges, or on jacks resting on bearing logs whilst the load is being built up (Figs. 219, and 224). Near the finishing stages of each loading operation, the wedges or jacks are slackened slightly to ascertain if the load is in balance, and the proper adjustments made before the whole load is balanced upon the pile only, or evenly distributed over a group of piles. The wedges or jacks are kept just clear of the load platform when the test load is freed, in case of collapse or undue settlement of any of the piles, and should be kept in adjustment at this position during the test.

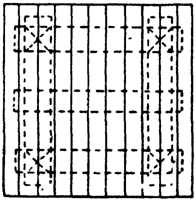


FIG. 221.—Timber Group Pile Test. Plan.

Materials for Test Loads. — The materials forming the test loads may be bags of sand, bars of pig iron, steel billets, or railway rails. All materials should be weighed before being placed upon the load platform, and be built up symmetrically, and the weight of the platform itself should be carefully ascertained or estimated.

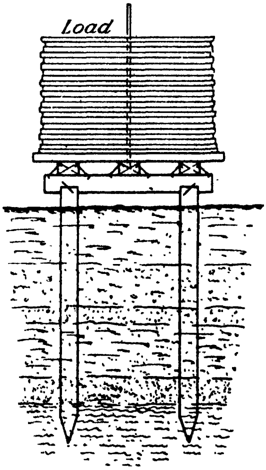


FIG. 222.—Timber Group Pile Test. Elevation.

Test Loads.—The piles should be gradually loaded, at the rate of about 10 tons a day, until the limits of the safe load which they are intended to carry is reached, when an interval of two to three days, or more, should be allowed to elapse before further loading is done. If settlement has then ceased, more weight may be added in increments until a total of about twice the safe load has been imposed, when an interval of rest of seven to ten days should be given. If undue settlement at any intermediate stage of loading goes steadily on, no further weight should be placed upon the piles, as it is then evident that the ground is loaded above its carrying capacity. If it is desired to test the bearing capacity above twice the safe load, the additional weights should be placed in small increments, with corresponding periods of rest between. With long, and well driven timber and concrete piles of large cross section, not depending upon skin friction for support, it is sufficient generally to apply test loads up to about 50 per cent. above the estimated safe loads, but piles depending for bearing upon skin friction should be tested at least to twice the safe load whenever possible, as it is important to discover the probable point at which frictional resistance and end bearing break down, as would be indicated by undue settlements, with a view to assigning proper safe loads. Short piles of all kinds should be tested to at least twice their safe estimated load. Pile driving near to a loaded test pile has a tendency to increase the settlements and should be avoided.

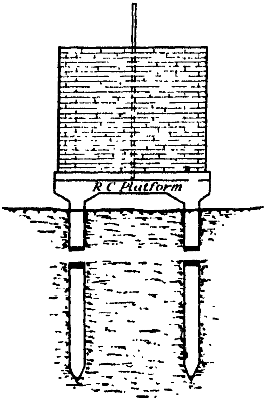


FIG. 223.—Concrete Group Pile Test, R.C. Platform.

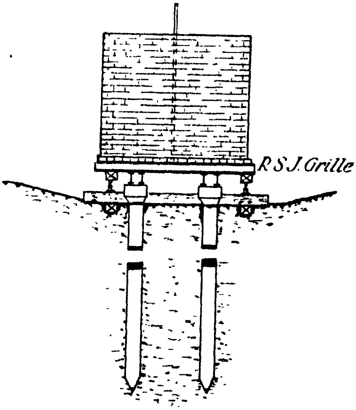


FIG. 224.—Concrete Group Pile Test, Steel Platform.

Tests of Piles not Driven.—Test piles which have been placed in position by other means than driving can only be tested for bearing capacity by mass loading, or its equivalent. This applies generally to timber, concrete, and iron piles sunk by jetting, or by driving and jetting, or by hydraulic jacks. Concrete piles cast in the ground, and iron screw piles, forced down by mechanical means must also be tested by a static load for bearing. In the case of piles put down by hydraulic jacks, the equivalent of a direct mass load may be obtained from a pressure reaction in the jacks, a method of testing frequently adopted in heavy under-pinning work, or the test may be arranged by supplying the necessary reactions, in the manner shown on Fig. 231. The methods of testing piles of the foregoing kinds are similar generally to those described above for piles driven by hammer in the ordinary way.

Measurement of Settlements.—Settlements of piles under test loading may be measured in the manner before described for "Direct Tests." As the loads are removed, levels should be taken at intervals on the load platform, as under certain conditions piles have a tendency to rise when the load is removed, a feature that has a direct bearing upon foundations subject to alternations of live and dead loads.

Recording and Plotting Settlements.—Settlements of piles under test loads may be recorded and plotted as before described for "Direct Tests." For important permanent structures, it is usual in practice to take the safe load on well driven timber and concrete piles, with a final set of, say, ten blows to 1 in., at one-half to two-thirds of the test load which produces a final settlement gradually of ½ in. after a period of ten days' rest. For well-placed, undriven concrete piles, in important foundations, and tested to twice their estimated bearing capacity, the safe bearing load has been taken in practice at one-half the test load which gives a settlement of ⅜ in. after a period of rest of ten days. There are, however, wide differences in the methods of constructing piles in the ground, and actual tests may show bearing capacities much above those estimated. The assignment of safe bearing loads in such cases is a matter of experience and judgment, founded upon the actual test data, and the method and quality of construction. A decision as to the safe bearing capacity of piles formed in the ground can be made with much more confidence if one or more of the test piles are withdrawn for examination after the loading tests have been completed. The safe bearing load on any kind of pile should not exceed the safe compressive stress of the material of which it is made, when considered as a column, according to its physical conditions.

(*b*) EXPLORATORY TUBES.

General Considerations.—Tubes may be used to prove the ground, particularly in confined places, and this method has been largely adopted where deep underpinning work requires the exercise of great care in avoiding disturbance of the strata on which heavy buildings rest. The usual application of this method is to sink a steel tube of large diameter to the required depth, and to carry out tests of the bearing and compression powers of the soil through it by means of an internal tube carrying a test load. Tests by this method have been made at depths up to about 50 ft.

Sinking of External Tube.—The external tube used for sinking through the strata is generally about 16 in. diameter and ½ in. thick, in lengths of about 5 ft., joined together by heavy outside screw couplings with bevelled edges. It is sunk through the overlying strata by means of a water jet, having a nozzle of ⅜ in. diameter, and a working pressure of 100 to 150 lb. per square inch, but jetting is usually combined with driving. The tube may be driven by a drop hammer, weighing about 1 ton and worked with a short drop (Fig. 225), or when space is confined, by a double-acting power hammer, about 1 ton weight, and having a stroke of 8 to 12 in. Where the headroom is limited, a hydraulic jack of 100 to 150 tons capacity can be advantageously used to force the tube down, when in close proximity to heavy existing structures from which a proper reaction can be obtained. Tubes which are driven are armed with a cutting shoe, and the method of sinking generally is similar to that described for lining tubes of deep bore holes in Chapter VI. The sinking of a tube in this way provides a geological record of the strata, and the bearing and compression powers of any particular stratum are obtained

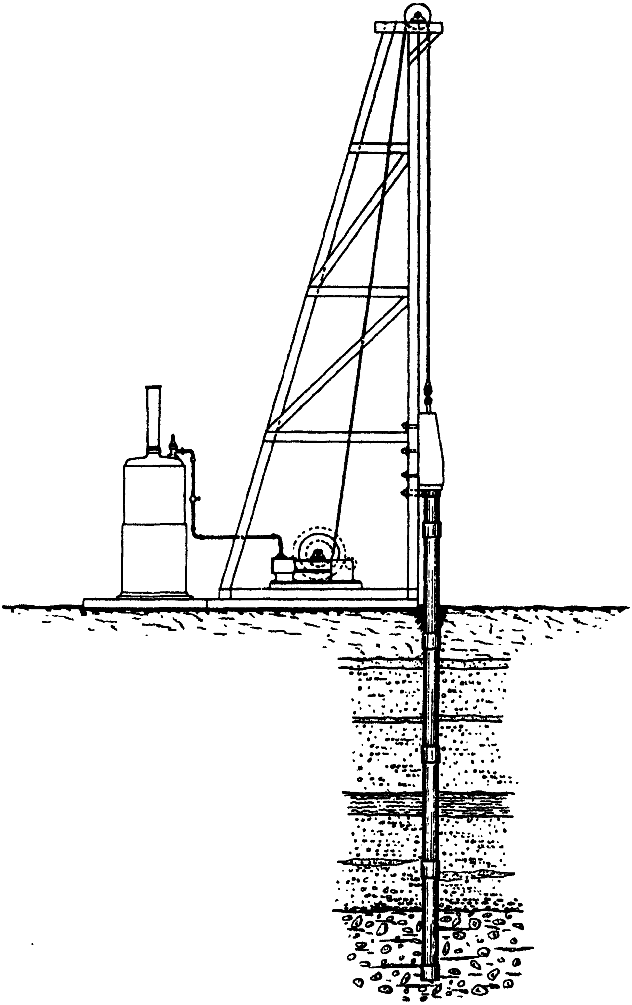


FIG. 225.—Driving an Exploratory Tube.

by placing a smaller tube inside the larger one, fitted with a flat-bearing end which rests upon the ground, and loading it as required (Fig. 226).

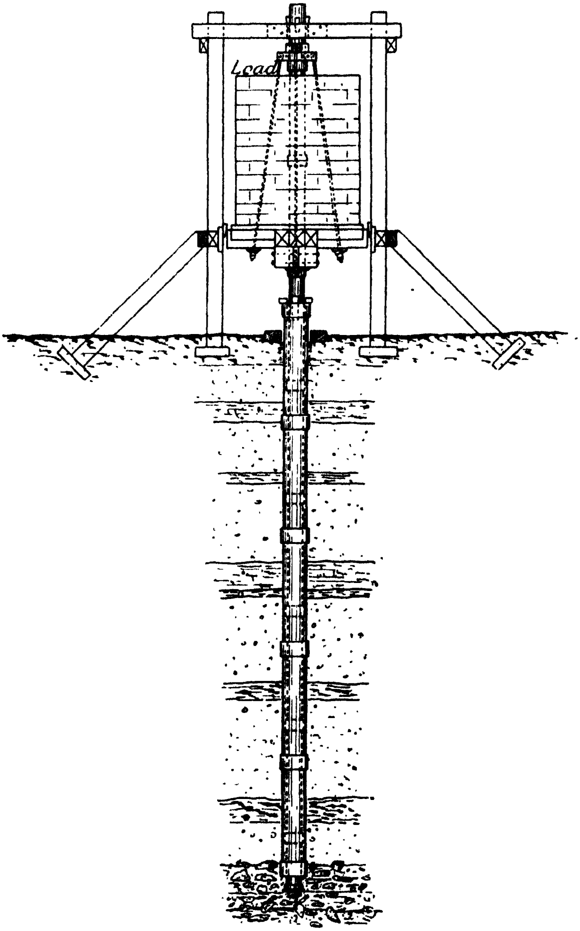


FIG. 226.—Exploratory Tube and Test Load.

Internal Test Load Tube.—The internal tube, which carries the test load, consists of heavy steel tubing, about 10 in. diameter, joined together with heavy external couplings. The bottom length of the tube is fitted with a strong cast iron, or steel base plate, stiffened by ribs on the top, and quite flat on the bottom where it bears on the ground. A central hole, about 1½ in. diameter, is provided in the base plate, so that it can be jetted down as required, and the nett surface provides an area of 1 square ft. (Fig. 227). The test load platform is placed upon the top of the tube, and may consist of four timber beams, 12 in. square and about 8 ft. long, placed at right angles to each other, the two bottom beams resting upon a flange or clamp on the tube above the coupling of the nearest joint, or rolled steel joists may be used in a similar way. The ends of the beams are supported by four inclined tie-rods, which are attached to the top of the tube by means of eye bolts secured in forged clamps. The beams are packed up level to carry strong planking on which the test load is placed (Fig. 226).

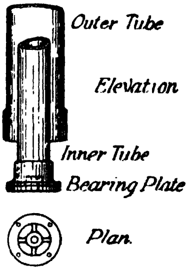


FIG. 227.—Bearing Plate of Load Tube.

Materials for Test Loads.—The materials composing the test loads are usually cast iron blocks, each weighing about 1 ton, fitted with lifting eyes, and are placed in position by a differential pulley block and tackle suspended from the staging round the load platform (Fig. 226). The use of large cast iron blocks for the test load is necessary in confined places, but pig iron bars, or railway rails may be used where space permits.

Procedure in Testing.—Before placing the internal tube in position, the external tube is cleared of silt or other materials which may have risen in the bottom, in order to get the base plate below the level of the cutting edge. It is important that the base plate should rest upon free ground, as otherwise an artificial compactness is created, owing to the soil being confined by the external tube when under the load pressure. If the base plate cannot thus be placed below the cutting edge level by reason of inrun of materials, it has to be jetted down to the proper level. When the bottom has been prepared, the inner tube is lowered down until it rests upon the ground by screwing on the necessary lengths of tube, and is kept in a vertical position by distance pieces of hard timber fitted to it, with just sufficient clearance to allow of its passing down the outer tube. The load platform is then fitted up, and the loading commenced. The test weights are placed upon the platform, 2 tons at a time, until the estimated safe load of the soil is reached, and the settlements read. A period of rest of three days should then be allowed, after which the loads may be increased to twice the estimated safe load in 2-ton increments, with periods of rest of three days between, during which the settlements are read, and further loading may be done in a similar way until the yield point of the soil has been satisfactorily established, the final load being allowed a period of seven to ten days' rest. When the loading is removed, the settlement should be measured to ascertain the amount of the recovery of the soil, if any. The loading test should be made generally in a similar manner to that indicated on Fig. 226.

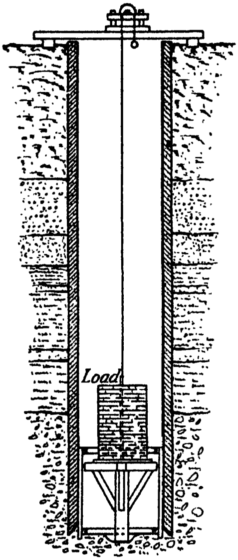


FIG. 228.—Dry-Cylinder Test.

Measurement and Plotting of Settlements.—The settlements are measured by a tripod level, and recorded and plotted as described for "Direct Tests."

(c) EXPLORATORY CYLINDERS AND CAISSONS

General Considerations.—When exploratory cylinders and caissons are available, tests for bearing and compression can be made on the ground opened out at the bottom, either by direct or indirect tests.

Dry Cylinders and Caissons.—When the bottom of a cylinder or caisson is dry, or nearly so, there is no difficulty generally in applying the method of direct loading by using a load platform with a unit base of 1 square ft., as shown on Fig. 228. Before placing the load platform in position, the ground at the bottom should be excavated and levelled, so that the centre post is below the cutting edge of the cylinder. The load platform is kept upright by vertical timbers, attached to the cylinder or caisson, on which are fitted well greased, iron, groove runners with which the knife edges of the platform engage (Fig. 229). The readings of settlement are best made by carrying a steel band from the load platform to the top of the shaft, as shown on Fig. 228, and the caisson itself should be carefully levelled when each reading is taken to guard against "creep," and probable disturbance of the conditions of the bottom.

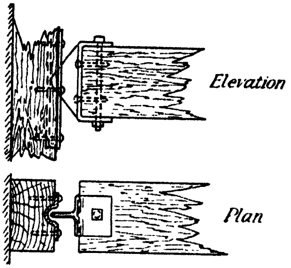


FIG. 229.—Load Platform Guides.

Wet Cylinders and Caissons.—In cylinders and caissons in which the water cannot be entirely pumped out, the ground may be tested for bearing and compression by using two tubes, as described for "Exploratory Tubes." The external tube should be sunk for some distance into the ground, so as to be below the cutting edge of the caisson, and be steadied by temporary struts from its sides, placed as low as the water will permit (Fig. 230). The tests may then be carried out as before described for "Exploratory Tubes." A foundation cylinder or caisson may be tested, in course of sinking, by the above methods to ascertain whether a stratum of suitable bearing and compression

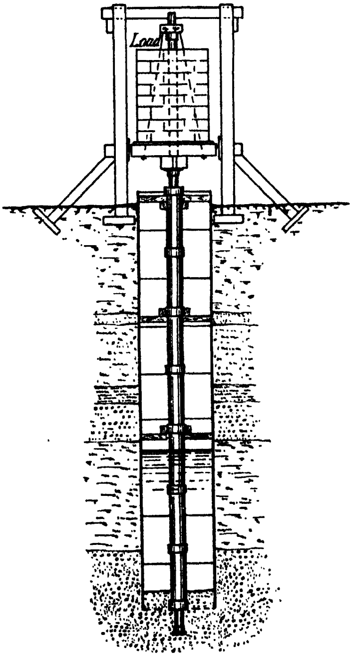


FIG. 230.—Wet Cylinder Test.

capacity has been reached, when no further sinking of the shell is necessary, or at what depth it may presumably lie, as a guide to further operations.

Testing a Completed Cylinder or Caisson.—In important foundations, an exploratory cylinder or caisson is sometimes filled up with concrete and completed, and then tested by loading it directly to discover the actual bearing and compression capacity of the soil on which it rests. In such cases the resistance due to skin friction, which can be ascertained from the sinking data, or otherwise estimated, must be deducted from the total weight of the completed cylinder and test load in arriving at the pressure per square foot on the foundation stratum. If the base of the cylinder is subject to water pressure, however, as in permeable strata, it is to some extent buoyant, and the upward hydrostatic pressure, which can be estimated from the head of free water in the open shell, must also be deducted from the total downward load in calculating the pressure per square foot on the foundation, and in cases where the bottom of the cylinder has been sealed in an impermeable stratum, the weight of water and soil displaced by the cylinder should be deducted. In practice, skin friction is usually discounted altogether in shallow cylinder foundations, owing to the uncertainty of its permanence, but in deep foundations some allowance is made for the deeper seated portion of the cylinder. Buoyancy, on the other hand, is usually taken at its full value, as being of a more permanent character, but cases arise where the tapping of water-bearing strata by deep excavations or shafts in the vicinity

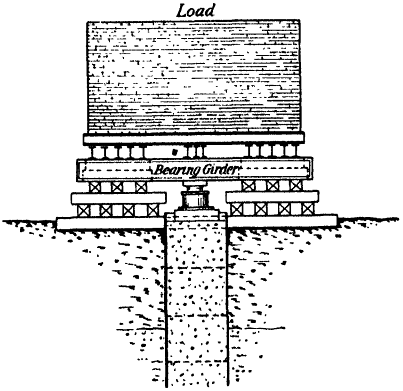


FIG. 231.—Test of a Completed Cylinder.

of a foundation lowers the original water level, and discretion must be exercised in using buoyancy allowances in such cases.

Should the dimensions or form of the cylinder or caisson not be convenient for direct loading, the test may be carried out by building up the load on an independent platform of beams, supported by timber bases, from which the necessary reaction can be got for a hydraulic jack placed on the top of the cylinder, and having a bearing girder under the load (Fig. 231). The load must be of a sufficient weight to give a positive downward reaction when the full pressure of the test load is applied through the jack, and so prevent it from being lifted off the supports. Settlement readings, with intervals of rest between, are taken directly on the cylinder, and the load should be disposed to permit of this being done.

Recording and Plotting Settlements.—The settlements may be measured, recorded, and plotted in the manner described for "Direct Tests."

BIBLIOGRAPHY

("Foundations." By W. Simpson, M.Inst.C.E.)

The following works may be consulted in connection with the subject-matter of this book :—

GEOLOGY AND GEOLOGICAL SURVEYING

"Applied Geology." By J. V. Elsden. Part I. The Quarry Publishing Co., Ltd., London. 1898.

"A Treatise on Mine Surveying," Brough and Dean. Griffin & Co., London.

"Civil Engineering Geology," C. S. Fox. Crosby Lockwood & Son, London.

"Engineering Geology," W. H. Penning. Baillière, Tindal & Cox, London. 1880.

"Engineering Geology," Ries and Watson. Wiley & Sons, New York, and Chapman & Hall, London.

"Field Geology," W. H. Penning. Baillière, Tindal & Cox, London. 1879.

"Geology for Engineers," Lieut.-Colonel R. E. Sorsbie, R.E. Griffin & Co., London.

"Geological Maps," R. M. Chalmers. Oxford University Press, London.

"Geological and Topographical Maps," A. R. Dwerryhouse. Arnold & Co., London.

"Outlines of Field Geology," Sir A. Geikie. Macmillan & Co., London.

"Structural and Field Geology," Professor J. Geikie. Oliver & Boyd, Edinburgh and London.

"Text Book of Geology," Sir A. Geikie. Macmillan & Co., London.

'The Principles of Engineering Geology," H. Lapworth. *Proc. Inst. C.E.*, 1907–08, Part III., London.

"The Study of Geological Maps," G. L. Elles. University Press, Cambridge and London.

BORING AND BORING APPLIANCES

" American Civil Engineer's Pocket Book," Professor M. Merriman. Wiley & Sons, New York, and Chapman & Hall, London.

" Coal Mining," Burns and Kerr, Part I. Sir Isaac Pitman & Sons, London.

" Earthwork in Railway Engineering," in the Glasgow Text-books of Civil Engineering Series. Constable & Co., London.

" Mining Engineers' Handbook," Professor R. Peele. Wiley & Sons, New York, and Chapman & Hall, London.

" Modern Practice in Mining," Sir R. A. S. Redmayne, Vol. I. Longmans, Green & Co., London.

" Well Boring," C. Isler. Spon, London.

" Well Sinking and Boring." Lectures by J. Mansergh, Pub. The School of Military Engineering, Chatham. 1882.

FOUNDATIONS AND SOIL TESTING

" A Treatise on Masonry Construction," Professor I. O. Baker. Wiley & Sons, New York, and Chapman & Hall, London.

" A Practical Treatise on Foundations," Professor W. M. Patton. Wiley & Sons, New York, and Chapman & Hall, London.

" Arrol's Handbook," A. Hunter. Spon, London.

" Civil Engineering," Professor Rankine. Griffin & Co., London.

" Engineering and Building Foundations," Fowler. Wiley & Sons, New York, and Chapman & Hall, London.

" Foundations," M. A. Howe. Wiley & Sons, New York, and Chapman & Hall, London.

" Foundations of Bridges and Buildings," Professors Jacoby and Davis. McGraw-Hill Book Co., New York and London.

" Masonry Structures," Professor F. P. Spalding. Wiley & Sons, New York, and Chapman & Hall, London.

GENERAL LITERATURE

Articles descriptive of engineering geology, test boring, and soil testing, from 1910 onwards, are to be found scattered throughout the following journals :—

Engineering, London.
The Engineer, London.
Engineering News, New York.
Engineering News Record, New York.
Engineering Record, New York.

INDEX

PRINTED IN GREAT BRITAIN BY THE WHITEFRIARS PRESS LTD.,
LONDON AND TONBRIDGE.

CENTRAL LIBRARY
BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE
PILANI (Rajasthan)
Call No.
Acc. No.
55078
DATE OF RETURN