AN INTRODUCTION TO THE PRACTICE OF CIVIL ENGINEERING

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PREFACE

It has been the author's experience, in practice and in teaching, that youths who have received a training in the principles of engineering at our Universities and Technical Colleges, are at first almost useless as assistants to engineers in practice, owing to their ignorance of the ordinary routine work carried on in an engineer's office. The greater part—although not necessarily the most important part—of this work has no relation whatever to mathematics, and the junior assistant is often somewhat discouraged to find the small value which his laboriously acquired knowledge possesses at the outset of his career, however indispensable it may prove to be later. That the Council of the Institution of Civil Engineers now attaches considerable importance to this non-mathematical knowledge, is evidenced by the addition to the examination syllabus for Associate Membership, of Section C, dealing, mainly, with specifications, quantities, and estimates.

This book is an attempt to provide a skeleton framework of knowledge—to use an engineering metaphor—which the young engineer may clothe with detail according to the particular branch of the profession in which he may be engaged. It is essentially a book of engineering commonplaces. Descriptions have been confined to normal materials and methods of construction, and underlying principles have been thrown into relief wherever possible.

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CHAPTER I

INTRODUCTORY

BRANCHES OF ENGINEERING

THE profession of engineering was originally divided into two great branches, viz. **military** and **civil**. These included what are now known as architecture, civil engineering in the present popular sense of the word, mechanical engineering and fortification. All works which were not distinctly military (such as fortresses, engines of war and the like) were comprised in the profession of the civil engineer, and it is this meaning which the term carries in the charter of the Institution of Civil Engineers, where a civil engineer is defined as one who directs the great sources of power in nature for the use and convenience of man.

In the popular sense alluded to above, however, the term **Civil Engineer** is restricted to one who deals with such works as railways, roads, bridges, harbours, water supply, sewerage, waterways and irrigation, in order to distinguish him from the mechanical engineer, who deals with machinery, and the electrical engineer, whose work is sufficiently indicated by his name. It is in the popular sense only that the term is employed in this book, and it is intended to be synonymous with the more recent expression, structural, or constructional engineer.

CLASSES OF CIVIL ENGINEERS

Civil engineers are divided according to their functions into the three main categories given below :—

(1) **Consulting Engineers,** who are employed principally by promoters of engineering projects in designing works, estimating probable costs, preparing particulars for Parliament where the work—as in most cases—requires Parliamentary sanction, preparing contracts for the carrying out of the works and the general supervision of those contracts ;

(2) **Contracting Engineers,** who are employed by firms of contractors, the principals of the firms being in most cases contracting engineers also, in carrying out the provisions of contracts prepared by consulting engineers ; and

(3) **Official Engineers,** working for large public bodies or private companies, such as municipal corporations, railway companies and government departments ; who often have to combine the functions of consulting and contracting engineers ; that is to say, they often devise and design engineering schemes, and also carry them out without the intervention of a contractor.

Consulting and official engineers usually employ on works which are being carried out by contractors a responsible assistant to see that the provisions of the contract are observed by the contractor with regard to quality of materials, workmanship, etc., to measure up as the work proceeds, and to make periodical reports on its progress. This assistant spends his whole time on the works and is known as the **Resident Engineer,** or, on small contracts, the **Clerk of Works.**

From the point of view of a junior assistant, a consulting engineer's work involves much time spent in the office, designing constructional details, copying and tracing drawings, preparing estimates, contracts and Parliamentary plans, while out-of-doors there will be the surveying necessary for the preparation of schemes, that required in the setting out of work to be carried out by a contractor, and the general supervision of such work in order to make sure that it complies with the requirements of the contract. A contracting engineer's assistant will usually spend less time in designing and drawing and more time out-of-doors on the works, setting out the work in conjunction with the consulting engineer's representative, preparing reports, plans and particulars showing the gradual progress of the work, devising methods for overcoming the thousand and one unforeseen difficulties which crop up during its execution, designing temporary staging, and in some cases dealing with the workmen's pay and time sheets.

It may be stated broadly that if there is any choice in the matter the theoretically trained youth is best in the consulting engineer's office, and that one with a practical bias would do better with a contracting engineer.

Training of Civil Engineers

Perhaps the commonest method of training is to take a three years course at an engineering college with the view of obtaining a degree in engineering, following this by practical experience gained upon works either as an articled pupil to a civil engineer or as a junior assistant. The qualifications required for a civil engineer are laid down by the Institution of Civil Engineers, association with which is almost universally required by those employing engineers. Certain degrees in engineering are taken by the Institution as exempting the holders from the requirement of passing two out of the three sections of their own examination, viz. A and B, and all pupils and students should obtain and study carefully the regulations regarding membership. Section C of the Examination for Associate Membership deals with specifications, quantities and estimates, and must be taken by all candidates. The Minutes of Proceedings of the Institution, supplemented by the professional papers, are a mine of information to all practising engineers, and should be constantly consulted by those engaged in designing.

Of professional societies, the work of which borders on civil engineering, with conditions of membership and requirements somewhat similar to those of the Institution of Civil Engineers, there may be mentioned :—

THE ROYAL INSTITUTE OF BRITISH ARCHITECTS.
THE INSTITUTION OF STRUCTURAL ENGINEERS.
THE INSTITUTION OF MECHANICAL ENGINEERS.
THE INSTITUTION OF ELECTRICAL ENGINEERS.
THE JUNIOR INSTITUTION OF ENGINEERS.
THE INSTITUTION OF MUNICIPAL AND COUNTY ENGINEERS.

The work of a junior assistant usually commences with the tracing of small plans and details, making minor surveys and plans, and taking off quantities under supervision. Later, as he gains experience, he is entrusted with the preparation of drawings of constructional details from rough sketches and particulars supplied to him ; and later still he may prepare the drawings, estimate, and specification for some small distinct work, which he will also probably supervise during construction.

EQUIPMENT AND REFERENCE PUBLICATIONS

The following chapters are intended to initiate the assistant into the work described above, commencing with draughtsmanship—since drawing is the language which all engineers have to learn both to write and read—while Chapter XIII will give him a general idea of the works carried out by engineers, sufficient to enable him to read intelligently technical accounts and drawings, and to appreciate their purposes. Further information may be obtained either from text-books, from the various engineering periodicals, which deal in a specialized manner with the branches into which civil engineering is divided, from the Proceedings of the Engineering Societies already alluded to, from drawings and particulars of works already carried out in the office in which he may be employed or to which he may have access, and from what he may see and note on his visits to other works in course of construction. Text-books alone take a small part in his education eventually, and he should be fully alive to the other means of gaining information and make use of them. A more detailed reference to these is contained in Appendix I., and under the heading Reference Publications in the Index.

The **equipment** of an assistant should comprise a good set of **drawing instruments**, a **two-foot rule**, and a **slide rule** for calculation. **Molesworth's Pocket Book** of engineering formulae will be useful for weights of materials, logarithms, etc. Frequent reference will be made in the following pages to **official publications** and regulations. These are essential in designing and specification writing. The British Standards Institution publishes a list of its standard specifications, which are rapidly superseding those drawn up by individual engineers as in the past. Such, for instance, are those dealing with portland cement, structural steel, road metal, glazed pipes, marine steel, etc. The complete list should be in the possession of the engineer, who can then order any specification which may deal with the particular work on which he may be engaged. (See

Appendix I.) Other official publications contain regulations which must be complied with in designing. Such are the Ministry of Transport regulations for railways, local bye-laws for buildings, the London County Council regulations for reinforced concrete, and regulations by the same body for steel-framed buildings The more important steel firms also publish handbooks, which are of great help to those who design structural steelwork. The British standard list of steel sections with their properties is also essential. The mathematical principles of design are taught in the ordinary college courses in engineering, as well as both the theory and practice of surveying and setting out, and they will not be dealt with in this book.

Catalogues are issued by various manufacturing firms giving details, and in some cases prices, of their products. These are in constant use when preparing a contract and should be frequently consulted. They may be obtained dealing with such goods as special bricks, builders' ironmongery, gates and railings, cranes, concrete mixers, patent glazing, sanitary appliances, etc. A complete list may easily be obtained from the advertisement pages of one of the technical papers.

Few works can be carried out in Great Britain without constant reference to the maps of the **Ordnance Survey.** These are printed to various scales, but the most useful to the civil engineer are :—

(1) The " inch " or " general " map, scale 1 inch to a mile, either plain or coloured, contoured and hill-shaded.

(2) The " six inch " or " county " map, scale 6 inches to a mile, useful for Parliamentary work.

(3) The " twenty-five inch " or " parish " map, scale $\frac{1}{2500}$, and, for some districts, the " enlarged 25 inch," scale $\frac{1}{1250}$.

Levels are marked on these maps, and the twenty-five inch gives areas of enclosures in addition. The different sheets are distinguished by numbers and letters, according to index maps, which may be obtained through booksellers. It is possible to obtain maps on an even larger scale, such as the town plans, to a scale of $\frac{1}{500}$ for certain districts only ; but they are not now revised and their issue will be discontinued. All ordnance maps are only revised at rare intervals, so that it is necessary to bring them up-to-date before using them, by rapid survey or sketching on the ground. The date of the last revision is printed on each sheet.

The constant **study of drawings** of works actually carried out is of great benefit in educating the eye to recognize usual and normal sizes and proportions in detail which cannot be designed on mathematical or mechanical principles, but have been evolved by engineers in the past through trial and error. It is in the design of such details that the young engineer finds his greatest difficulty, as he has no experience to fall back upon. He should, therefore, endeavour in this way to profit by the experience of others and so train his judgment.

Data for Designing

One of the most difficult problems which confronts the young engineer, when he is called upon to design on his own responsibility, is the selection of a suitable **working stress** or factor of safety for his structure. The ratio of the ultimate strength of a material to the working stress allowed is usually called the **factor of safety,** but a better term would perhaps be " coefficient of uncertainty." There are many uncertainties in most engineering designs.

There is : (1) the uncertainty as to the load to be sustained ; for example, in the case of the actual wind pressure on a roof.

(2) There may be uncertainty as to the stress caused by the load, or as to the correctness of the theory by which the stress is calculated, as in the case of the overturning of retaining walls.

(3) There may be doubt as to the actual ultimate strength of the material, due to its great variability and the impossibility of obtaining material identical with a tested specimen—particularly with timber.

(4) The workmanship in the structure may modify to an uncertain degree its strength, notably in the case of reinforced concrete and the placing of the bars.

(5) The method of application of the load may affect the strength of the structure, as in the case of railway bridges with trains running at high speeds, or it may affect the durability of the material itself, as with loading many times repeated or reversed.

(6) There may be a gradual deterioration of the structure due to corrosion, for which a margin should be allowed in the design.

All these uncertainties are present in the mind of the designer—it may be unconsciously—and he therefore allows a working stress very much lower than the actual ultimate strength of the material. His judgment is also influenced to some extent by the possible results of a collapse. The more serious the results, the more cautious he will be and the larger factor of safety he will use. The actual factor of safety taken, which will be influenced, consciously or unconsciously, by all the above considerations, may be called the **overall stress factor of safety.** It is possible, though not usual, to use as a factor of safety the ratio of the load on a structure which would cause collapse to the actual working load. This ratio will not give the same figure as the previous one, and may be called the **load factor of safety.** Where a design is prepared to comply with official regulations as to working stress, the problem is, of course, solved as far as the design is concerned.

Appendix II gives particulars of working stresses for various materials, and should be consulted after reading the later chapters on construction in the various materials, and, of course, after the mechanics of construction has been mastered.

CHAPTER II

DRAUGHTSMANSHIP

VALUE OF DRAUGHTSMANSHIP

AN engineer's assistant spends a large amount of time over the drawing board, and in many offices his value to his employers depends at the beginning of his career almost entirely on his **draughtsmanship.** However small or apparently unimportant a drawing may be, few engineers will allow it to be prepared in a slovenly or careless manner, particularly if it is to be sent away, and the draughtsman should bear in mind that the prestige of the office is likely to suffer from badly or carelessly prepared drawings.

INSTRUMENTS AND MATERIALS

Instruments and materials should be of good quality. It is impossible to do good work with cheap instruments, and in the end a good set results in eventual economy, since it will last more than a lifetime if well looked after. It is not necessary to purchase the instruments in a case ; in fact, many draughtsmen obtain their instruments separately as they require them, and keep them wrapped up in a roll of flannel or chamois leather. To commence with, the following may be taken as the indispensable minimum.

1. **Drawing pen** with screw adjustment for varying the thickness of the lines. It is convenient if one nib is hinged so that the whole pen may be opened for cleaning.

2. **Large compass** with "needle points," and fitted with pen and pencil legs for use as required, and also with a lengthening bar for large circles. One with legs about 5 in. long is suitable for general work. The "needle" points referred to above make very fine holes in the paper and are not so likely to damage it as the old-fashioned triangular "bayonet" points. The pen leg should be capable of adjustment in a similar manner to the drawing pen, and both it and the pencil leg should be hinged so that they may be kept perpendicular to the paper however far the compass may be opened.

3. **Small spring bow compass** to draw ink circles, and one also for pencil. These compasses are usually sold in sets of three, including a pair of spring bow dividers. The pen and pencil ones are indispensable.

4. **Scales** of boxwood or ivory. The usual scales for civil engineering are 20 ft. and 40 ft. to an inch for surveys and plans; 1, 2, 4 and 8 ft. to an inch for constructional work and details; and $\frac{1}{2500}$ for work on ordnance maps of that scale. Some scales are subdivided into minute divisions along their whole length and are called close divided, while others have only the larger subdivisions marked along the scale, with the exception of one of these divisions at the left-hand end, which is minutely subdivided. These latter are called open divided scales. Both kinds are in common use. The scales should have bevelled edges, and when a distance is required to be marked on the paper they should be applied to the paper and the distance marked off direct, not transferred from the scale to the paper by means of dividers. A *sharp* pencil should be used, or a needle fixed in a handle, for accurate survey plans.

5. **Pencils.** H pencils are perhaps in most common use for engineering drawing. Architects prefer softer pencils in order to obtain a more expressive line, since architects' drawings aim to some extent at artistic effect. On the other hand, for the plotting of surveys and in plane table work very hard pencils are used to ensure accuracy. For engineering drawing the pencil should be kept sharp by an occasional rub on a strip of glass paper pinned to the board, and the point which is most in favour is of flat chisel shape. The novice will find it difficult with the chisel point to start and stop his lines at the exact ends, and the best plan is to carry the lines right through so that they are really longer than is required, the exact length of the line being marked by its intersection with another line crossing it. This plan of carrying the lines through is much practised nowadays by architectural draughtsmen, and there is no doubt it gives a " dash " and decisiveness to the drawing which the want of a definite intersection destroys immediately. The great fault to guard against in any case is that of stopping the lines inadvertently just before they reach the points required, so that an infinitesimal gap is produced where there should be a definite intersection. This applies also to lines drawn in ink.

6. **Rubber.** This should be soft, and care should be taken to see that ink eraser is not used on paper by mistake for ordinary rubber, as it destroys the surface and renders it difficult to ink or colour over the erasure. Rubber is sometimes used for cleaning a drawing all over, and some of the softer rubbers are suitable for this. A good plan, however, is to crumble a piece of soft new bread over the drawing and rub this with the flat of the hand. The bread becomes worked into little balls which pick up the dirt, and the whole can be brushed off. This method does not injure the surface of the paper. Much of the dirt which accumulates

on an elaborate drawing is due to the constant rubbing of the tee and set squares over the surface of the paper, carrying pencil dust from the lines already drawn, and this can be remedied to some extent by folding a piece of paper over the front edge of the drawing board, and rubbing the faces of the tee and set squares hard against the sharp corner of the board so covered. The fold of the paper will collect much of the dust. The squares should be washed occasionally if of celluloid or of well-varnished wood.

7. **Ink.** This is usually provided by the office, and nowadays one of the ready-mixed Chinese or Indian inks is used. These inks are quick drying, and the bottles, which are usually wide and flat to avoid the possibility of a spill, should be kept corked to prevent thickening, being opened each time the pen is to be filled. The cork of the bottle is generally provided with a quill which dips into the ink, and this is inserted gently between the legs of the drawing pen in order to charge it. If there is no quill, an ordinary pen may be used in the same way. It frequently happens that the ink thickens in the pen while it is being used, and in that case the pen must be cleaned out at once with a pen-wiper or folded paper. Ink should never be allowed to harden in the pen; indeed a good draughtsman, if he is called away from his drawing for a moment, invariably wipes his pen.

Before the bottled inks were common, many draughtsmen spent the first ten minutes each morning in "rubbing up" ink for use during the day. A stick of solid Indian ink was held vertically in a small saucer containing about a teaspoonful of water, and the end was rubbed on the porcelain until the water assumed the desired tint. This was ascertained by blowing a little of the liquid away from one side of the saucer. When the ink was sufficiently rubbed, that portion of the saucer from which the liquid had been blown remained black owing to a thin film of the ink adhering to it. This ink, although rubbed up with water, is sufficiently waterproof to allow of colouring over the lines with ordinary water colours.

Coloured inks are made by rubbing up cakes of water colour in the same way, but these should be used *after* the water colour wash has been carried out, as they would otherwise be likely to smear. Most of the bottled inks are waterproof, and these should always be employed for ordinary work. The non-waterproof kinds are, however, best when they are to be diluted and used for solid grey washes, being in this case painted on with a brush.

8. **Colours.** For engineering drawings the best colours are those sold in solid sticks, which may be rubbed up as described above, but, of course, only to the depth of tint required. Plenty of colour should be prepared, the drawing board should be sloped, and the colour applied by a large and well-charged brush, so that it saturates the whole surface to be coloured. The object in an engineering drawing is to obtain a perfectly flat and even tint, and the great difficulty is to carry out the work quickly enough to avoid having to join partly dried edges on to new colour. Of course, the lighter the tint the easier it is to form an even wash, but if a tint is put on too light and it is desired to darken it later by washing over it again, the greatest care must be taken to see that the first wash has been thoroughly dry for some time. It often facilitates matters to wash over the drawing with perfectly clean water first. This becomes absorbed by the paper, and prevents the quick drying of the colour when it is applied.

In architectural drawings a slight graduation of colour is often not objected to, provided it is all done while wet, and there are no hard edges between portions of the same wash. It is advisable to commence with the lighter tints and gradually to proceed to the darker ones. Materials shown in section are coloured much darker than the same materials in elevation, and a strong contrast should be preserved between the two. The exact colours to use are generally specified by the chief draughtsman, who often prepares a standard list for use in the office, but the following may be used as a guide in the absence of such a list. Many draughtsmen blend these colours slightly with others in order to modify their crudeness, and on the other hand some engineers prefer the tints to be as crude and forcible as possible. This is a matter for individual taste.

Brickwork -	Venetian red, tinged with crimson lake.
Stonework -	White (paper left untouched).
Woodwork -	Burnt sienna.
Plaster - -	Dull purple (crimson lake, cobalt and sepia).
Concrete - -	Green (in section, spotted in places with black).
Slates - - -	Dull green of blue and sepia.
Lead - - -	Payne's grey.
Glass - - -	Neutral grey.
Tiles - - -	Venetian red and sepia.
Cast iron - -	Payne's grey.
Steel - - -	Purple.
Wrought iron	Prussian blue.
Earth - - -	Sepia.

With regard to brushes, sable is undoubtedly the best, and a large sable brush which has been worked well to a point by use is worth constant care. It will be found that with practice a large brush can be used for fine work as accurately as a small one, and it should be so used whenever possible. Camel hair is not so expensive as sable, but is not quite so resilient.

9. **Paper.** The drawing paper in general use is of the various kinds. Where it is purchased in sheets, these may be bought in standard sizes. Imperial and Double Elephant are the sizes in most common use : 30 × 22 in. and 40 × 27 in. respectively.

(*a*) **Cartridge paper.** This is one of the cheapest qualities, and can be obtained either cut in sheets or in a continuous roll. There are many qualities and thicknesses, but speaking generally, they all have a soft surface, and are only suitable for pencil drawings which are not to be inked in afterwards. A very hard pencil should not be used, as the rough use of rubber destroys the surface. The two faces of each sheet are slightly different in texture, but either may be used.

(*b*) **Drawing paper.** This is often described as machine made or hand made. It is more expensive than cartridge paper, and the surface may be either smooth (hot pressed) or rough (not hot pressed). It is the only paper suitable for finished or show drawings, and takes colour well, the rough kinds especially giving a special charm to the colouring, while the smooth varieties are more suitable for accurate engineering drawings. The proper face to use is that which is viewed when the paper is held to the light and the watermark appears correctly and not in a reversed position.

(*c*) **Mounted paper.** Cartridge and drawing papers are sometimes sold in continuous rolls mounted on a fine canvas backing. They are often used for record and contract drawings, and are stiff and very durable. They are not, however, so good as the proper drawing paper for preparing " show " drawings, as the surface is rather absorbent, and is consequently more difficult to colour upon.

(*d*) **Detail paper.** This is the name given to any cheap, tough paper, used for drawing out to a large scale details of construction, the drawings being used on the works. The kind in most general use is a tough "rice" paper, obtainable in large rolls, smooth and semi-transparent. It is very convenient for making tracings of simple details, but is not transparent enough for tracings of intricate work. It buckles a good deal if coloured in large washes, and is used as a rule for drawings of temporary interest only. Either face may be used.

(*e*) **Tracing paper** can be obtained in many qualities either yellowish or light blue in tint, and is transparent enough to permit of the most intricate work being traced. It has a slightly greasy surface, if of the "smooth" variety, and ink does not take very well on it. It becomes brittle with age, is easily torn, and should not be used for record drawings.

(*f*) **Tracing linen** is usually purchased in rolls. It is in very common use as it is transparent enough for intricate tracings, and is yet tough and will withstand erasure and much hard usage on the works. Its chief drawbacks are that it becomes spoilt if wet; it shrinks and expands with the weather; and pencil and ink do not take readily upon it. This latter difficulty may be overcome in the case of ink by lightly dusting and rubbing the surface with finely powdered whiting or blackboard chalk, or, for small tracings, carefully wiping with a piece of soft rubber. If the ink which is being used has been rubbed up from the stick, a little ox-gall—purchased in a pot from an artists' colourman—mixed with it by means of a camel hair brush enables it to "bite." The two faces differ, one being dull and the other shiny, and draughtsmen differ in opinion as to which to use.

It is usual in colouring tracings, both on this material and on tracing paper, to apply the colour on the back of the tracing, so that the inequalities of the wash—which is extremely difficult to apply evenly on these materials—are not so apparent. Small and deeply coloured sections, such as walls, etc., are best coloured on the face, as it will be found that strong colours will not show well through the linen however thickly they are painted on. The colour should be mixed with a little ox-gall, or soap, to overcome the greasy nature of the surface.

(*g*) **Photo papers.** These papers are purchased in light-tight containers, and are already sensitized. There are many varieties on the market, the commonest of those used in engineers' offices being the ferro-prussiate giving white lines on a blue ground, and the ferro-gallic giving dark purple lines on a white ground. Other kinds give brown or black lines on a white ground, but they are not so simple to use as the ones mentioned. Sun printing, as it is called (although in large establishments much of it is done by means of arc lamps), has taken the place of much of the laborious tracing which had to be done formerly when copies of drawings were required, each copy being carefully checked with the original. Nowadays the usual method adopted in drawing offices is to prepare drawings carefully in pencil, make a master tracing in ink on paper or linen with strong, firm lines, and then sun print as many copies as are required.

The printing is done by laying first the tracing face downwards as a negative on the plate glass front of a large printing frame in semi-darkness, then a sheet of sensitive paper face downwards, then a pad of felt, and lastly the back of the printing frame is clamped down securely. The face is exposed to the light for a period varying from three to thirty minutes, according to the degree of brightness of the light, and the frame is then opened in semi-darkness and the print placed in a large flat bath, thoroughly washed in running water, and pinned up to a rail to dry. Prints of this kind are practically permanent, and if on a white ground—"white prints"—they may be coloured in a manner similar to original drawings in order to show the different materials of construction. "Blue prints" cannot be so coloured, and if it is desired to show different materials on them the tracing negative must be line shaded in some conventional way. The photo paper may be obtained ready mounted on linen. There are various firms in London and the larger provincial towns which carry out sun-printing, and many engineers prefer to send their tracings to such firms rather than carry out the work themselves. Manuscript notes on blue prints are best written either in red ink or black drawing ink.

10. **Other instruments.** The following instruments are sometimes required by the draughtsman, but they are usually provided by the office, and it is not as a rule worth the individual draughtsman's while to purchase them.

(*a*) **Roller parallel rule.** One of ebony with gun metal rollers, about 12 in. long, is most convenient.

(*b*) **Planimeter.** This is usually of the Amsler pattern, and is used for computing the areas of figures bounded by irregular lines. One which gives the area in square inches is the best for general use, as the area of any survey may be obtained from the area of its plotting by multiplying by the *square* of the ratio $\dfrac{\text{actual length}}{\text{plotted length}}$. The instrument itself consists of two jointed arms, one of which is furnished with a needle point to be kept pressed into the paper and a recording wheel, and the other with a tracing point, which must be run carefully round the boundary of the area to be measured. For accurate work it is best to make a quick, rough determination first to use as a check on the more accurate ones to be made later, principally with regard to the position of the decimal point in the computed area. Then three careful determinations should be made, great care being taken to start and finish with the tracer at exactly the same spot, the mean of the three being taken. In converting from area of plan in square inches to area of ground, the relative scales or representative fractions should be very carefully measured on the plan owing to the possibility of the paper having stretched or contracted after plotting. Directions for use are supplied with the instrument by the makers.

(*c*) **Beam compasses.** These are sometimes required for large circles. They consist of a long horizontal arm with sliding attachments for holding pen, pencil or divider point.

(*d*) **" French " curves.** These are flat pieces of pear wood, celluloid or vulcanite, cut to curves of varying curvature, and are often used with the drawing pen for filling in curves which are not arcs of circles, and which otherwise would have to be drawn freehand. It is difficult to draw freehand with a drawing pen, and the use of an ordinary pen which makes a line of slightly varying thickness shows at once on the drawing.

(*e*) **" Railway " curves.** These are similar to French curves, except that they are made to arcs of circles of large radii, too large for ordinary or beam compasses. The radius of each curve is usually stamped upon it in inches.

(*f*) **A large protractor** is sometimes used, fitted with arms and needle points, and with a vernier for the minute subdivision of angles.

(*g*) The most important of all the instruments are the **tee square, set squares** and **drawing board.** The tee square is best edged with ebony, the set squares are now usually of celluloid, and the drawing board should be at least 2 in. longer and wider than the largest standard size of paper used in the office. The best boards are clamped to allow for expansion and contraction with the weather without warping, and there is often a strip of ebony let into the left-hand edge for the head of the tee square to slide against. Patent drawing tables are sometimes used, which can be lifted to any height and tilted to any angle, and some of them are fitted with a tee square which can be set at any angle and will then hold its position, even if the board be tilted almost vertically. They are not yet in common use, but should obviate much of the wearisome and harmful stooping over a large board which, when used with an ordinary tee square, must of necessity be nearly horizontal.

PREPARATION OF DRAWINGS

The first requirement in preparing drawings is to pin the paper down securely to the board, keeping it stretched evenly and using sufficient pins to take out any creases or buckles. Next the drawing must be carefully set out, so that it will come appropriately on the paper. Where several drawings are to be arranged on one sheet, the size of each should be roughly worked out and faintly blocked in, to see that they do not come too near one edge of the board and that a proper space is left for title, scale, etc. Most drawings are finished with a border, and as this is drawn last, its position may be adjusted slightly to improve the placing of the drawings and the sheet trimmed off to correspond. In some offices, however, the border and title are already lithographed on the sheet, and thus no adjustment of this kind is possible, and trouble taken over the arrangement will be well repaid.

The drawing should then be proceeded with, using firm lines, and whether in pencil or in ink, finishing the lines with decided square ends carried well into the intersections. For tracings to be sun printed, the lines should err on the side of thickness, and even on ordinary drawings lines are now made much thicker and bolder than was the case a generation ago. Centre lines for sun printing are usually drawn dash and dot; hidden parts a series of short dashes; and dimension lines a series of long dashes. On drawings where colours are allowed, centre lines are often drawn in red, dimension lines in blue, but figures and arrow heads in black. The draughtsman should be careful not to scramble over small details, such as bolts and nuts to a small scale, and above all not to attempt to sketch them in with an ordinary pen, although the conventional way of showing screw threads by long and short parallel lines is admissible. The method of showing rivets varies in different offices. They may be shown on the drawing as they actually appear, the heads being drawn to the proper scale, or in order to save labour they may have the centres only indicated by small crosses, the sizes of the rivets being described.

When the drawing is completed it must be dimensioned and printed up, and here the draughtsman encounters one of the most difficult portions of his work. Nothing but long practice will enable one to print quickly and well at the same time, and the best way is to decide as early as possible on a suitable type and practise it thoroughly (Fig. 1). In some offices "block letter" is insisted upon for titles, and it is a difficult type to do well. The beginner will encounter three difficulties after he has ruled his top and bottom lines giving the height of the printing. He must set it out so that some of the letters do not look wider than others, he must keep it upright, and he must keep it of even thickness. The first condition does not mean that all the letters are to be of the same width, and the only way is to measure the relative width of the letters of an approved type until the eye becomes so trained that they can be sketched in without measurements. The second difficulty can be avoided by drawing a few faint vertical lines as a guide, and the third can be overcome with care only.

It is possible to carry out block letter entirely with instruments, but it is difficult to do so without making some of the letters disproportionate. The letters should be drawn with an ordinary pen, outlined, and blacked in. In some offices block letter is now discarded and a much easier single line type adopted, every endeavour being made to keep the letters well proportioned. Roman type is also easier and quicker to do than block letter. If the type is sloping, a few faint inclined lines can be drawn to keep the angle of slope constant. The draughtsman should also practise a smaller type, such as italics, for notes other than titles, and he should carefully guard against any tendency to carelessness in such small type or in the figures of dimensions. Lines should be drawn as before to define the sizes of the letters and figures, and vertical or inclined lines when necessary. Titles are usually underlined to give them more prominence. There is a growing tendency now to print

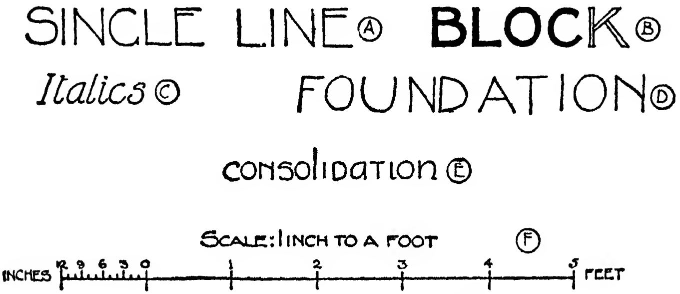

FIG. 1.—Specimens of Pen Printing.

A Done with single strokes of the pen.
B Block letter showing outline and filling in.
C Italics.
D Common faults, letters not upright, of varying heights, N and D crowded, A too widely spaced.
E Another common fault, mixed capitals and small letters.
F A convenient method of showing scales.

titles at the *bottom* of drawings, for convenience when filing them in trays.

Many draughtsmen save much time by stencilling their titles. The stencils are of thin sheet copper or zinc with the letters pierced through, obtained from makers of drawing instruments. The ink is in the form of a solid pad contained in a box, and a short, stiff brush is employed. The brush is slightly damped on a piece of wet flannel, dabbed on the ink and then on the stencil, which has been carefully placed in the proper position. If the ink is too wet, it will run under the edges of the stencil and blur the letter.

In the same way, a definite form of north point should be practised and a method of drawing scales. Modern north points are not so elaborate as the old-fashioned ones, and distinguish between true and magnetic north, true north being indicated by a star, and magnetic north by an arrow head. A scale of distances should be drawn so that it may be used with dividers, and it should also be described to facilitate the use of a boxwood or ivory scale on the drawing.

On elevations and vertical sections it is frequently the practice to mark the levels of important portions of the work by means of broad arrows, giving near them in figures the reduced levels in feet and decimals above some convenient datum, often the datum of the Ordnance Survey. This affords a ready means of comparing the levels of different portions of the work which may be far apart.

The drawing may now be cleaned off, coloured, a border line drawn round it, and the margin trimmed off.

It is important that the draughtsman's and tracer's names or initials should appear at the corner of the drawing, and also the date when it was completed. These dates are very useful when working up record drawings, and should never be omitted. In many offices a rubber stamp is used on the drawing, with spaces for these particulars.

CLASSIFICATION AND FILING OF DRAWINGS.

In the routine of a drawing office the question of the **classifying and filing** of drawings is important. Drawings may be divided into :—

(*a*) **Preliminary sketches** and drawings, prepared to show some projected scheme in outline, often in pencil only.

(*b*) **Contract drawings** prepared as a basis on which a contractor may tender before the work is commenced; inked and coloured.

(*c*) **Detail and working drawings,** prepared during the execution of the works.

(*d*) **Record drawings,** prepared after the completion of the works to show, amongst other things, the position of drains, service pipes, cables, etc., for future reference.

Drawings should always be filed flat in large drawers and not kept rolled up, and it is a good plan to allow no one to replace drawings in the files except one particular clerk who should do this each evening, drawings which have been taken out by other persons being returned by them to a tray on the plan drawers.

CHAPTER III

ESTIMATING

OBJECTS OF ESTIMATING

THE young engineer will learn early that no projected work will be put in hand before those responsible for its inception know approximately what it will cost to complete it, and a large proportion of his time will be spent either in **estimating** costs of projected works, or in **analyzing** costs of works already carried out in order to obtain trustworthy data on which to base such estimates.

CONTRACTOR'S ESTIMATES

In order to estimate the cost of any proposed work, *e.g.* a highway bridge over a river, it is necessary first of all to calculate the **quantities of the different materials** to be used, the **amount and kind of labour** required, and thus, knowing the cost of the materials and the rates for labour, to arrive at the nett cost of the bridge. To this cost, however, must be added many other items before the total cost to the promoters is arrived at. There will probably be land to be purchased, offices to be rented, machinery to be hired, clerks and engineers to be employed, insurance to be effected on plant and on workmen, and a host of other things, which, with the exception of the purchase of land, are generally included in the term "Establishment charges."

To prepare an estimate of this kind, which analyzes the cost of every item of the work into its three components—materials, labour, and detailed establishment and other charges—is a very intricate and laborious business. The quantities of materials are readily calculated from the complete drawings of the bridge and its foundations, and are priced at market rates, which are usually obtained by writing to the firms supplying such materials and obtaining from them quoted prices at which they are willing to supply, to which must be added the cost of transport.

For this purpose it is necessary to know in what units the materials used in construction are sold. The commonest are the following :—

Bricks, per thousand.
Stone, per cubic foot.
Timber, per standard of 165 cubic feet for soft woods, and per load of 50 cubic feet, or per cubic foot, for hard woods. Boarding, however, is sold at per square of 100 sq. ft., measuring each board its full width, and making no allowance for grooves, etc. Hard wood boarding is often sold per sq. foot " as inch," that is, the price quoted is that for a board 1 in. thick, other thicknesses bearing a price proportionate to the thickness.
Iron and steel, including corrugated sheets, per ton.
Cement, per ton.
Gravel, sand and shingle, per cubic yard.
Slates, per mil of 1200 with 60 added to allow for breakage.
Roof tiles, per 1000.
Nails, per lb. or cwt.
Lime, per ton.
Water, per thousand gallons.
Electricity, per Board of Trade unit of one thousand watt-hours.

The rates for labour are nowadays generally ascertained as standard Trade Union rates; a list of the foremen, gangers and other supervisors is made out with their probable rates of pay, the various other items of the establishment and overhead charges are carefully analyzed and separately estimated, and thus the total is arrived at. Labour costs are sometimes also estimated from **constants of labour.** These are figures showing the number of hours required in ordinary circumstances to carry out certain operations, *e.g.* to dig a cubic yard of earth, build a cubic yard of brickwork, etc. These are used in conjunction with the rate of wages for ascertaining the actual labour cost. A list of such constants is given in most engineering pocket books.

This is the kind of estimate which is usually prepared by a contractor's engineer when he is asked to tender for the construction of any large work.

Consulting Engineer's Estimates

When a consulting engineer estimates the cost of a work, however, in order to advise his clients as to the amount of capital required, he usually bases his estimate on the ascertained cost of some similar work. If this work was carried out by contract, he has by him a list of the quantities of the materials in that work together with the prices of those materials, only in this case the prices include labour, material, and establishment charges all together. For example, a contractor in estimating the cost of the concrete foundation for a bridge pier would require the amount and price of the ballast, sand and cement, the cost and quantity of water, the number of men and time required for mixing, and the cost of foreman's time, together with an allowance for establishment charges. A consulting engineer, however, generally keeps by him a list of prices, one of which will be for concrete of a definite mixture, the price being given per cubic yard of concrete, and including in one figure cement, sand, ballast, water, labour and supervision. This " overall " price, of course, reduces the labour of estimating very much, since it is only necessary to know the number of cubic yards of such concrete in order to estimate its cost.

As already stated, the price is obtained from an analysis of **past contracts**, and a certain amount of judgment has to be exercised when it is applied to conditions which are not identical with those of the previous contract, such as where there are alterations in price of raw materials or rates of labour, special difficulties of site, difficulties in transport of materials, etc. The exercise of such judgment is not usually left to a junior assistant, however, and his chief function is to obtain accurate quantities of materials in the units required, that is to say, yards or feet, square or cubed. For example, timber is given in cubic feet, concrete in cubic yards, rubble stonework in cubic yards, and so on, the particular units adopted being the result of custom.

BILLS OF QUANTITIES

The list of quantities prepared as above is called a **bill or schedule of quantities**, and when it is completed the engineer has only to put the appropriate price to each item and find the total in order to arrive at the estimate. This method of billing a small job is fairly simple and easily understood, but the bill for a large undertaking may be very elaborate, the different kinds of work being measured according to certain trade rules; members of a separate profession, termed quantity surveyors, devoting themselves to the preparation of such quantities.

For engineering work, the following list gives the most usual items, and their method of measurement :—

Excavation is billed in cubic yards. The quantity is arrived at by measuring the nett size of the hole, no allowance being made for the increase in bulk which occurs when the soil is dug out and piled in a heap. **Filling** is measured when it is in place *after* consolidation. If the sides of the excavation are so high that they will require to be supported by boarding, the superficial area to be so supported is measured and billed as a separate item.

Concrete is billed in cubic yards, the actual measurement when in place being taken. If concrete is laid in sheets six inches thick or under, it is billed in square yards, but a note is made in the bill of its thickness. If the concrete surface is levelled off carefully with cement mortar this is billed as a separate item in square yards.

Brickwork is billed in cubic yards, except for small works in London and the South of England where the quantity is given in terms of a "rod," that is, 272 square feet 13½ in. thick. The **face** of brickwork which is exposed to the view when the work is completed is measured separately and billed in square yards, to allow for the extra cost of using facing bricks and pointing the joints.

Timber in framing is billed in cubic feet, but where a piece of timber is cut to a tenon the full cube is taken *before* the tenon was cut. Similarly, nothing is deducted for holes or mortises. Timber of small section, say under 3 in. × 2 in., may be billed at per foot run.

Rubble stonework is given in cubic yards, more expensive **dressed stone** in cubic feet.

Steelwork in girders, stanchions, roof trusses, etc., is billed by weight in tons, cwts. and quarters.

Where an item is described as "extra only," or E.O. on another item, the price to be put to it should not include the cost of the first item. *E.g.* E.O. on brickwork for facings, means only the cost of the facing over and above the cost between ordinary brickwork; or the difference in cost between ordinary bricks and facing bricks. (See Appendix III.)

The actual preparation of a bill of quantities is usually carried out on a definite and standard system. Unless some such system is adopted there is great danger of confusion in the multiplicity of items and quantities taken from different parts of the work. In ordinary practice there are three separate steps in preparing a bill of quantities, viz. :—

1. Taking Off and Squaring,
2. Abstracting,
3. Billing,

and each step is carried out on paper ruled in a distinct manner. (See Appendix IV.)

The **taking off** is performed on "taking off" or "quantity" paper, of foolscap size, divided down the middle and each half ruled into four columns, the right-hand one being about 2 inches wide. The dimensions are booked in feet and inches whether the ultimate quantity be required in feet or yards or any other units, and in the fourth column is entered a description of the item. The dimensions are entered *under each other in the second column only*, and a short line is drawn under the last dimension. Thus, if there are two dimensions we know that the resulting quantity obtained by multiplying them will be an area; if there are three, a volume.

It frequently happens that there are several quantities in a work which are identical; for example, there may be 10 buttresses in a certain length of wall. In that case we enter the dimensions of one buttress in the second column and in the *first column* enter 10 with an oblique stroke after it. This is called "timesing." If we found afterwards another 3 buttresses previously omitted, we should enter in front of the 10 a 3 followed by a dot. This means 3 plus 10, or 13. In fact, the dot corresponds to an addition sign and the stroke to a multiplication sign. In other cases we may wish to add up a list of small dimensions to arrive at a total length. This is done in the wide fourth column, called "on waste," and the total entered opposite in the second column with the description as before in the fourth column. This "taking off" and booking is the most important part in the preparation of a bill of quantities, there being a risk of omitting some item or perhaps of taking it twice over. Freedom from interruption while engaged on it is essential.

When the whole of the quantities are taken off in this way they are **squared**, that is, the several dimensions are multiplied together to obtain the area or volume, whichever may be required, not forgetting the timesing or dotting on, the figure so obtained being entered in the third column.

It is frequently convenient to take off the whole quantity of a portion of a work and then make deductions from this quantity, as in the case of a wall with openings, where the wall would be taken off as one item and then the openings deducted. In that case the contents of the openings are entered as if they were solid wall, but in the fourth column with the description is entered the word "Deduct," or "Ddt."

After the squaring comes the **abstracting.** This is done on paper of double foolscap size, ruled into parallel vertical columns about 1¼ inch wide. Each column is headed with a short description of one of the items to be entered on the bill, and the units in which it must be billed, *e.g.* Brickwork, cub. yds.; Timber, cub. ft., etc. Then each item in the third column of the quantity paper is carefully transferred under its appropriate heading on the abstract paper, and as it is transferred it is ticked off on the quantity paper by a long tick which is joined up to the ticks above and below. By this means it is readily seen if any item has been missed. Items of the same kind are thus grouped together on the abstract paper, where they can be added up, the necessary deductions made and the whole converted into the appropriate units for billing.

Bill paper is of foolscap size ruled into nine vertical columns, four narrow ones on the left, a wide central one, and four narrow ones on the right. Numbering these columns from the left, the first three are for yards, feet and inches respectively; the fourth describes whether the item is "lineal," "super," or "cube"; the centre one gives a clear and detailed description of the item; the sixth the rate of price per unit of measurement; and the three remaining ones are for the pounds, shillings and pence obtained by multiplying the quantity by the rate. It should be noted, however, that quantities are usually squared out by duodecimals, and that the column headed inches really gives for each unit a twelfth of a foot, that is to say, an inch in the case of linear items, 12 sq. inches for super items, and 144 cubic inches for cubic items. Each item is then transferred from the abstract to the bill and ticked off at the same time. When the quantities are thus billed, the estimate is completed by adding on sums to represent such items as may be required in addition, and are generally included in the terms establishment or overhead charges, and an amount at the end for contingencies which may vary from 5 to 25 per cent. In most cases the prices put against the various quantities, if obtained from previous bills of quantities, include an allowance for establishment charges in the rates themselves, in which case no further allowance is necessary.

Bills of quantities are also got out in this way for another purpose, viz. to enable intending contractors to prepare accurate tenders for work which they desire to carry out. The bills in this case contain very full and careful descriptions of the quantity and kind of work to be done, and are issued to the intending contractors (the price columns being left blank), who thereupon price out each item and total up to arrive at the amount of the tender. This system will be dealt with more fully in the chapter on contracts.

Capital and Running Costs

Questions frequently arise in which an engineer has to compare the costs of two different methods of carrying out a piece of work. This is, of course, a simple matter when lump sums or capital expenditure only are concerned. For example, the comparison between two different methods of bridging a river may be easily made when quantities have been prepared.

The case is very different, however, when balancing **capital expenditure** against **running costs.** As an example, let us consider the following problem. A seaport town desires to get rid of its refuse. The Town Council may either build a refuse destructor and utilize the steam obtained from the burning refuse and so reduce the cost of burning, or they may employ a contractor to take away the refuse and dump it at sea at an inclusive price per ton. The question is : which method will be the cheaper for the town ? We will assume that the following data have been ascertained.

Cost of destructor, chimney, boiler, etc., £9000.
Amount of refuse to be destroyed, 6000 tons per annum.
Value of refuse in heat raising, $\frac{1}{15}$ value of steam coal at 28/- per ton.

Cost of stokers' wages, etc., £10 per week.

Estimated cost of repairs to destructor, £200 per annum for thirty years, when the furnaces, boiler and chimney would be worth practically nothing, their "economic life" being finished.

Against the above, the contractor's tender to take the refuse clear away, providing all labour, barges, etc., is 3/- per ton.

In order to compare these two alternatives we must convert the first one into an annual charge as follows :—

Repairs to destructor	-	£200	per annum.
Labour (stokers, etc.)	-	520	,, ,,
Total	-	£720	,, ,,
Less $\frac{1}{15} \times \frac{6000}{1} \times \frac{28}{20} =$		560	value of refuse as coal.
Leaving	-	£160	

In addition to this must be reckoned the **annual charges** on a capital cost of £9000. Now, the Town Council, in order to obtain this £9000, will have to borrow it at, say, 4 per cent., and therefore the cost in interest alone to them will be £360 per annum. This is not all, however. At the end of thirty years they will have a worthless destructor and be faced with a liability to pay back the £9000 they borrowed. They may deal with these two liabilities, viz. interest and repayment of loan, in various ways :

(1) They may put by an annual sum sufficient to pay interest on the loan, and in addition to cover the gradual depreciation in the value of the plant, assuming that the **depreciation** is uniform over the whole of the life of the plant. In this case the sum required will be £360 plus $\frac{9000}{30}$, or a total of £660 per annum.

(2) They may put by an annual sum sufficient to pay interest on the loan, and in addition they may invest a sum

each year[1] in a **sinking fund** which at compound interest will in thirty years amount to £9000. With this £9000 they may then pay off the debt. It will be found on consulting the compound interest tables given in most engineering pocket books, that a sum of £1 invested at 4 per cent. each year will in thirty years from the time of the first investment have amounted to approximately £56. Therefore, a sum of $\frac{9000}{56}$ = £160 (approx.) will under the same conditions amount to £9000, and the total annual charges for interest and redemption of capital will be £360 plus £160 = £520. If tables are not available for reference the following formula may be used. If M be the accumulated amount of £1 invested annually at p per cent. for n years, then $M = \frac{100}{p}\left\{\left(\frac{100+p}{100}\right)^n - 1\right\}$.

(3) They may repay each year a sum[1] which will be sufficient to " kill " the original loan plus its interest in thirty years. The sum required will be more than £360 per annum, the excess over £360 being used at the end of the first year to reduce the amount of debt incurred. This will reduce the amount of interest due the second year, and so in future years an increasing proportion of the annual instalment will be available for reduction of debt. In this way the debt is reduced each year by an increasing amount. The annual amount required for a loan of £9000 to be wiped off in thirty years comes out at £520 by this method also. If A = annual amount required, L = total amount of loan, n = number of years, and p = rate of interest per cent., then

$$A = \frac{Lp}{100}\left\{\frac{\left(\frac{100+p}{100}\right)^n}{\left(\frac{100+p}{100}\right)^n - 1}\right\}.$$

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[1] At the *end* of each year.

For rough and preliminary estimates engineers often calculate the loan charges by the first method, which possesses the advantage of simplicity, but the second and third methods give more accurate results and are those adopted by accountants. In the case given above, the total annual cost of burning the refuse in a destructor, including operating costs and loan charges, will be £160 plus £660 or £820 per annum by the first method, and £160 plus £520 or £680 per annum by the second and third methods. These costs have to be compared with a total inclusive cost of 6000 × 3/- = £900 per annum for barging away the refuse, and it is on the basis of this comparison that a decision will be made.

ROUGH ESTIMATES

Rough estimates may be made by adopting special units of measurement; thus buildings may be **cubed**, that is, the volume ascertained by measuring the superficial area contained within the outer faces of the external walls, multiplied by the height from the top of the foundation concrete to the mid-point between the eaves and ridge. This will give the volume of the building, which may be priced at a figure per foot cube obtained from some similar completed building the actual cost of which is known. Hospitals may be estimated at per bed in the same way, and railways per mile of track, etc. Such estimates, however, should only be used for rough preliminary purposes, and great care should be taken to make due allowance for special difficulties of site, etc.

CHAPTER IV

LEGAL AND PARLIAMENTARY

REGULATIONS AFFECTING ENGINEERS' WORK

THE activities of engineers in Great Britain are limited and defined by Acts of Parliament in many ways. The **Board of Trade** and **Ministry of Transport** issue regulations which must be complied with concerning railways, tramways, harbours, steamships, electric lighting, and roads.

Town and **Urban** and many **Rural District Councils** have bye-laws, with the authority of an Act of Parliament, regulating the erection of buildings. Some rivers are governed in this way by **River Conservators,** and harbours by **Harbour Commissioners** or **Boards. Fire Insurance Companies** have regulations as to construction of buildings and electric wiring, which must be complied with if insurance is to be effected. **Lloyds Registry** for vessels, and **Boiler Insurance Companies,** have their own rules. **Power and Light Authorities,** whether private companies or public bodies, will not allow any unauthorized connection to be made with their mains, nor will **Water Authorities** with theirs. In addition, lighting and water services must be to the requirements of the supplying authority. **Local Authorities** have their regulations as to disturbing roads and connecting to sewers. Engineers must be familiar with the regulations governing their work in the district in which they propose to carry it out. They may obtain copies of the regulations from the authorities in question, and should consult them before proceeding far with the design of any scheme.

Parliamentary Work

There are, in addition, many engineering schemes which if carried out would involve interference with long vested interests, the chief of which is interest in land. A typical case is that of a projected railway. The promoters of such a scheme endeavour to find a route for the proposed line which shall be as direct and convenient as possible, and in order to do so they have to purchase a continuous strip of land of a certain width. In negotiating with the landowners they may encounter opposition; in fact, one landowner, by refusing to sell even if tempted by a high price, may stop the whole scheme. On the other hand, the projected line may be of the utmost value to the rest of the district, or even to the country at large, and therefore Parliament has given promoters certain powers of compulsory purchase under well-defined conditions.

In the first place, no such line must be constructed without an Act of Parliament authorizing it, and certain formalities must be complied with, as laid down in the **Standing Orders of the Houses of Parliament.** These formalities are designed to allow all persons affected in any way by the proposed scheme to bring forward reasonable objections. The engineer's duties in connection with such a scheme are generally limited to the production of **Plans, Sections, Estimates** and a **Book of Reference**, or schedule of property giving the names of owners, lessees, and occupiers of all land touched by the proposed works. Notices are served on all persons affected, and documents deposited for public reference at the Houses of Parliament, Board of Trade, local Town Halls, etc.

The engineer obtains a copy of the Standing Orders of the Houses of Parliament, and prepares the document carefully according to the rules laid down therein, so that no objection can be lodged by those opposing the work on the ground of non-compliance or inaccuracy (Appendix VI). Plans have to be to a scale not smaller than 4 in. to a mile, sections 1 in. to 100 feet vertical and 4 in. to a mile horizontal, and plans of buildings 1 in. to 400 ft. In England, in areas where there are no buildings, the 6 in. to a mile ordnance map is generally corrected and brought up-to-date by careful survey on the ground and is used, or if buildings are to be shown the 25 in. ordnance map is used, corrected in the same way. The plans are traced in black when corrected, and lithographed by firms who make a speciality of this work.

The work of the assistant is to make and correct these plans. A tracing of the ordnance map is first made on tracing paper, pinned on a board, and carefully corrected and brought up-to-date on the ground. The corrected tracing is then transferred to a sheet of drawing paper of the size of a sheet of the lithographed "book of plans," by means of carbon or black lead paper placed under the tracing, which is lined over with a hard pencil. The drawing is inked in, and the particulars required by the Standing Orders of the Houses of Parliament are roughly but accurately printed upon it, the lithographers copying the drawing and notes, but employing their own type in printing.

The promoters may show on their plans "limits of deviation," not exceeding a certain amount, on each side of their proposed centre line, within which limits, if they obtain the powers asked for, they may alter the line of the proposed works if necessary, owing to unforeseen obstacles, without the necessity of having to obtain fresh powers. The assistant preparing the plans should be careful to see they are accurate in every detail as they may be minutely examined by opposing parties familiar with the ground, and the promoters' case prejudiced if there is any error. The estimate is made out in round figures in the form prescribed by the Standing Orders, which do not call for detailed quantities, and the Book of Reference is printed at the same time.

The particulars for the book of reference are not usually obtained by the engineer, but he should see that the reference numbers correspond with those on the plans. These particulars are prepared in the late autumn, so that all documents are ready to be deposited in November. The bill is then promoted by solicitors, called **Parliamentary Agents**, who have an intimate knowledge of the procedure required.

If the Standing Orders are found not to have been complied with in any material way the bill cannot go forward, but may be promoted again next session. If it is correct it is read formally in the House, and then referred to a committee of the House of Commons, where it is thoroughly discussed and objections heard. After this, with possibly some modification agreed upon by the promoters and opposers in committee, it is read again in the House and passed if the committee reports favourably. This is repeated in the other House, and it then receives the Royal Assent and becomes an Act.

In order to cheapen and simplify this procedure, certain works may be authorized by a **Provisional Order** of the Board of Trade. Plans, sections, estimates and book of reference are prepared as before and lodged with the Board of Trade in November. The Board takes evidence and considers the proposal, and if it reports favourably a covering bill is promoted in the following June. Upon this bill receiving the Royal Assent the Provisional Order becomes invested with the authority of an Act of Parliament, and the work may be commenced.

Engineers holding positions under large companies must, of course, be familiar with the terms of the Act authorizing the formation of such companies. Those employed by public bodies, such as Town Councils, must also be conversant with the various public acts governing their work, such as the great Public Health Act of 1875 and its amending Acts, which prescribe what local authorities may do, may not do, and must do, in connection with roads and sanitation.

CHAPTER V

EXECUTION OF WORKS

COMPARISON OF METHODS

THERE are two usual methods of carrying out engineering works: (*a*) **by direct labour**, (*b*) **by contract.**

If **direct labour** is adopted, the engineer who prepares the scheme is also entrusted with the duty of carrying it out, and this entails much labour in obtaining quotations for and buying materials, hiring or buying plant such as cranes, timber for stagings, tools, pumps, ladders, etc., and engaging and insuring workmen. The work is then put in hand, constant supervision is exercised, a system of accounting is devised to see that stores are bought and checked as required, and to enable the actual cost of any portion of the work to be ascertained; and on completion the staff and workmen are paid off, and the surplus stores and second-hand plant sold.

By the **contract** method, the engineer who prepares the scheme prepares also a contract, consisting of a set of drawings showing as clearly as possible the work to be done, and a specification describing this work and the materials to be used, and in most cases also a bill of quantities giving the exact amounts of the different kinds of work to be carried out. After these documents have been carefully checked and several copies of each made, intending contractors are invited to tender for carrying out the work. In some cases an advertisement is published in local and technical papers inviting tenders, in others certain firms of known repute and standing are invited by letter to tender. Each intending contractor obtains a copy of each of the contract documents and examines them carefully, and finally, on the basis of the stipulations contained in these documents, offers to carry out the work for the lowest sum which he thinks will give him a reasonable profit. The various tenders are considered and compared by the engineer or a committee, and the lowest one, if satisfactory in all respects, is accepted.

It is customary to require a small deposit from persons invited to tender by public advertisement, to avoid having to supply copies of the contract documents to irresponsible persons who merely require them out of curiosity. This deposit is returned on the receipt of a bona fide tender. Certain precautions have to be adopted to prevent any possibility of a contractor ascertaining the tender of a rival contractor before the contract is let. Tenders should be in sealed envelopes, and should never be opened before the time stated in the advertisement. When the contract is let, it is usual to publish the amounts of all the tenders, but not the detailed prices, which are always regarded as confidential.

The work is then commenced by the contractor, who has now to obtain materials, labour and plant, and is paid from time to time certain agreed sums by the engineer—based on measurements of the work taken periodically by an assistant, entered up in a note-book ruled in a similar manner to quantity paper, squared out, abstracted and billed—until the contract is completed and the total amount paid.

Speaking generally, the contract system is adopted where possible for works which can be clearly described and foreseen. A contractor who specializes in this class of work can often carry it out more economically than the engineer, owing to his special experience in organization, and also owing to the fact that he can use his special and sometimes costly plant several times on different contracts of the same kind. There are some works, however, such as large excavations under water or in treacherous ground, which are extremely difficult to describe in a contract, on account of unforeseen difficulties which may occur. Drawings, for example, may show foundations to be taken 20 feet below a river bed, and a contract may be prepared and let on this basis, yet when the work is commenced the river bed may be found to be so soft that the foundations have to be taken much deeper, necessitating extra excavation, timbering, pumping and concrete, for which the contractor will expect to be paid.

The difficulty of adjusting such payments on an equitable basis, or of preparing a contract which shall be fair both to the promoters and the contractor, often causes the engineer to determine to carry out the work by direct labour. Radical alterations of method can then be adopted during the works without any dispute as to how they shall be valued and paid for. Cases also occur occasionally, though rarely, where the usual conditions may be reversed and the engineer may possess special knowledge, personnel and plant enabling him to carry out work cheaper than a contractor, when the method of direct labour would again be adopted.

DIRECT LABOUR OR ADMINISTRATION

Under the direct labour system, general drawings of the scheme are first prepared and approved. Land is set apart, or if necessary rented or purchased, for erecting the plant necessary, such as railway sidings, cranes, concrete mixers, cement sheds, general stores, brick, steel, and stone yards, block-making yards, workmen's sheds, workshops, mess rooms and cookhouses, latrines, pay offices, offices for assistants, etc. Careful consideration is given to the most economical arrangement of these in order to avoid confusion in the handling of material. At the same time letters are written to various firms supplying material asking them to quote prices. These quotations are analyzed and compared, and the most favourable one accepted by letter.

While comparing the quotations, due regard is paid to the question of cost of carriage and cartage. Prices are sometimes quoted to include carriage, but more often they are quoted f.o.r. (free on rail) at the despatching station, which means that the purchaser must pay the railway charges to his nearest station and also the cost of carting to the site of the works. The railway charges may be obtained from the local railway goods agent or from a study of the complicated railway rates book, and the cartage costs may be quoted for by a local cartage contractor, or cartage may be performed by carts or lorries purchased or hired by the day or week.

When the quotation is accepted and the goods are ordered to be sent forward, a copy of the order is handed to the storekeeper so that he may know what to expect, and when the goods are despatched by the supplying firm, a "pro forma" invoice is sent by them by post to advise the recipients. This invoice is not usually priced, and merely gives a detailed description of the goods, the date of despatch and route, and how they are packed. This is also handed to the storekeeper, who checks the goods with it on arrival, signs the carter's delivery book as having received them, and enters them into his store book. After a time the suppliers send their bill or priced invoice, which is checked against the goods actually received, and if correct is certified for payment.

Every bill should be certified as to the goods having been received, their quality, and their price. Without entering deeply into the principles of **stores accountancy,** it may be stated that the essential points to be borne in mind are as follow :—

(*a*) A copy of every order should be sent out. In most offices a notice is printed on the order form to the effect that no orders not on the official form are to be recognized as coming from the engineer. The order forms are kept—usually in books—by the chief clerk, and thus no goods can be ordered without his knowledge. This is a necessary precaution, as otherwise he would not know how to estimate the value of unfulfilled orders when he wished to prepare a financial statement during the progress of the works.

(*b*) All stores coming under the charge of the storekeeper should be entered into the stores ledger, and all stores issued to the works should be booked out to their respective jobs. By this means an estimate of what is in stock can be made by reference to the books.

(*c*) The ordering clerk usually requires a signed and dated requisition from anyone who wishes to order goods, in order to protect himself. Assistants are sometimes supplied with official requisition forms. The orders are numbered and dated.

(*d*) Quotations and invoices should be filed for use in checking the bills when they are received, first with regard to prices, second with regard to quantities.

(*e*) When a bill is certified as correct and passed to the financial authorities for payment, an entry should be made on the counterfoil of the order. Whenever a bill is received the corresponding order (which should be referred to on the bill) is turned up, and it is then seen if it has already been paid. It sometimes happens that two or three bills for the same order are received in succession, and if memory alone were trusted to, it is quite possible that payment might be made more than once on the same order.

The foregoing brief account will enable an assistant to keep track of goods which he has perhaps requisitioned some time ago, and the delay of which in arriving may be keeping back a portion of his work.

With regard to the **labour** employed, the more responsible posts, such as resident engineers, assistants, and clerks of works or managers, are usually filled by advertising the vacancies and appointing the best qualified applicants after interview. Their rates of pay or the character of their work are such as to avoid the necessity for compulsory insurance referred to below. Workmen are taken on when suitable as they apply. Each man is insured under the national scheme against ill-health, and also against unemployment, and the employer has to pay a contribution each week towards the cost of this, and in addition deduct and collect a certain small sum from the man's wage for the same purpose. These two contributions are put together by the employer, who purchases stamps to cover their value, affixes these stamps to the workman's card and cancels them. Besides this, most employers pay a weekly premium to some approved Insurance Society in order to insure against their statutory liability, under the Workmen's Compensation Act, for accidents to their men.

The rates of pay are in most cases those standardized by the Trade Unions or a little above, and it is necessary to be familiar with the Trade Union rules governing the work appropriate to each trade, so that fitters, for example, may not be set on to work which should be done by plumbers.

Each man has his time booked by a timekeeper, who also puts down the number of hours worked by him on any particular job, thus enabling a cost clerk to find out the actual material and labour cost of that job from the time book and the stores issue book. These **analyses of costs** are useful for obtaining accurate estimates of projected work of a similar kind later.

The men are usually paid weekly on Friday nights, but when a man is taken on it is often the practice to "sub" him, or pay him a portion of his wage in advance, deducting it at the pay day.

An important part of the assistant's duty will be the inspection and testing of material delivered to the works. This involves a certain amount of responsibility, and the details of it are discussed under the appropriate headings in later chapters.

CONTRACTS

The previous section gives an outline of the duties of the engineer and his staff where the work is carried out by direct labour. Where the **contract system** is employed these duties devolve upon the contractor and his staff, those of the engineer being confined to the preparation and supervision of the contract.

A **contract** is an agreement (in writing in the cases we are considering) between a party who wishes the work to be done and undertakes to pay for it, usually called the employer, and a party, who undertakes to do the work for the agreed sum, called the contractor. It is a legal document, prepared by lawyers, duly stamped with the proper Inland Revenue stamp, and signed by the two parties and witnesses. Large contracts usually embody the following documents as well, viz. :—

(*a*) **A form of bond for sureties.**
(*b*) **A form of tender.**
(*c*) **Drawings.**
(*d*) **Specification and conditions of contract.**
(*e*) **Bills of quantities.**

These are all bound in with the contract after they have been signed and witnessed, and will now be considered in detail.

The **bond** is a legal document prepared by lawyers and signed by a responsible person or persons, who guarantee to pay a named sum of money, usually from $\frac{1}{5}$ to $\frac{1}{2}$ the contract amount, in the event of the contractor failing to carry out his contract. If such occurred the employer might find himself saddled with half-finished work by a defaulting or bankrupt contractor, the cost of finishing the work or of even protecting what was already completed having to be borne by the employer in circumstances which might render the expense very heavy.

The **form of tender** is also a legal document. One is sent to each intending contractor on which he submits his tender, so that there is no doubt about its being in the correct form.

The **drawings** on which the contract is based must be prepared with the utmost care. There are often many sheets of them headed with the name of the contract and numbered consecutively. They should show the situation of the works in the form of a block plan, the details of construction generally to a scale, usually of 8 feet to an inch, and, if necessary, further details to a larger scale (often 2 feet to an inch). Before they are prepared it is advisable to dig **trial holes** on the site of proposed foundations, or drive **boreholes** in order to ascertain the nature of the subsoil. The data obtained from these trial holes are stated on the drawings, and this information is available for the intending contractor when tendering. The conclusions drawn from such data are often found to be untrustworthy when the main excavation is carried out during the progress of the work, and may lead to much unforeseen extra work in the foundations and a troublesome adjustment of the price with the contractors. Dimensions are freely employed on the drawings, and the usual method of preparing these nowadays is to make careful pencil drawings on good drawing paper, trace these in ink on to linen, and then make white sun prints--either on paper or on linen—which are coloured up by hand. A complete set of these is bound up with the contract, another set is supplied to the successful contractor, and others are set aside for use on the works. It is an advantage if they are printed on linen, as they often have to withstand rough usage.

The **specification** is a long document written by the engineer, and giving a detailed description of the work to be done. It is often prepared by altering some specification of similar works carried out in the past to fit the conditions of the new work. Although it is prepared by the engineer, it contains many legal clauses, and the meaning and bearing of these on the work must be clearly understood by those in charge.

Before the work is described technically, there are many general clauses called the **general conditions of contract,** which are based often on a standard form prepared by the solicitors to the promoters, with sundry slight modifications made by the engineer to fit them for the particular work. The most important clauses define the **extent** of the contract; state that all **plant and materials** have to be provided; and specify how **payment** will be made, usually at the rate of 80 per cent. of the value of the work done, this value being ascertained each month by the engineer, who writes out a **certificate** authorizing payment. These certificates are usually made out on printed forms, and show the contract amount, the total value of the work carried out by the contractor up to date, after deducting retention money, etc., the amount of past payments made to the contractor, and by subtraction the amount of money still due to the contractor (*v.* example at end of this chapter). In arriving at the amount it is customary to allow for half the value of materials brought on to the site by the contractor. There are clauses providing for the proper **lighting** of the works; **fencing** the site; the provision of **watchmen**; the **insurance** of the work against fire risks as it proceeds; the liability for **accidents** to fall on the contractor; and the prevention of **subletting** the contract by the contractor without written permission from the engineer. The times of **commencement** and **completion** are stipulated, and a penalty clause is inserted to deal with avoidable delay by the contractor. The work has usually to be maintained and kept in repair by the contractor for a period after completion, part of the contract sum being retained until this period expires.

One of the most important clauses is that relating to **variations** of the contract. Few contracts can be so definitely foreseen in all their details that no variation from the scheme detailed in the specification is necessary. This applies particularly to works which involve excavation and foundations, where an unexpected change in the strata may necessitate serious modifications in the whole design. This has already been mentioned in connection with the subject of trial holes and borings, and it is obvious that the payment to the contractor must be adjusted to allow for any extra work which is necessitated, or to allow on the other hand for any work which has been omitted from the original scheme. These variations are known as **extras** and **omissions**, and one of the most arduous duties of the engineer is their equitable valuation, leading to long conferences and disputes in many cases with the contractor. The specification clause dealing with this point needs to be carefully written, and generally stipulates that variations shall not render the original contract invalid, and that disputes shall be referred to **arbitration**, the name of the arbitrator being often specified.

A further clause is often inserted, dealing with the question of **sureties** and form of bond for the due performance of the contract. This has already been explained when dealing with the bond as a contract document.

The **general conditions of contract** just described are often in the form of a separate document attached to the specification proper. Standardized forms, such as that published by the Royal Institute of British Architects, will probably be used by most engineers in the future.

The **specification** itself often commences with preliminary technical clauses dealing with the following points, though these clauses are best embodied in the general conditions above mentioned. **Discrepancies** between the various contract documents are to be submitted to the engineer, who will decide which is to be followed. **Setting out** is usually done by the engineer's and contractor's representatives, but the contractor is held responsible for its correctness, the engineer's representative merely assisting and advising. Definitions are given of such terms as **prime cost** and **provisional sums**, which will be dealt with in more detail under the heading of bills of quantities, and other clauses specify that **notices** shall be given by the contractor to the local authorities where required by them and the necessary fees paid by him, as, for example, where a road has to be dug through or a connection made to a sewer or water main, or a hoarding has to be erected around the site of the works. It is usually specified that a **contractor's representative** shall be kept constantly on the works, so that there may be no delay in receiving instructions from the engineer.

An important clause gives details of the procedure to be adopted where unforeseen work is ordered by the engineer for which there is no price in the bill of quantities. In that case **daywork** has to be resorted to; that is, the contractor has to keep a record of the materials consumed and time employed on that particular work, a copy of this record being sent to the engineer's representative for verification and check while the work is going on. The method of taking measurements for the **valuation** of the work is also stated, and provision is usually made for the contractor to erect an **office** for the resident engineer, **latrines** and **work sheds** for the workmen, **stores** for the material—especially cement, which must be kept dry—the laying on of **water** to the works, and precautions to prevent **damage** either to the public or to surrounding property or roads.

After these come the strictly technical clauses specifying in detail the qualities of the various **materials** to be employed, and the **workmanship** in all branches of the various trades, with a final clause to ensure that all surplus material, plant and rubbish are cleared away at completion. The requirements of the purely technical clauses are alluded to in the later chapters on construction.

The last, and in some respects the most important, of the contract documents to be considered is the **bill** or **schedule of quantities.** This has already been referred to in the chapter on estimating, and the method of preparing it is there described. Small contracts are often prepared without a bill of quantities, and in such cases the intending contractor in preparing his tender works out his own quantities from the drawings and other particulars supplied to him. Usually, however, the engineer preparing the scheme includes in the contract documents a bill showing in detail the quantities and kinds of all the materials and labour required to carry out the contract, and in most cases these quantities are guaranteed to be correct by the engineer; that is to say, if larger amounts than those contained in the bill of quantities are found to be required on the work while it is being carried out, then the contractor will be paid extra for these larger amounts at the same price per unit quantity as is given in the bill. These prices are all filled in by each intending contractor, the total forming the tender. Not only the quantities, but also the descriptions of the workmanship and materials must be accurate and complete to enable an intending contractor to estimate correctly. The bill usually commences with a series of **preliminary items** copied from the preliminary clauses of the specification, many of these items seriously affecting the cost of the work. The most important are the clauses relating to the provision of water, light, fencing, offices and sheds, time required for completion, etc.

In addition, definite **provisional sums** are often included in the bill for works which cannot at the time be foreseen sufficiently clearly to enable a detailed bill of quantities to be prepared for them. Such are a general provision for **extra works** which may be ordered, without necessarily specifying the nature of the work in the bill, or for some separate section of the main work, such as a heating system in the case of a large building, or a dock caisson in the case of a dry dock, which is often not designed until the main contract is well under way. These provisional sums are not paid to the contractor up to the full amount, but only the portion of them which covers the actual cost (including profit) of the work ordered by the engineer to be carried out under those headings. The actual cost is usually ascertained by daywork returns, and an agreed amount added for the contractor's superintendence and profit, often 10 or 15 per cent. In some contracts the amount to be added for superintendence, etc., is stated in the contract.

Besides these provisional sums, **prime cost** sums are often mentioned in the bill. There are many cases where definite articles have to be bought by the contractor and fixed by him. In such cases the items dealing with these in the bill specify the prime cost of these articles, that is, the nett cost at which the contractor buys them in the first instance—not the list price, which in many cases is subject to a heavy "trade" discount to contractors—and the contractor in pricing the bill allows for his own profit and the cost of carriage and fixing. If the article should cost more or less than the price laid down in the bill, the payment to the contractor is adjusted accordingly, the same amount being allowed for profit, superintendence, carriage and fixing.

Occasionally the bill of quantities is not guaranteed by the engineer, but must be checked by the contractor before tendering. Its sole use is then as a schedule of prices on which variations on the contract can be valued, the actual amounts in the quantities, even if proved to be incorrect during the execution of the works, not affecting the total or "lump sum" contract figure.

The blank bills of quantities, as prepared by the engineer, containing amounts and descriptions but not prices, are usually typed or lithographed by some firm making a speciality of the business, and those copies priced by intending contractors are treated as strictly confidential by the engineer, the greatest care being taken to prevent any contractor from seeing the detailed prices of any of his competitors, with the exception of the total amount of each tender, which, as before stated, is made public when a tender is accepted. In fact, only the detailed prices relating to tenders which are likely to be accepted are seen by the engineer in many cases, the bills of quantities relating to the higher tenders being often returned to the competitors in their sealed envelopes.

Bills of quantities for small and intricate works, such as repairs to buildings, are sometimes prepared in a similar form, with the exceptions that no quantity is stated in the columns on the left hand of the bill paper, and that a unit price is printed by the engineer in the column reserved for that purpose. Detailed descriptions of the work to be done are also printed in the centre column, and the contractor when tendering merely states at what percentage above or below the printed prices he is prepared to carry out the work. Such a percentage applies equally to all the prices. The actual quantity of the work is not known until it is carried out, when it is measured up on the spot by the contractor's and engineer's representatives, and priced according to the printed rates, with the contractor's percentage added or deducted as the case may be. The bill of quantities in this case is more correctly termed a **schedule of prices.** In some cases a similar method is adopted with the exception that the unit price column is left blank, and the contractor in tendering inserts his own rates at which he proposes to carry out the work. Contracts based on such schedules are often called **"measure and value contracts."**

GENERAL CONDITIONS OF CONTRACT

The following section gives a short set of **typical conditions of contract** and **preliminary specification clauses,** together with a **form of tender, form of advertisement** and **engineer's certificate.** Those which are not self-explanatory have already been described. Some engineers prefer to include the preliminary specification clauses in the general conditions of contract, and restrict the specification proper to technical descriptions of materials and workmanship. The wording of the following clauses has been somewhat simplified from the legal phraseology usually employed for large contracts, in order to render the essential principles more distinct. It would do for small contracts, however, as it stands. Important technical clauses are given at the ends of the appropriate chapters on construction. Note that the remarks in parentheses are merely the author's comments, and do not form part of the specification.

Basis of contract. This contract includes the preparation for construction and completion of...and all works appertaining thereto. The documents on which the contract is based are the specification, the plans and sections marked........................, the conditions of contract and the bill of quantities. A contract deed will be prepared and stamped, and the parties to the contract will sign this and the documents on which the contract is based.

Copies of documents. A copy of the plans and sections, specification and bill of quantities will be supplied to the contractor, and must be returned to the engineer at the end of the contract.

Plant, etc. The contractor is to supply all materials, labour, plant, and everything necessary for the complete execution of the works.

Accidents. The contractor is to indemnify and keep harmless the employer from all claims for accidents, loss, or damage to his workmen through the operation of this contract.

Insurance. The works are to be insured when required by the engineer to the full amount of the contract in an approved office and the policy deposited with the engineer.

Commencement and completion. The works are to be commenced within seven days of the receipt of a written order, and are to be completed within.............................days of the date of the order under a penalty of............................ per day as ascertained and liquidated damages, to be deducted from any money which may otherwise be due to the contractor, or to be recovered by action at law. (A bonus may be specified similarly for completion within the required time, the amount depending upon the time saved.)

Maintenance. The works are to be maintained and kept in good order for a period of..............................months from the actual date of completion as certified by the engineer. During this period all defects are to be made good at the contractor's expense, and all handed over at the expiration in good working order.

Payment. Payment will be made monthly on the engineer's certificate at the rate of 80 per cent. of the value of the work completed, and 50 per cent. of the value of materials brought on the site, as ascertained by periodical measurements agreed on by representatives of the engineer and contractor. A further payment of 50 per cent. of the balance will be made on the engineer's certificate that the works have been fully completed, and the rest of the balance will be paid at the end of the period of maintenance if the work is entirely satisfactory. All balances will be paid without interest.

Damage. The contractor is to be responsible for any damage to the general public or adjoining property, roads, or works which may accrue through the operation of this contract. Suitable and approved fencing and hoardings are to be erected and maintained, and the works are to be properly watched and lighted at night. The contractor is to construct any temporary roads required at his own expense.

Variations. No additions, alterations or deductions shall invalidate the contract. Their values are to be ascertained by direct measurement and priced at the same rates as those in the bill of quantities where these apply. In other cases the value is to be ascertained by daywork as described below.

Daywork. Where any variation is ordered by the engineer, to which in the opinion of the contractor the prices in the bill of quantities do not apply, he is to notify in writing to the engineer, who, if he agrees, may order the work to be carried out by daywork. In such a case a weekly return of the men, materials and transport engaged on that particular work shall be rendered to the engineer through the clerk of works, who will check and countersign it if correct. To the nett cost of such daywork a fixed percentage will be added to cover superintendence, expenses and profit, viz. 10 per cent.

Claims. The contractor shall not be entitled to make any claim for extras unless he has received a written order from the engineer authorizing him to commence such extra work.

Instructions. The engineer may issue detailed instructions by means of drawings or in any other way, but such instructions shall not be deemed to be orders for variations unless they state so explicitly.

Subletting. The contractor is not to sublet the contract or any part of it without the written sanction of the engineer.

Sureties. The contractor is to find two good and substantial sureties to the satisfaction of the employer to be jointly and severally bound with him in the sum of .... for the due fulfilment of his contract.

Royalties and tests. The prices are to include any cost of royalties, patent rights, rents for gravel, etc., incurred on any of the plant or materials used on this contract. Any tests required by the engineer are to be carried out at the contractor's expense if such test shows that the material is below the standard specified.

Bad work. All bad work is to be removed and made good without delay in accordance with the engineer's instructions at the contractor's expense.

Contractor's foreman. A responsible foreman is to be kept constantly on the works, to whom instructions may be given in the absence of the contractor, and whose acceptance of such instructions shall bind the contractor.

Methods of construction. No method of construction or use of special plant is to be commenced until it has been submitted to and approved by the engineer.

Access. The engineer and his representatives are to have free access to the work at all times.

Arbitration. Where any dispute arises which is not covered by the contract, and on which the engineer and the contractor cannot agree, the question shall be submitted to an arbitrator, who shall be the President of the Institution of Civil Engineers or such other person as may be mutually agreed upon, and whose decision and award shall be final, both as regards the matter referred to him and as regards the payment of the costs of the arbitration. The arbitration is to conform to the provisions of the Arbitration Act, 1889, and any subsequent modifications.

Lien on plant and materials. All plant and materials brought by the contractor on to the site of the works are to be deemed the property of the employer, who is to have a lien on the same until the completion of the contract, and they are not to be removed without the sanction of the employer.

Materials and workmanship. All materials and workmanship are to be to the satisfaction of the engineer, who may reject any which in his opinion are unsatisfactory; and the same are to be forthwith removed from the site and replaced at the contractor's expense.

Workmen. The engineer shall be at liberty to dismiss any person employed by the contractor who in his opinion is unskilful or incompetent.

Determination of contract. If in the opinion of the engineer the contractor does not carry out the work with due diligence and despatch, the employer shall be at liberty to determine the contract by notice in writing, and to take possession of all materials, plant, etc., then on the site of the works.

PRELIMINARY CLAUSES IN SPECIFICATION

Discrepancies. Should there be any discrepancy between the different contract documents, the engineer will decide which is to be followed, and his decision is to be final.

Setting out. The contractor is to be responsible for the correctness of the setting out, and all mistakes which may occur are to be made good at his expense.

Prime cost sums. Where prime cost or p.c. sums are specified or referred to in the schedule of quantities, they are to be taken to mean the actual cost to the contractor at the manufacturer's works, after deducting trade discount, but not discount for cash, and the contractor in pricing is to add his own allowance for cartage, carriage, profit and fixing. When the work is carried out, the money due to the contractor will be the actual prime cost, whether this be more or less than that specified, plus the amount which he allowed for cartage, carriage, profit and fixing.

Provisional sums. Where provisional sums are specified or referred to in the schedule of quantities the contractor in pricing is to add his own allowance for superintendence, management, office expenses and profit. Whatever sum be actually spent during the progress of the works under this head, a proportionate amount of this allowance will be certified as money due to the contractor.

Notices and fees. Where notices and fees are legally demandable by public or other bodies during the carrying out of the work, these are to be given and paid by the contractor, who is to include an allowance for them in his tender.

Stores. Suitable stores are to be provided in order to protect materials from deterioration, including one with a boarded floor for cement.

Worksheds, etc. The contractor is to allow in his tender for any sheds or workshops required for efficient work by the workmen, and also any necessary mess rooms, conveniences and latrines, all being cleared away and the site made good on completion without nuisance.

Clerk of works' office. A suitable weathertight lock-up office, not less than 8 ft. square, with boarded floor, stove and lamp are to be provided. The office is to be fitted with a window, desk, and lock-up drawer; and fuel, oil and service are to be provided as necessary for heating, lighting and cleaning. The office is to be removed and the site made good on completion of the contract.

Examine site. The contractor is to examine the site before tendering, and is to include in his price everything necessary to complete the work, such as temporary stagings, cofferdams, dolphins, pumping, etc.

Antiquities, etc. All objects of value found on the site are to remain the property of the employer.

Covering in. No work is to be covered in before it has been inspected by the engineer or his representative.

Bad weather. The work is to be stopped during unfavourable weather at the discretion of the engineer, and the contractor in tendering is to make any allowance required to cover any costs or loss of profit incurred through such stoppage.

TYPICAL FORM OF TENDER

[Name of Employer.]
[Descriptive Title of Works.]

To the Directors of the ....

GENTLEMEN,

...., the undersigned, do hereby offer to execute the whole of the proposed works in accordance with the plans, sections, conditions, specifications and schedule of quantities and prices, which we have carefully examined, and subject to the stipulations contained therein, for the total sum of ....

.... also agree to sign a Contract Deed and Bond, to be prepared by the Solicitors to the Company, and hereby propose ....
and...
to be sureties in the sum of ....

....

for the due performance of the contract.

Signed ....

Address ....

Dated this .... day of ....

TYPICAL FORM OF ADVERTISEMENT

The Directors of the .... invite tenders for the construction of .... The tenders, which are to be on the prescribed form, are to be sealed, endorsed in the upper left hand corner Tender for ...., and delivered to ...., the Engineer to the Company, before .... p.m. on the .... day of .... Plans and specifications may be seen and schedules of quantities and forms of tender obtained at the offices of the Engineer at ...., between the hours of .... and ...., on payment of a deposit of three guineas, which will be refunded on receipt of a bona fide tender. No pledge is given to accept the lowest or any tender.

TYPICAL FORM OF CERTIFICATE

[Name of Employer.]

Contract No. ...., for the execution of

....

Progressive certificate number on above contract - - - - - - No. ....

Value of work completed up to date £ ....

..........per cent. of above according to contract £ ....

Value of materials on site - £ ....

.... per cent. of above according to contract £ ....

Total for work done and materials on site £ ....

Total amount of previous payments - - £ ....

Amount now due to contractor - £ ....

I hereby certify that .... pounds .... shillings .... pence are now due to the contractor on the above contract.

(Signed)..

Date............................ *Engineer.*

CHAPTER VI

EARTHWORK AND FOUNDATIONS

DIVISION OF SUBJECT

The civil engineer has no more troublesome task than that of dealing with **earthwork**, either in the form of cutting or embankment. Its variable character, the possible presence of water, and the difficulty of inspecting it thoroughly before the excavation is carried out, all combine to cause constant anxiety to the engineer during the progress of the work. The subject may be conveniently divided into the following sections for more detailed consideration, viz. : **preliminary trial holes and borings; open trenches and cuttings; shafts and pits; excavation under water; headings and tunnels; embankments; construction of foundations generally.**

PRELIMINARY WORKS

Before a work of any magnitude is commenced, and in most cases even before a contract is prepared, it is necessary to know something of the nature of the ground on which the structure is to rest. In the British Isles the detailed maps of the Geological Survey furnish much useful information, particularly with regard to the general dip of the strata and the presence of sudden changes in the rock due to " faults." More detailed knowledge is usually required, however, and this is best obtained by digging a series of **trial pits** on the site of the proposed works to the depth required, where the ground is not too much waterlogged to prevent this being done, and making a careful examination of the strata passed through. This is the method adopted wherever possible and is the most satisfactory.

There are many cases, however, where the digging of trial pits would be too expensive and difficult, as, for example, near a river bed where excavations might become flooded, or where the depth required would be too great for a pit to be sunk without incurring great expense. In these cases **boring** is usually resorted to. Boreholes of a few inches in diameter are driven where necessary, usually by some firm specializing in this kind of work. A boring **rig** or **derrick** is erected immediately over the position of the required borehole, and special tools are used, slung from this derrick. In the case of soft soil the boring tool is often shaped like a large auger fitted with a handle which can be turned by men on the platform. When the tool has been turned sufficiently it is hoisted up, bringing with it a " core " of excavated material, which is an indication of the bed passed through. In hard soil, gravel, chalk and rock the auger is replaced by a tool like a large heavy chisel or jumper, which is worked by being hoisted up a few feet and then allowed to drop, water being meanwhile poured into the hole to keep the tool cool. After a number of blows have been delivered in this way, the tool being rotated a little between successive blows, it is hoisted out of the way, and a special tool is lowered in order to pick up the debris, which is raised and examined as before. As the borehole deepens, lengths of iron rod are screwed on to the upper end of the tool, until in some cases a depth of some hundreds of feet is reached.

Large boring plants are often equipped with tools in the form of a hollow cylinder studded with diamonds at the lower edge. These tools are rotated and drill out a clean circular hole with a solid centre or core, which is brought to the surface by a special tool and shows the strata through which the tool has passed in their correct order. In many cases the diamonds are replaced by chilled steel shot, which have a similar effect in cutting rock. A constant stream of water is pumped down the borehole, and this washes up the debris. The information thus obtained is useful, but as boreholes are expensive, they are sometimes put down so far apart that important variations in the soil are missed, and are only found when the work is actually being carried out. This in many cases causes a complete change in the design of the underground work.

Open Trenches and Cuttings

Small trenches and cuttings are carried out by hand labour. The tools used comprise the **shovel**, either the "London" type with square edge or the ordinary navvy type with rounded edge; the **spade**, with a narrower and straighter blade for digging in clay; the **pick**, with a steel-pointed head; the **pickaxe**, with a narrow, chisel-shaped point; the **grub axe** for digging up roots, with a broader chisel-shaped point on one side and a flat adze-like blade on the other; and the **crowbar** for levering up roots and stones. These tools are required for excavation in soft or moderately hard ground. For excavation in rock there are required in addition **drills**, which are made usually of octagonal steel bars, flattened at one end to a chisel point which is rather wider than the body of the bar itself. These are struck with a steel-faced sledge hammer, or in some cases, where the holes are deep, the bars themselves are so heavy that they can be lifted and dropped in the holes exactly as in the operation of boring, water being poured in to keep the tool cool. For hard gravel and road surfaces short pointed steel wedges called **clinks** are used, struck with the sledge. Clinks, pickaxes and drills require to be re-sharpened from time to time, and this is generally done by the smith at a portable forge, the operation consisting of heating the tools to red heat, drawing them down by hammering to the required shape, and re-hardening and tempering.

Digging in clay is usually done with the spade, the navvy keeping a bucket of water by his side with which to lubricate the blade in order to prevent the clay from sticking. The excavated material is removed from the trench in **wheelbarrows**, each holding roughly $\frac{1}{10}$ of a cubic yard when well heaped up, and flat planks or, in some cases, strips of sheet iron about 6 in. wide and $\frac{1}{8}$ in. thick are laid down to form **runs** for the barrows. Where the length of barrow run exceeds 60 yards it is often more economical to employ **carts**, into which the excavated material is loaded direct, and on more extensive works still a **light railway** track of narrow gauge is laid down, on which run tip-waggons, drawn either by horses or by a small locomotive ; or even in some cases, where the run for the loaded waggons is downhill, by the men themselves. The precise method to be adopted is a matter for careful preliminary consideration by the contractor, and the arrangement of the working parties, the proportion of shovellers, pickmen and wheelers is usually left to the ganger, who seeks to avoid unnecessary handling of the material while keeping all the men regularly employed.

In large excavations it will pay to instal some form of mechanical excavator, of which there are three main types (Fig. 2). The first, or **grab**, is used more for underwater excavation than for open cutting. The second, or **steam**

navvy, is usually run on a railway track into the bottom of the excavation, where it scoops out the sides and tips the material—called "spoil"—into waggons running usually on the same track. In this way it gradually "eats" its way forward, the width of the excavation being dependent on the length of the jib of the machine. A modification of this is known as the "drag line" excavator. In this type the scoop is suspended from the jib of a crane and dragged over the earth by a cable from the engine. Rails for these types of machine, and also for most temporary purposes on works, are of the flat-bottomed type, spiked down to timber sleepers, except in the case of very narrow-gauge tracks, when they are often permanently fixed in lengths to pressed steel sleepers; a whole length of track—from 10 to 20 feet—being laid at one operation, and bolted to the preceding length with fishplates.

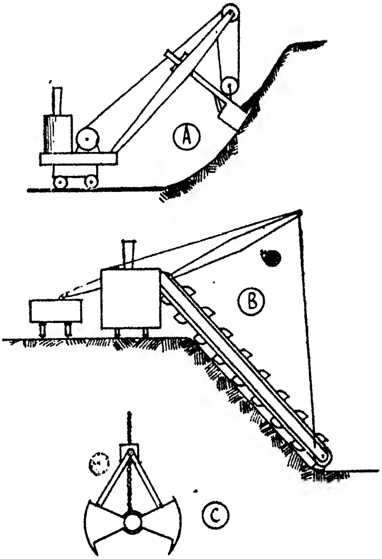

Fig. 2.—Excavating Machinery.
(A) Steam Navvy.
(B) Ladder Excavator.
(C) Grab, suspended from crane.

The third type of machine is the **ladder excavator**, running usually on rails at the side of the trench and delivering into waggons at that level.

Care must be taken to keep excavations free from water, and where a trench cannot be commenced at its lowest end to provide a natural outlet, sump pits must be dug at convenient intervals and pumps installed, ranging from the ordinary hand "diaphragm" pumps to steam or oil-driven centrifugals or pulsometers. The water to be dealt with may be either subsoil water from springs tapped in the course of the excavation, or surface water draining from the surrounding country, and it may at times tax the powers of the pumping plant to the utmost.

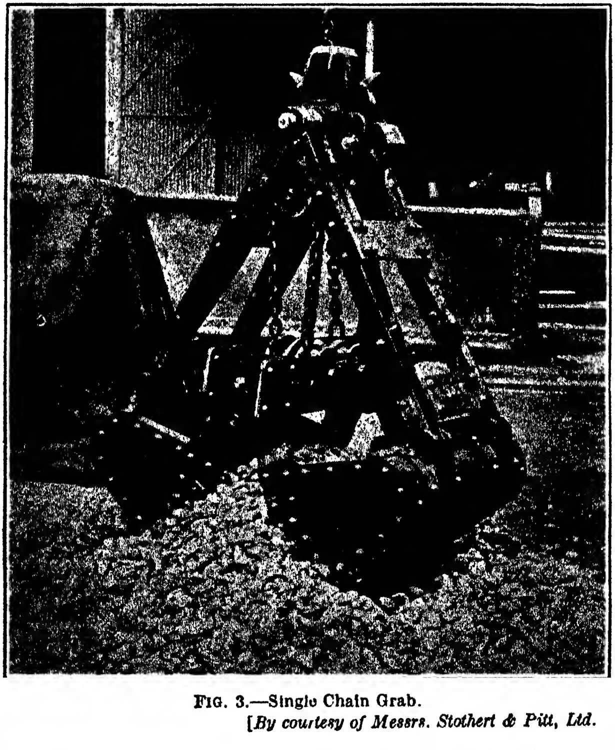

FIG. 3.—Single Chain Grab.

[*By courtesy of Messrs. Stothert & Pitt, Ltd.*

In excavating deep trenches by hand, platforms of boards are rigged up at vertical intervals of about five feet, usually supported by the timbers fixed in the trench to prevent the sides from caving in. The excavated material is shovelled from the bottom of the trench to the surface stage by stage. In some cases, where this method becomes uneconomical owing to the depth, the earth is hoisted out in wheelbarrows or buckets by means of a tripod erected over the trench and fitted with a single large pulley called a "gin-wheel," the hoisting rope being attached to a small windlass in the case of heavy loads. In confined spaces, such as the excavation for a cellar in a busy thoroughfare, it may be necessary to carry the excavated material out in baskets to the carts waiting to receive it. The cost of this "excavating and basketing out" is, of course, high.

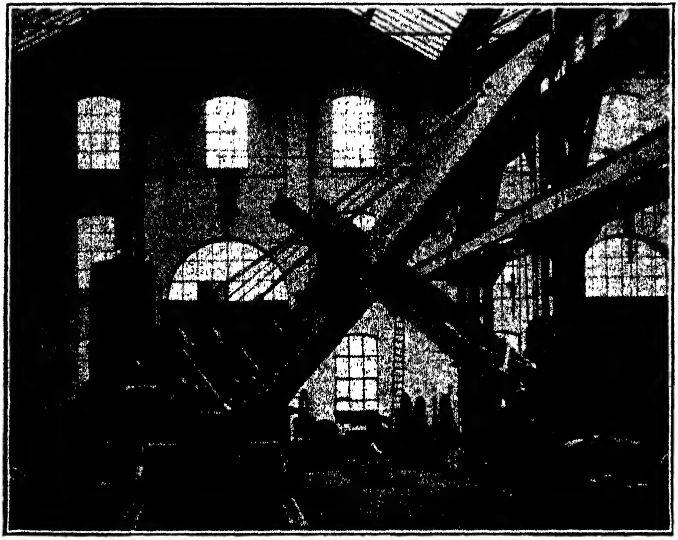

Fig. 4.—Steam Crane Excavator, or Steam Navvy.

[*By courtesy of Messrs. H. Berry & Co., Ltd.*

Where large cuttings have to be made it is usual to dig a narrow trench or gullet the full depth of the cutting and lay a track at the bottom of this on which ordinary earth waggons may run. Planks are then placed across this gullet at the top, on which the barrows may run and the earth be tipped direct into the waggons waiting underneath. In this way the cutting is gradually widened down to the final or "formation" level. The sides of such a cutting must be well sloped back to avoid any chance of the soil afterwards slipping into the cutting. The usual slopes are

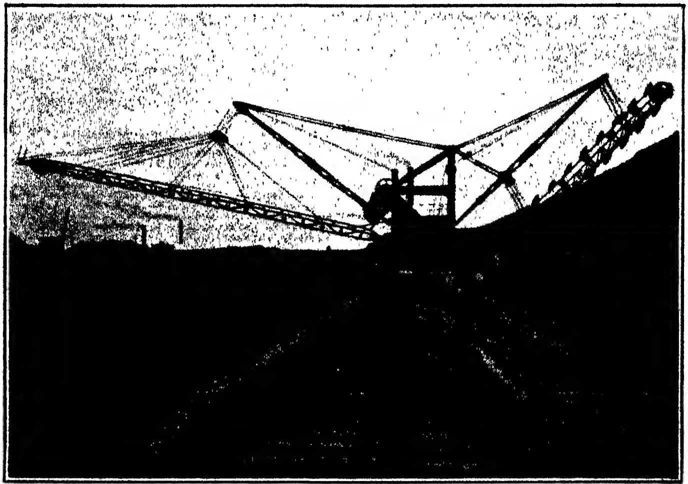

Fig. 5.—Chain Bucket Excavator of special type, with long arm conveyor for dumping excavated material.

[*By courtesy of Messrs. H. Berry & Co., Ltd.*

$1\frac{1}{2}$ horizontal to 1 vertical for ordinary soil, 2 horizontal to 1 vertical for clay, 1 horizontal to 4 vertical for rock.

The **setting out** of trenches and cuttings is usually entrusted to an assistant, who first pegs out the centre line of the proposed cutting—that is, the centre line of the finished surface at the bottom, a peg being put in, say, at every 100 feet. The level at each peg is carefully ascertained with the dumpy level, and the finished depth below each peg marked on it. Then pegs are set out to right and left of the centre line along the whole length of the cutting, showing exactly where the tops of the side slopes of the cutting intersect the existing surface of the ground. These " half-breadth " pegs will be at varying distances from the centre line, according to the varying depth of the cutting and the side slope of the ground. With the aid of these pegs the ganger in charge of the navvies can give exact directions as to where they are to dig and how deep. The side slopes are often finally covered with 6 in. of soil and sown with grass seed.

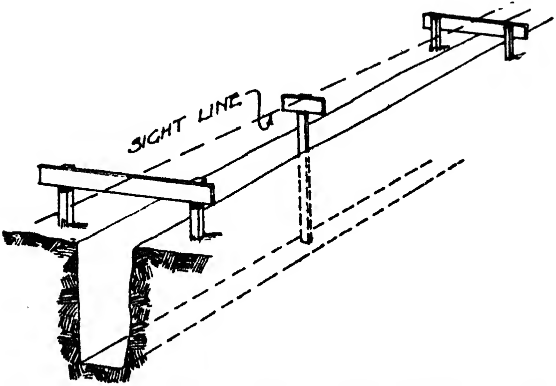

FIG. 6.—Setting out a Trench, with two sight rails and boning rod.

The setting out of smaller temporary trenches with vertical sides is carried out somewhat differently (Fig. 6). The centre line is first marked out to give the line of the trench. No half-breadth pegs are required, as the width is constant with vertical sides whatever the depth, and so can be easily marked off by the ganger. At intervals along the trench a **sight rail** is set up by the assistant in charge. This is a horizontal board, laid on its edge, spanning the trench about three feet above the ground level, being held by an upright at each end firmly driven into the ground. The sight rail is carefully fixed at a definite and known height above the proposed finished bottom of the trench at that point. Another sight rail is fixed, say, 50 yards away on the line of the trench and the same distance above the bottom.

These sight rails give the depth to which the excavation must be carried where they are fixed. At intermediate points the depth is measured by means of a **boning rod.** This is a long batten with a T-shaped head, of exactly the same overall length as the depth from the top of a sight rail to the finished bottom of the trench, and the excavation between the sight rails is carried on so that the boning rod, when stood on the bottom of the trench at any point between the sight rails, shall have its head in the same straight line as the two rails. This is tested by a man standing near one of the sight rails, and sighting past the boning rod on to the other sight rail. Boning rods are often used in sets of three on small works in a similar manner, sight rails being dispensed with.

It must be borne in mind when deciding where to tip the excavated material or "spoil" that it will occupy a larger bulk after being excavated, the increase ranging from practically nothing in the case of pure sand to forty per cent. for rock.

Excavation in rock is usually carried on by **blasting.** Holes are drilled or " jumped " in the rock in suitable spots. On large works mechanical drills driven by electric motors or compressed air are employed. Into the holes are inserted charges of gunpowder, or one of the many forms of nitro-glycerine made up into some kind of dynamite or blasting powder. The hole is then filled up with clay " tamping " tightly rammed in. A charge of gunpowder may be fired in two ways : either by a fuze (or slow match), which is ignited at the open end and burns slowly through the tamping till it reaches the powder; or by means of a copper conductor containing a thin wire where it is embedded in the powder.

The conductor, consisting of two wires, is led a considerable distance away to an **exploder**, which is really a small dynamo operated by hand. The firer turns the exploder, this causes a current of electricity to pass along the conductor and so heats up the thin wire embedded in the powder to incandescence, and this, of course, fires the powder. Dynamite or blasting powder will not explode, however, if ignited in this way, and it is necessary to insert in the charge a "detonator" consisting of a small tube containing fulminate of mercury. This material is highly explosive, and if the detonator is connected by copper wires to an exploder and a current is passed, the shock of the exploding detonator is communicated to the main charge of dynamite in which it is embedded, which explodes in turn. Such detonators may be also fired by ordinary fuze. The proportioning, placing and firing of the charges are usually in the hands of a skilled ganger.

Trenches with vertical sides in material other than rock or chalk have usually to be lined with timber in order to prevent the earth from collapsing into the trench. The system of **timbering** adopted varies with the kind of soil. In the case of dry clay or hard gravel it is often possible to excavate several feet deep without any danger of the soil falling in, and in these cases all that the excavator does is to place a few short vertical boards called **poling boards** at intervals in pairs along the trench, kept in position by **struts** of round or square timber tightly wedged between by being put in diagonally and then driven horizontal (Fig 7A). The poling boards are usually about 7 in. × 1¼ in. and 4 ft. long, and the struts about 3 in. diameter. Such timbering does little to prevent the earth from falling into the trench once it begins to move, but it acts as an indicator of any tendency of the whole side of the trench to fall in bodily.

Where the soil is looser, the poling boards must be placed closer together—in some cases even touching—and as the number of struts in such a case would render it impossible for the men to work in the trench, horizontal timbers 9 in. × 3 in. or 9 in. × 4 in. in section and about 14 ft. long, called **walings**, are introduced, and strutted apart at the ends and at the middle. It is possible in fairly good ground to excavate 4 feet deep, put in a "setting" of poling boards, walings and struts, then excavate another 4 feet below, and repeat the operation to any required depth (Fig. 7B).

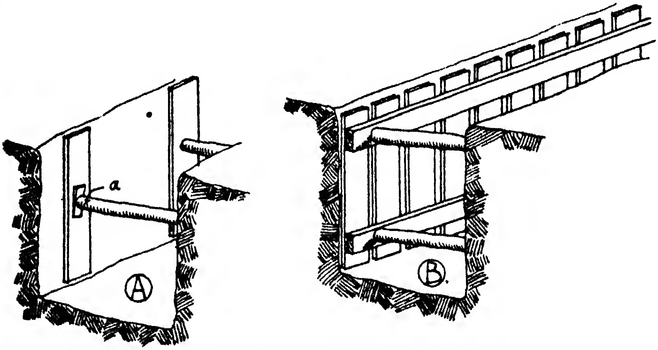

FIG. 7.—Trench Timbering.
(A) In good ground.
(B) In moderately good ground.

If the soil is loose and it is impossible to excavate 3 or 4 feet without danger from the soil falling into the trench, one of two other methods may be used. The first is that of **horizontal sheeting** (Fig. 8). The poling boards in this case are long—say, 12 to 15 feet—and the work is commenced by excavating the trench 9 in. deep, placing a horizontal poling board on each side and strutting apart.

A further 9 in. is then dug out and another pair of boards fixed under the first pair and strutted as before. This is continued until the trench has been sunk about 3 feet, when short vertical walings are fixed at each end and at the centres of the horizontal boards and strutted apart, thus dispensing with the first set of struts.

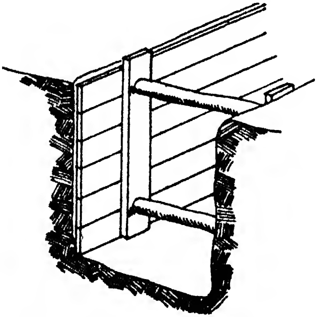

Fig. 8.—Horizontal sheeting in very loose ground.

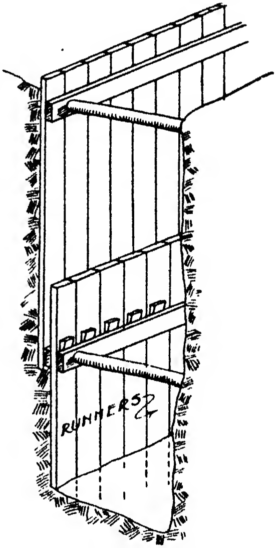

Fig. 9.—Timbering by runners in bad ground. Upper portion in this figure consists of ordinary poling boards.

A more common method, however, in bad ground is to use long vertical poling boards sharpened at one end and driven by a maul or wooden sledge hammer, which does not split them as an iron one would do (Fig. 9). These long boards are called **runners**, and are usually about 8 ft. long, 7 in. wide and 2 in. to 3 in. thick, so that they are stiff enough to be driven. These runners are ranged on each side of the trench, and either dug in or driven from a trestle as far as they will go, almost touching each other. The trench is then excavated out *nearly* to the points of the runners, and a horizontal waling is fixed on each side of the trench near the top, and strutted in the usual way, thus holding the runners to line. Each runner is then separately wedged back from the waling to press against the earth. The excavator now removes the wedge from one runner, thus freeing it to some extent, and excavates under its point so that it may be driven, say, another foot. It is then wedged again, and the process repeated with the other runners in turn.

By this means the whole line of runners is lowered a foot, and when the operation has been repeated on the other side of the trench the earth can be dug out from the centre, care being taken not to dig so deep as to undermine the runners. When the trench has been sunk to a depth of about 7 ft. a fresh set of runners must be driven inside the first set, thus narrowing the trench at the bottom. This narrowing must be taken into account when setting out the top width of the trench.

Where trenches are dug in ground which is liable to shrinkage owing to the pumping of subsoil water, the sides are often made to slope, the width of the trench being greater at the top, so that if the timbering settles owing to the trench widening, it will wedge itself lower down and so prevent an accident.

Large trenches are required in excavating for dock wall foundations, often in very difficult ground. Such trenches may be up to 30 ft. or 40 ft. wide, and the methods of timbering must be modified (Fig. 10). The runners become longer and thicker, and before they are driven a row of square (" whole timber ") piles about 10 ft. apart is driven on each side of the trench, to which the walings are bolted as the trench is sunk. These piles and the walings attached to them near the top serve to keep the runners in line. The struts, which are also whole timbers in this case—say, 12 in. × 12 in.—would be expensive and unmanageable if of a length equal to the width of the trench, therefore a row of piles is driven down the centre of the trench at the commencement of the work. These piles are called **king piles,** and must be driven to the full depth of the trench.

The struts are then butted on opposite sides of the king pile, and at intervals it is usual to run struts raking downwards from the side of the trench to the king pile to obviate any tendency of the latter to rise. The main struts, where they butt against the walings, have **lip blocks** spiked to them to prevent them from dropping if the sides of the trench should give way at all, and the walings themselves are blocked up from the bottom of the trench by a series of short timbers called **puncheons** for the same reason ; sometimes also by long vertical planks spiked to several sets of walings, and called **soldiers.**

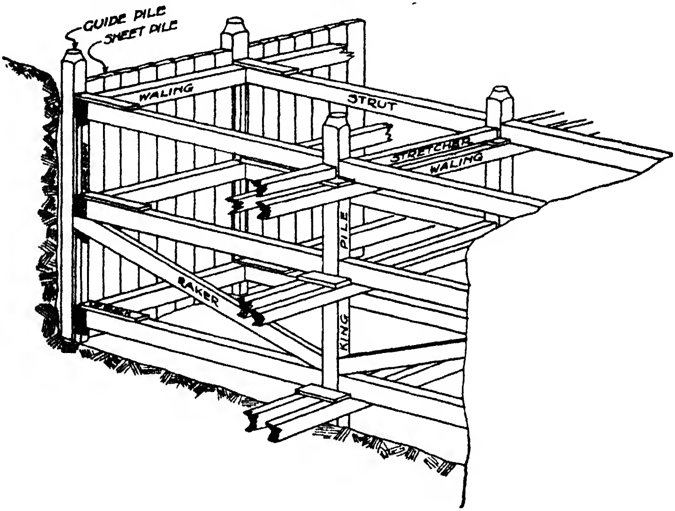

FIG. 10.—Timbering of wide and deep trench in wet ground.

Large **open excavations** with vertical sides are usually timbered as trenches, the work being often commenced by sinking a trench all round the site, timbered in the usual way. When the soil remaining in the centre—or **dumpling**, as it is often called—is removed, the outer face of the trench has the walings strutted by long **raking shores** from the bottom of the finished excavation.

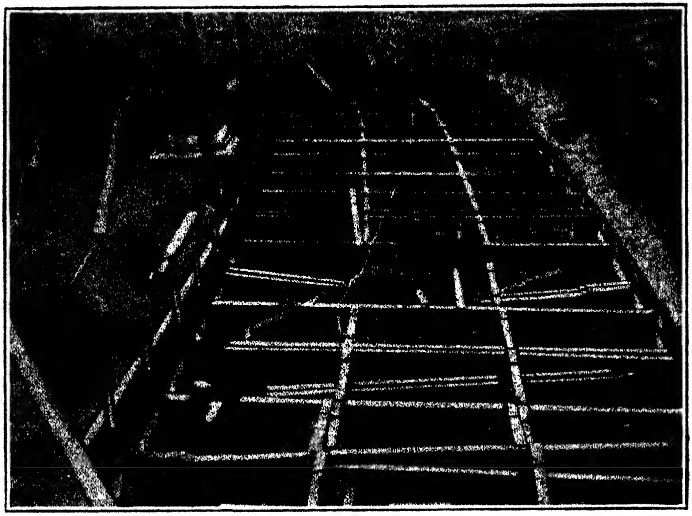

FIG. 11.—Timbering of Trench.
[*Engineering*, 2nd May, 1913.

SHAFTS AND PITS

When shafts or pits have to be sunk, methods of timbering based on those used for trenches are used. For shafts from 4 ft. to 10 ft. square—4 ft. is the minimum in which a man can work comfortably—in good ground, walings and poling boards, often called **cleadings**, are used (Fig. 12). The struts, however, are dispensed with, as they would occupy too much space in the shaft, and the walings, which are usually 4 in. thick in small shafts, are kept apart by letting each pair of walings act as struts to the pair at right angles to them. Puncheons and soldiers are fixed to prevent settlement of the timber if the ground shrinks. If the ground is bad, runners are used in the ordinary way, the shaft gradually becoming smaller as each "setting" is driven.

Large shafts more than 10 ft. square are usually timbered in the same manner as large trenches, with a central king pile and struts abutting on its four sides from the centres of the walings.

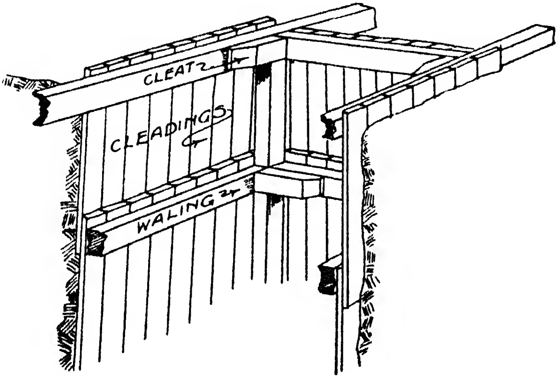

FIG. 12.—Timbering of Shaft.

The chief difficulties the excavator has to surmount are in dealing with soft chalk and clay, which have a tendency to swell and exert very great force on the struts, which must be made correspondingly stout, and in excavating through running sand, whether perfectly dry or very wet. This material trickles between the poling boards and leaves gaps behind the timbering, which may thus collapse. In this case the only thing to do is to caulk between the runners or pack behind the poling boards with straw or litter.

EXCAVATION UNDER WATER

A third and very common difficulty, that due to the presence of very large quantities of **water**, will now be considered. It has already been explained that the bottom of an excavation is usually given a slight fall to a **sump pit**, in which is placed the suction pipe of a pump. Where large quantities of water are met with in open trenching, powerful pumps are required to keep the bottom sufficiently dry for the men to work in it. If the quantity is too great for the pumps to deal with, after every known source of influx has been carefully dammed, the only thing to be done is to carry on the excavation under water level by means of **grabs** or **dredgers**, or by helmet **divers** (men clad in a special diving dress), the "timbering" now developing into a system of lining the sides of the trench by means of **sheet piles**—which are merely large runners close together—driven from above well below the finished level of the trench. The sheet piles are kept to line by being driven against a waling, or in some cases being driven between two walings bolted at intervals to previously driven king piles along the sides of the trench. In modern work the sheet piles are often constructed of steel plate or flat rolled steel sections with patent interlocking edges.

The problem of sinking shafts—as distinct from trenches—through water-bearing strata is somewhat different. If the pumps are insufficient to keep the water down and allow the excavation and timbering to be carried out in the usual way, one of several different methods may be adopted. Circular brick shafts or **wells** are often sunk without any timbering at all, even in good ground. There are two methods of doing this. In the first, or **underpinning** method, if the ground is firm, a circular hole is dug of the required size and of such depth that the earth will stand without timber;

and at the bottom is laid and carefully levelled a **curb**, or circular frame of elm made in section and bolted together. On this frame as a foundation is built the circular brick lining of the shaft up to ground level. A small hole is then dug in the centre of the shaft about 3 feet down and a block of timber is securely bedded at the bottom of this hole. From this block raking struts are radiated upwards and outwards until they are wedged hard up against the underside of the curb at four or six points in its circumference, the earth being cut away in sloping channels from the centre hole to allow this to be done.

The curb and the weight of brickwork above it being thus supported by the struts, the earth can be excavated away underneath for the whole width of the shaft to a further depth of 3 feet, a new curb bedded on the bottom, and brickwork built up to the underside of the first curb, except at those points where it is supported by the struts. These can be now taken away one by one, and the brickwork at these points filled in. This process can be repeated indefinitely as long as the ground is sufficiently firm.

In the second method, which is adopted when the ground is waterlogged, a curb, so constructed that it rests on a sharp cutting edge, is built on the surface of the ground. On this a height of about 3 ft. of brick lining is built with a platform across the top, loaded with **kentledge**—a term used to denote any material which is used for the sake of its weight—of old rails or any other heavy material. The soil is then excavated carefully from the centre and just under the cutting edge, causing the whole cylinder to sink. This is repeated, fresh brickwork being added until the required depth is reached, or until the friction of the earth on the outside of the brick lining prevents further sinking, when the first method may be resorted to, or a fresh well of smaller diameter sunk inside.

Circular shafts which are only required for temporary purposes may be sunk in corresponding ways without brick linings. In good ground, circular curbs are constructed, behind which short poling boards are fixed, the curbs replacing the usual system of walings and struts, one setting below another until the required depth is reached. In bad ground a drum curb is used, that is a hollow cylinder about 3 ft. long of boarding fixed with three circular ribs inside and a cutting edge at the bottom. This is weighted and the earth excavated from inside as in the case of the " well " foundation previously described.

SINKING BRIDGE PIERS

The commonest method of sinking deep circular shafts nowadays is to line them with cast iron **tubbing**, usually less than 1 in. thick, constructed and put together in sections with internally flanged and bolted joints. The lowest ring of tubbing is cast with a cutting edge and the whole is sunk by means of kentledge loaded on the top, excavation being carried on as before from inside. Where the ground is waterlogged and the pumps cannot cope with the flow, the excavation may be carried on under the water by a grab if the ground is soft and suitable, or—more rarely—by helmet divers, who are necessarily expensive if much has to be done.

The most usual method, however, in such a case is to use **compressed air**, a modern invention which has rendered feasible many works which would otherwise have been quite impossible. This is a method in very common use for sinking cylinder piers for bridge foundations in a river bed. The cylinders are bolted together on a staging over the position they are finally to occupy, a bed is levelled for them by helmet divers, and they are sunk vertically in the river, their upper ends being above the water level and open to the atmosphere, and loaded with kentledge. As soon as they have penetrated enough to make a watertight joint with the bed of the river, the water in them is pumped out and regular excavation begins inside, the cylinders gradually sinking under the weight. As long as the strata through which they sink consist of clay, this can go on indefinitely ; but where gravel is encountered, this usually means a large influx of water under considerable pressure, due to the head of river water above it, and it is in these circumstances that the compressed air is required. The top of the cylinder is sealed down by plates, and compressed air is pumped into the cylinder at a pressure just a little above that of the incoming water. This drives the water back, and enables the men to continue their excavation ; only, of course, they are working now in a closed chamber and breathing compressed air (Fig. 13).

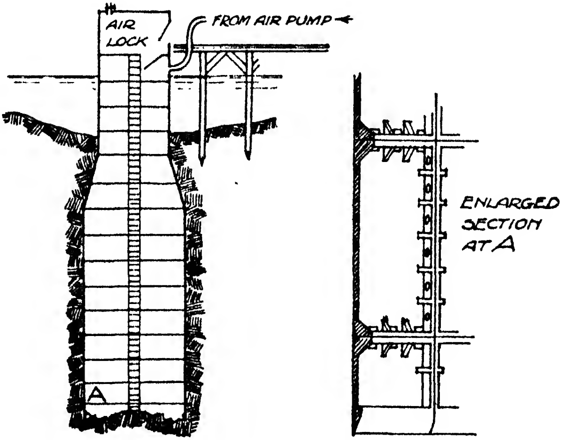

FIG. 13.—Cylinder bridge pier in river bed.

Provision is made for the ingress and egress of the workmen, and that of the excavated material, at the top of the cylinder through an **air lock.** This is a cylinder of sheet steel bolted on to the top of the main cylinder with a flap door at each end, one opening from the outer air, the other into the main cylinder. A workman wishing to enter the main cylinder from the open air first enters the air lock and closes the outer flap door. He then opens an air cock connecting the air lock and the main cylinder. The air lock thus becomes gradually filled with compressed air, and the workman can then open the flap door communicating with

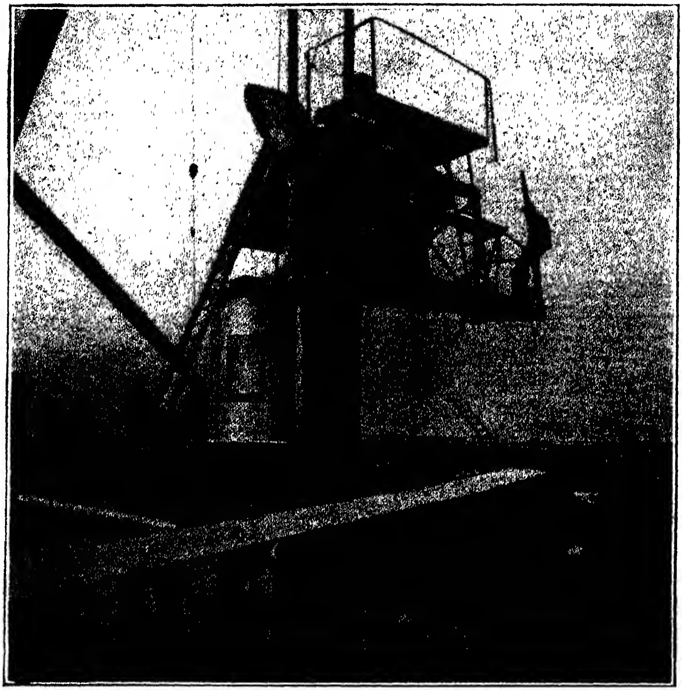

FIG. 14.—Air lock used in widening Blackfriars Bridge.
[*Engineering*, 10th September, 1909.

the main cylinder. The process is reversed when leaving the cylinder, or when discharging excavated material. In this way the excavation can be proceeded with and the cylinder sunk to the depth required. The greater the depth the greater is the air pressure required to keep back the water. For most men a pressure of more than 25 lbs. per sq. in., corresponding to about 60 ft. head of water, causes great discomfort, and care has to be taken that the hours of work in high pressures are kept short, with plenty of resting intervals. The process of "decompressing" when the men are in the air lock before coming out into the open must be very gradual.

When cylinders such as those just described are sunk as bridge piers, they are usually filled up afterwards with cement concrete to form a solid mass within the iron plates. In many cases abroad, where the cost of carriage of the cast-iron plates is high, lighter cylinders made of steel plates $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick are used, riveted together and stiffened by angle or tee bars riveted inside, the lower edge of the bottom ring acting as a cutting edge. The method of sinking is the same, and in both cases the cylinders are finally filled with concrete.

For large bridges, where cylinders or groups of cylinders are not required, **caissons** of steel plate are constructed. These are not usually circular, but follow the shape in plan of the masonry bridge pier required. They are made in the same way as cylinders, but with a false floor about 8 feet above the cutting edge, from which rise one or more tubular shafts fitted with air locks at the bottom (Fig. 15). The working chamber below the false floor is under compressed air, but not the whole caisson, which may be open to the atmosphere at the top if well above water level. When excavation has proceeded to the required depth, the lower chamber is filled with concrete, its ceiling of plates is taken away and the pier built up within the outer casing of steel or iron plates, until above water level, when these are removed to as great a depth as is possible or convenient.

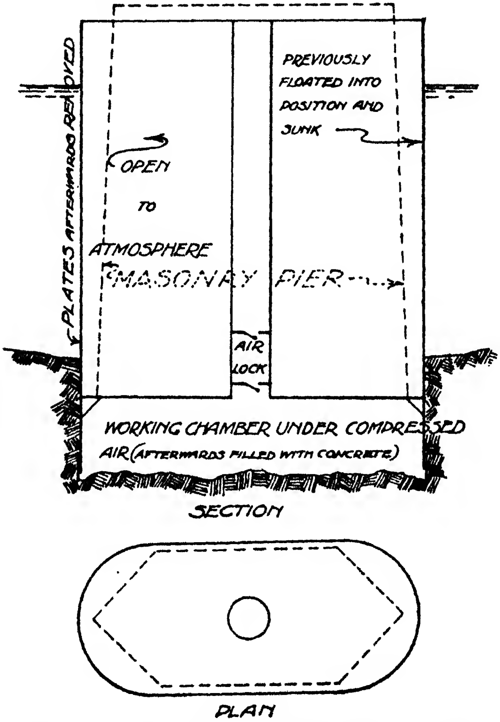

FIG. 15.—Caisson for masonry bridge pier in river bed.

This type of caisson must not be confused with the American or **stranded** type, which is a large hollow box, usually of timber, big enough to contain the bridge pier, with a solid timber floor and no cutting edge. It is floated over a site which has been previously levelled by dredging, blasting, or helmet divers. When over its exact position the bridge pier is built inside it, resting directly on the plank floor, and as the masonry rises the caisson sinks until it rests on the prepared and levelled bed, the sides of the caisson always being kept above water level so that the building of the pier may be carried on in the dry. When built to its final height the sides are taken adrift and the pier remains resting on the plank floor, which in turn rests on the prepared bed of the river. This type of caisson is thus not an appliance for excavation, but for building in the dry. Such foundations usually have mounds of broken rock deposited round them from barges, so that they may not be undermined by the river current.

Diving bells are not much used nowadays, having been largely superseded by the modern helmet diver. They were formerly in demand for examining and levelling foundations under water, and consisted of a domed chamber open at the bottom, with air pipes running from an air compressor into the roof. There was a shelf running round inside on which the workmen could sit or stand, and the bell was lowered by a crane from a barge until it rested on the spot to be examined, compressed air being continually pumped into it at a pressure sufficient to keep the water from rising inside, the excess air bubbling up through the water outside. This left the bed of the river exposed to examination by artificial light within the bell.

Dock Walls

Excavation which is under water level may often be carried out in the dry by building a watertight **cofferdam** around the work; for example, where a dock wall has to be built on an existing foreshore, a stout cofferdam may be built in front of the proposed wall, extending along its length with ends returned into the shore. If this dam is watertight, the water inside it may be pumped out, leaving a dry site for the excavation of the trenches of the wall. Where the head of water is not great, light cofferdams may be constructed of sheet piling—either timber or steel as previously described—driven between walings held in position by upright king piles. If the sheet piling is well driven, little water will leak through the joints, and what does run through can be dealt with by pumps. The dam must, of course, be well strutted from inside to resist the overturning pressure of the water on its outside face.

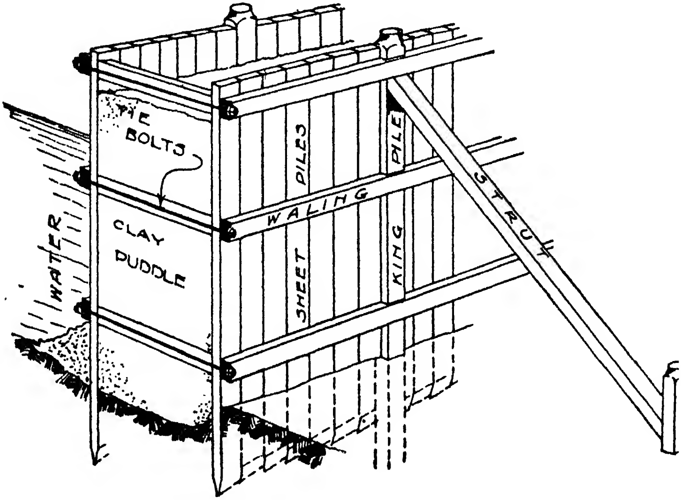

FIG. 16.—Puddled Cofferdam.

More substantial dams are constructed of two lines of sheet piles driven as before described in parallel rows about 3 ft. apart, and well bound together by walings along their length and by transverse tie bolts connecting the two rows together (Fig. 16). The space between the two rows is then filled with **clay puddle**, that is, clay mixed with a certain proportion of sand, and well worked into a pasty mass with water. This thick clay wall effectually prevents any leakage of water through the dam.

The foundations of dock walls are often constructed by means of large caissons or **monoliths** of concrete, the lower edges of which are sharp. These are sunk in a manner similar to that described for sinking bridge piers, and are afterwards filled solid with concrete, on which the wall is erected.

Dredging

Excavation under water is often carried out most economically by **dredging**. For very small works and soft mud this can be done by using a long pole fitted at the end with a large scoop and bag. To the end of the pole near the scoop is fixed a drag line. The apparatus is worked from a barge. The scoop is dug vertically into the mud and is dragged horizontally and then lifted by the line, the contents being emptied into the hold of the barge. For larger work steam dredgers are used, either on the grab principle or as a ladder dredge with an endless chain of steel buckets gradually scooping out a channel and discharging the spoil into a lighter lying alongside. The lighter may be of the "hopper" type, that is, the floor of the hold may be formed of steel trap doors, which can be opened and the contents discharged through the floor of the barge without having to be lifted over the side. The barge itself is, of course, kept afloat by airtight compartments.

Another form of dredge suitable for soft mud and sand is composed of a powerful pump, the suction of which is let down to the sand and is provided with rotating cutters. When these are put into operation the mud is churned up and enters the suction pipe with the inflowing water, by which it is carried to the outlet, which may be over a hopper barge, or may be through a long length of delivery pipe to a spot on the shore where an embankment is required.

Where under-water excavation in rock is required, it is either blasted out by charges placed by helmet divers, or is broken up by extremely heavy pointed **steel rams** suspended from a lighter and allowed to drop at intervals.

It is also possible to excavate in waterlogged ground by inserting pipes, through which very cold brine is circulated from a refrigerator; this **freezes** the earth and water around the pit required.

HEADINGS AND TUNNELS

Headings are temporary tunnels, generally of small size, about 5 ft. high and 3 ft. wide being the least dimensions in which a man can work with any comfort. Except in solid chalk and rock, headings require timbering, particularly the roof. In soil which is at all friable, the method is as follows. A frame of timber consisting of a head and two side posts—usually round timber about 5 in. diameter—is let into the vertical face of the ground where the heading commences. If the ground is soft the side posts may rest on short lengths of plank as footblocks, or on a sill piece of round timber. Over the head is driven a row of sharpened poling boards. These are " eased " and caused to penetrate the face of the cliff by being excavated under their points, one at a time, until they have penetrated their full length, care being taken that at the sharp end each poling board is well driven into the solid earth, and that they have all been driven slightly upward. The remaining earth under these poling boards may now be excavated down to ground level. Another frame of head, tree and side posts is now fixed in position at the far end of the short tunnel thus made, the second head being kept about

1½ inches below the poling boards immediately over it. A second row of poling boards is then driven between the first row and the second head tree, again pointing slightly upwards, and this process can be repeated indefinitely (Fig. 17).

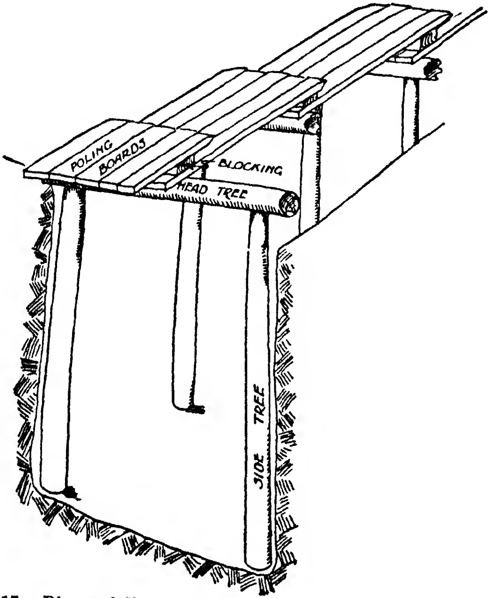

FIG. 17.—Dissected diagram of timbering of heading. Direction of driving away from spectator.

Sometimes the poling boards are driven at a slightly higher angle, and a 3 feet blocking of squared timber is fixed under the sharpened ends, which in turn is supported by the head tree, being kept about 1½ in. off the head tree by small packing slips. This leaves a wide slot between the blocking and the head tree, through which the next set of poling boards may be driven. In this way there is less friction in driving and the ends of the poling boards are more accessible by the maul used for driving them. In bad ground it may be necessary to drive poling boards behind the side posts in the same way. Headings of this kind are generally driven on a slight upward gradient to facilitate drainage.

Various systems are adopted for the driving of large permanent tunnels for roads, railways and canals, which have to be lined, usually with brickwork; but in ordinary ground a heading is always driven first. In long tunnels, shafts are sunk on the line of the tunnel where possible and headings driven both ways from the foot of each shaft, in order to hasten the work by increasing the number of working faces. The heading is usually driven at the level

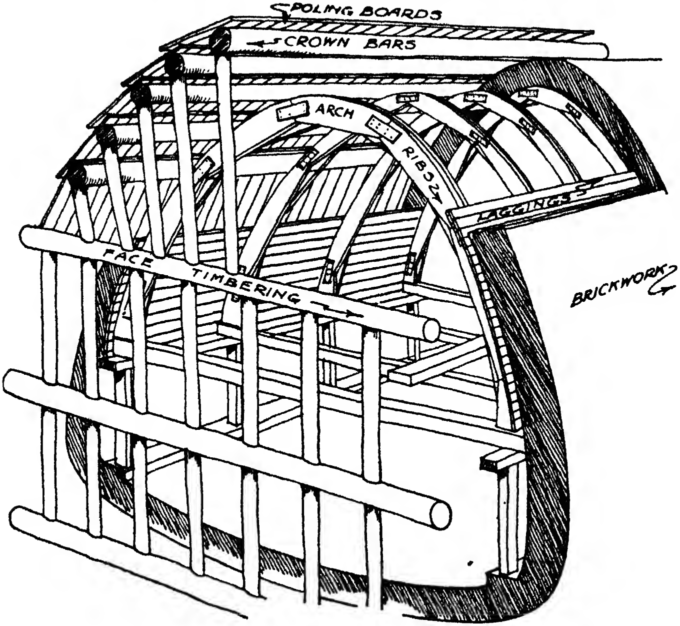

FIG. 18.—Dissected diagram of tunnel. Direction of driving towards the spectator. The poling boards of the face timbering are not shown.

of the top of the finished tunnel. Along the top of this heading is fixed a heavy log, about 15 ft. long and 12 in. diameter, called a **crown bar,** supported at each end by stout props. Over this crown bar are driven sharpened poling boards in the usual way, but in this case running at right angles to the length of the tunnel (Fig. 18). When these are driven, under their ends is fixed another stout crown bar, thus widening the headway. This is repeated until the heading is widened sufficiently on each side, its roof being arched and supported by rows of poling boards, these in their turn being supported by the crown bars.

The floor of the heading is now deepened, stout timbers being fixed under the ends of the crown bars down to the new or finished level, and in this way the whole of the section of the tunnel is opened out into a large chamber, the exposed vertical face at the end of the tunnel being timbered by poling boards and raking struts. In this chamber are erected the arched ribs, on which are fixed the boards or laggings to hold the brickwork of the arch as it is being built. When the tunnel has proceeded beyond one crown bar length, the rear end of each crown bar rests on the finished arch of the length behind it ; and as the heading is widened for a new length, the crown bars are drawn forward in turn and serve again. The method of building the brickwork will be described in the chapter on brickwork.

Many modern tunnels have been constructed under London through the clay by means of a steel **shield,** made of the full size of the finished tunnel (circular). This shield, which resembles a circular box fitted with a cutting edge, is pressed forward by hydraulic jacks and so cuts its way through the clay, the excavated material being dug out from the centre and taken away. The tunnels are lined with **cast-iron segments** similar to the tubbing used for cylinder foundations, and the shield obtains a " footing " for its pressure against the segments already fixed in position. Headings and timbering are thus dispensed with.

Another use for such shields is in tunnelling through waterlogged strata, or under rivers which are liable to break in and flood the whole tunnel. In such cases the tunnel is lined as before with cast-iron segments, and the whole is put under compressed air with an air lock at the entrance to the tunnel. By this means the water is kept out and the work carried on in the dry—comparatively speaking.

In rock and chalk, tunnels may be driven without timbering, or even for the most part without subsequent lining, but any loose places must be carefully lined with brickwork or concrete.

EMBANKMENTS

Embankments have often to be constructed, either to form a foundation for works such as roads and railways, or to get rid of a surplus of material obtained from excavation, this surplus being generally known as **spoil.** Where the embankment is to be used as a foundation, it is essential that precautions should be adopted to prevent it from settling unduly or from slipping. If the foundation of the embankment itself is on sloping ground, the top soil should be removed and the ground excavated into steps or terraces first, to prevent any tendency of the whole embankment to slip bodily. Before the embankment is commenced, all streams on its site must be culverted by building either iron pipe, brick, stoneware, or concrete culverts, over which the soil may be tipped.

Large embankments are usually formed by running lines of narrow-gauge railway along the top of the embankment as it is formed. The earth is loaded at the excavation into end-tipping waggons, which are formed of a body resting on an undercarriage. The waggons are hauled to the top of a slight gradient, down which they run on to the embankment. At the end of the track on the embankment is a buffer stop, which arrests the waggon so suddenly that the body tips up and discharges its contents. The waggon is then hauled back into a siding and another tipped in the same way, until a train of empty waggons is collected and hauled back to the excavation. The head of the embankment is furnished with several of these tracks branching out from a main track, so that the tipping goes on for the full width of the embankment.

In some cases a narrow embankment is first pushed forward in this way, and then trains of side-tipping waggons are employed, the earth being tipped down the side of the embankment in order to widen it. This method is more economical in time than the other, but many engineers consider that there is a tendency for the slopes of a side-tipped embankment to slip down, and it is therefore sometimes prohibited. The general surface of the layers of an embankment is usually made slightly hollow. The centre line of the embankment is set out before the tipping begins by means of a row of long poles, each of which has two cross pieces nailed to it, to show respectively the height to which the tipping must be carried, and the finished height of the bank. The difference between these is due to the fact that the earth will settle for months—at the rate of about 1 inch for every foot in depth for ordinary soil—and therefore the tipping must be carried out to a correspondingly higher level.

The foot of the slope is often provided with a dwarf retaining or toe wall to guard against any tendency to spread, and, as with slopes of cuttings, the surface is covered with a layer of soil and sown with grass seeds. The side slopes are usually allowed to be a little flatter than the cutting slopes of the same material, which have been given previously. It is in almost all cases necessary to construct a drain along the toes of the embankment—and the same applies to the toes of cutting slopes—in order to carry off water which might otherwise soak under the slopes. These drains are either open channels if in rock, or ditches filled with broken stone, flints or clinker and furnished with drain pipes with open joints. At intervals along these drains, brick or stone pits should be built to collect any silt which may be washed through the drain during heavy rains.

Small embankments are dealt with in a similar manner, except that the tip waggons and light railway track are replaced by barrows and barrow runs.

FOUNDATIONS

The design of **foundations** is one of the most important and at the same time one of the most difficult problems with which the engineer has to deal. If anything goes wrong with the foundation of a structure, it is generally impossible to remedy the defect, and it is therefore necessary to exercise the very greatest care and caution in the design. The weight of a proposed structure can usually be determined with fair accuracy, but it is much more difficult to estimate the supporting power of the soil. A test may be made when the foundation has been excavated and laid bare by loading the earth and determining the amount of settlement due to a pressure equivalent to that brought to bear by the work to be built upon it. Except with rock, there is bound to be some settlement, and the amount to be allowed is a matter of experience and judgment, and therefore lies rather beyond the usual duties of an assistant. In estimating the pressure to be expected from the superstructure, regard must, of course, be had to its distribution. For example, the pressure under the foundation of a retaining wall is not evenly distributed, but may be very severe near the toe. *As a rough guide only* to the safe pressures on various kinds of soil the following table is given, but it must be used with discretion, which really means in the case of an assistant that a decision should be obtained from the chief engineer.

Safe Foundation Pressures

Natural bed of soft clay or wet or loose sand - - - - - -	1 ton/sq. ft.[1]
Natural bed of ordinary clay or confined sand - - - - - -	2 ,, [1]
Natural bed of compact gravel, London blue clay or chalk - - - -	4 ,, [1]
Made or filled ground (avoid if at all possible) - - - - - -	½ ,,

Modern foundations are almost invariably of **concrete**, and the methods of mixing and preparing this are dealt with in a later chapter. For very small works, such as houses, a common rule is to make the width of the concrete 12 in. wider than the brick footings, which are themselves twice the width of the wall. Thus an 18 in. wall would have a foundation 4 ft. wide. This rule is based principally on the convenience of the men building the wall, who thus have a trench giving a 6 in. pathway on each side of the brickwork. On soft ground the concrete may be extended, or in some cases the whole building may be founded on a solid raft of concrete—often reinforced—extending over the whole site.

Piles and Pile Driving

Usually with soft ground the expedient of **piling** is resorted to. If the piles, which are long balks of timber

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[1] Prescribed by the London County Council.

or of reinforced concrete driven into the ground, can reach a hard stratum, so much the better. If not, they may still be of use in supporting the weight by friction of their sides with the earth. Timber piles may be driven in groups under isolated piers, or in rows over the whole site of a building or work. In the latter case they are called **consolidation piles**, and their effect is to consolidate the ground between them and so render it capable of sustaining a heavier load. Consolidation piles are usually short logs of elm or beech, with the branches cut close off to the main trunk (Fig. 19B). One end is adzed off to a point, and the other end is adzed round to take a wrought-iron ring which is driven on. The pile is then hoisted over the spot where it is to be driven, resting vertically on its point, and the driving is carried out by allowing a heavy cast-iron ram to fall on it in successive blows. Larger piles are constructed out of squared balks of imported timber, the kind depending on the market price prevailing at the time. Thus, red deal, pitch pine, jarrah, karri, black butt and greenheart are all used, arranged here somewhat in the order of increasing cost, the red deal and pitch pine being usually creosoted. Greenheart, though very expensive, is strong and durable, and is used for marine work principally.

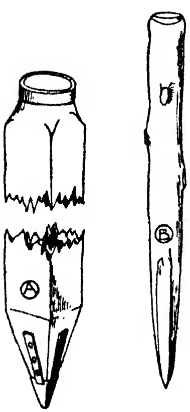

FIG. 19.—Timber piles.
(A) Squared, with ring and shoe.
(B) Beech or elm log trimmed to shape.

Where the driving is likely to be "hard," in addition to the ring at the top a cast-iron shoe is spiked on to the point (Fig. 19A). This is usually in the form of a pyramid of cast iron, with four wrought-iron straps cast into it, through which holes are drilled for spiking to the timber. The wrought-iron ring prevents the head from splitting under the blows from the ram, and is knocked or cut off when the pile is driven. If the pile is driven to its full depth without giving the necessary resistance—this being judged by the amount of penetration during the last few blows of the ram by means of one of the well-known pile formulae, such as $P = Wh/8d$; where P = safe load in lb., W = weight of ram in lb., h = height of fall in inches, and d = penetration of last blow in inches—a further length of timber is spliced on, ringed, and the driving continued.

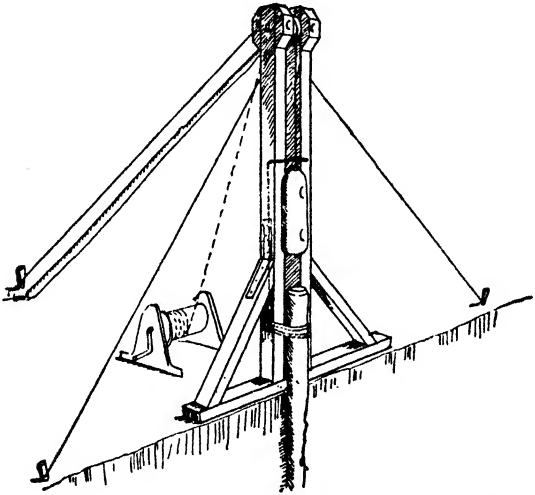

FIG. 20.—Old-fashioned type of "ringing engine" for pile driving.

The simplest form of apparatus for driving small piles is called a **ringing engine** (Fig. 20), and consists of an upright called a "leader," formed of two long pieces of timber fixed parallel with a space between. This is fixed on a timber foot-block and struts, and is placed nearly over the spot where the pile is to be driven. At the top is a large pulley, and guy ropes are led to pickets driven in the ground to keep all steady. The pile is hoisted up against the leader by a rope passing over the pulley at the top and down to a windlass near the pile frame, and is either loosely lashed to the leader or is fixed by a long bolt passing completely through the pile and between the two timbers of the leader to a block, which slides down behind the leader as the pile sinks. This keeps the pile vertical. Meanwhile the ram is hoisted up the leader and rested on the top of the pile, the hoisting rope being connected to its top by means of a special hook which can be tripped by a light line hanging down the frame.

When driving is commenced, the ram is slowly hoisted by the winch, the trip line is pulled by a labourer, and the ram drops on to the head of the pile, its direction being controlled by a lug cast on the body, this lug sliding in the gap between the timbers of the leader. The line is then hooked on again, the ram hoisted, and the process repeated.

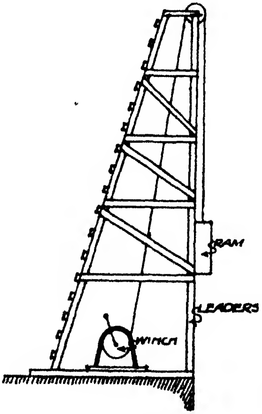

FIG. 21.
Side elevation of pile frame.

An ordinary **pile frame** is similar to a ringing engine, except that it is larger, is more rigidly braced, and the winch usually stands on a platform connected to the frame (Fig. 21). For more important work, a steam winding engine is employed instead of the hand winch. The weight of the ram—which is sometimes called a "tup" or "monkey"—may be up to 30 cwts., or even more for reinforced concrete piles. The latter are described in more detail in the chapter on concrete; they are made usually of about the same dimensions as timber piles and fitted with shoes. Where the heads of the piles must be driven below the level of the frame, a timber "dolly," similar to a short length of pile, ringed at each end, is used, of the necessary length.

In driving concrete piles there is often great danger of breaking the head of the pile. To obviate this, a **helmet** is generally used, to cap the head of the pile. It may be constructed of steel plate and filled with sawdust. It is sometimes necessary to use a timber dolly in addition, but the use of a dolly diminishes the effectiveness of the blow. Where piles have to be driven in a sloping direction, the pile frame must have its leaders sloped also, by packing up at the bottom if the angle is not great. The direction of the blow must always be along the axis of the pile.

Sheet piling is set and driven in the same way. The shoes, however, are generally made of such a form that, in driving, the pile tends to draw closer to the pile last driven, and this ensures a tight joint. In addition, the side joints are sometimes grooved and tongued for this purpose, or "birdsmouthed" (Fig. 22A). Sheet piling is usually driven as previously described between guide walings, which themselves are bolted to guide or king piles of balk timber. The sheet piles, which may be 9 in. × 3 in. or 9 in. × 4 in. or some similar section, are driven in rows commencing against a guide pile, until the next guide pile is nearly reached, the last pile being shaped exactly to fit the opening left. It must be remembered that piles cannot be driven *exactly* where required, hard ground or a single boulder causing the point to travel sideways, and that, therefore, a superstructure to be fixed directly to the piles must have provision made in its design for possible slight alterations in spacing, if the designing is carried out before the piles are actually driven. Concrete sheet piles can be made and driven exactly as timber sheet piles, the last pile in a row being specially cast and driven later if tight work is required.

There are patent forms of sheet piling on the market, mostly composed of long narrow sections pressed out of steel plate, with various forms of interlocking joints. These are driven in the same way, and are gradually ousting the ordinary timber sheet pile. There is also for ordinary piling a system which consists of driving a steel tube fitted with a specially designed shoe, and so formed that after driving concrete can be poured down the tube, which is then hoisted little by little as the concrete is poured in, until it is entirely withdrawn, leaving a pillar of solid concrete in its place. The shoe either remains at the bottom of the pile, or in some cases a specially designed shoe is used which is hoisted with the tube, and is of such a form that it allows the soft concrete to pass through it.

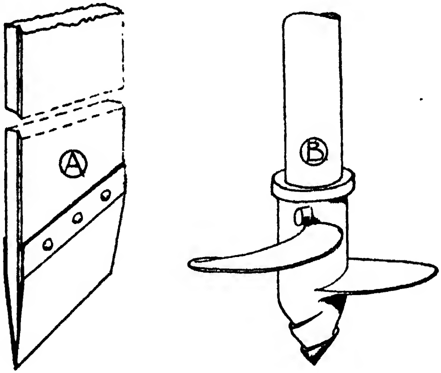

FIG. 23.—Pile shoes.
(A) Sheet pile shoe of sheet iron. (B) Screw pile.

Driving of piles in soft mud or sand can be greatly expedited by running a small iron pipe down the side of the pile to the point, and pumping a supply of high-pressure water through it. This washes away the sand from the point and enables the pile to penetrate much more easily. In concrete piles the pipe is sometimes cast into the centre of the pile.

Screw piles are often used for the foundations of structures such as piers, jetties or beacons on the sea-shore (Fig. 22B). They are composed of solid steel columns about 3 in. to 6 in. diameter, with a cast-iron spiral flange bolted or keyed on at the lower end, the diameter of the thread varying from 2 ft. 6 in. to 4 ft. They are driven by being pitched in position vertically, and then turned by means of long arms bolted to the upper end, and worked by man power from a platform built around them, in exactly the same way as a carpenter's gimlet. Larger screw piles are made, also of hollow cast-iron cylinders, up to 2 ft. 6 in. diameter, with a spiral flange keyed on in the same way. These are sometimes used for bridge foundations.

Foundation piles if of timber are usually sawn off at the required level if they cannot be driven to it, and the heads connected by timber stringers and cross pieces, or embedded in concrete, on which the superstructure is built. Reinforced concrete piles usually have the concrete of the upper 18 inches oi so broken away to expose the steel reinforcement, which is then cased by timber and embedded in the concrete of the superstructure.

Piles for marine works are usually driven from a special barge, which is moored by several anchors in the required position, the pile frame being mounted upon it.

Other usual methods of forming foundations, namely by means of wells, cylinders, caissons and box caissons, have been dealt with under the heading of excavation. When they are sunk to the required level, they are usually filled with concrete, brickwork or masonry.

OUTLINE SPECIFICATION CLAUSES FOR EARTHWORK AND FOUNDATIONS

Specification clauses dealing with the most important items of excavation and foundation work are given below :—

Excavation. Excavation is to be carried out to the full widths and depths shown on the drawings, or until in the opinion of the engineer a firm foundation is reached. Should more be taken out than is required by the engineer, it is to be filled in to the required level with good concrete at the contractor's expense.

Keep dry. The contractor is to provide all pumping plant necessary to keep the excavations dry during the progress of the work.

Timbering. The trenches are to be properly timbered and strutted by the contractor. Should any timber be left in by the instructions of the engineer, it will be paid for at schedule rates. Otherwise the timber must be removed when directed.

Sand and gravel excavated. Should the contractor excavate sand or gravel during the progress of the work, the same is to be deemed the property of the employer. The engineer may allow its use in the work at an agreed price.

Trenches. The bottoms of trenches are to be kept dry and level, and rammed where directed.

Surface excavation. Surface soil, trees, bushes, etc., are to be dug and removed as directed. Turf is to be carefully stripped, rolled and stacked where directed.

Disposal of spoil. Excavated material which is not required afterwards for filling is to be taken directly from the works to a shoot to be provided by the contractor (or alternatively to a specified spot where it may be required for filling).

Embankments and filling. Embankments are to be formed where shown of spoil excavated from the cuttings (or from borrow pits to be provided by the contractor, or to be dug on land coloured .... on the drawings). The thickness of each layer in the embankments or in any filling is not to exceed 9 in., well punned and watered. End tipping only will be allowed in large embankments, and the direction and level of the layers are to be to the satisfaction of the engineer. Approved selected material only is to be used in filling behind retaining walls.

Measurements. The measurements of excavated material are to be made before it is excavated, and the measurements of filling after it has been put in place, rammed, and has settled, and the contractor is to make his own allowance for increase or decrease in bulk.

Blasting. Excavation of rock is to be carried out by wedging, except where the engineer gives permission for blasting to be used.

Soiling. All banks coloured green on the plan are to be soiled with good soil 4 in. thick and sown with a mixture of rye grass and clover at the rate of 30 lb. per acre, well raked in and covered.

Piling. Where piling is required the timber piles are to be of the quality specified in carpenter, and those of reinforced concrete as specified in concretor. They are to be pitched accurately in the positions shown, and driven until a set of not more than ....in. is obtained by six blows of a ram weighing 30 cwt. with a drop of 6 feet. Timber piles are to be properly ringed and shod before driving, and cut off neatly to the required length. If in the opinion of the engineer the set at each blow is too great, the pile is to be lengthened by scarping, and so driven until the required set is obtained ; the extra timber, including the labour of scarping, being paid for at schedule rates. All piles driven out of position or damaged are to be replaced at the contractor's expense.

CHAPTER VII

CONSTRUCTION IN MASONRY

Classes of Stones

The stones used in masonry construction may be divided into three main classes—**igneous** rocks, such as granite; **sandstones**; and **limestones**: their main distinctive characteristics being that igneous rocks have at one time been in a molten condition and are of a very hard and crystalline nature; sandstones are composed of grains of quartz (silica) cemented together by various substances; and limestones are composed principally of carbonate of lime.

The two essential requirements of an engineering stone are strength and durability. The first is easily tested in an ordinary testing machine, but the second it is almost impossible to foretell. Chemists, geologists and engineers have all tried to discover some simple criterion of durability, either in the chemical composition or the physical structure or the geological position of the strata. None of these researches has been successful, and it is still necessary for the engineer who proposes to build in masonry to ascertain its durability from old structures which have been erected of it, or by direct experiment—which is necessarily a long business.

For small works it is best, perhaps, to obtain quotations from well-known quarry owners, local stone being usually cheaper than that from a distance on account of carriage costs, though not necessarily so if the local quarries are not worked in an economical manner. The kinds of stone in most general use in the South of England only are dealt with here. It must be remembered, however, that there are many excellent stones quarried and used in their own localities which are not so well known elsewhere.

Granites. These, which when true granites, are composed of quartz, felspar and mica in crystals, come principally from Aberdeen and its neighbourhood and from Cornwall. A large quantity of the granite from Aberdeen is really of Norwegian origin, being shipped to Aberdeen to be worked. In addition, there are the native Aberdeen grey and Peterhead red. Many other granites are used for road metal and paving setts, such as the Guernsey, Leicestershire, Dalbeattie, etc., but they need not be further noticed here.

Granite is the hardest and strongest of our building stones, its crushing strength being often 1000 tons per sq. ft., though it must be understood that the figures given here for crushing strength may vary very much from those for any individual specimen. For important work, samples of the stone should be worked to a cube of, say, 3 in. side and tested in a testing machine, the specimens being properly bedded in plaster of Paris or on soft pine boards to ensure even bearing and prevent " spalling " of corners during the test.

Practically all granites are very durable and at the same time difficult to work. They should be used in preference to other stones for such situations as dock copings, bed stones for very heavy girders, and steps where much wear is expected, although they are apt to become slippery.

They are also used in many situations solely for the sake of their appearance, particularly when polished.

Sandstones. The durability of a sandstone depends entirely on the nature of the material cementing the grains of quartz together, the quartz itself being practically indestructible. The best guide, however, as mentioned before, is the evidence given by structures erected many years ago. The commonest varieties in general use are the **York** sandstones from the West Riding, varying in colour from grey to brown; the sandstones of the Bristol district, such as the **Blue Pennant**; and the **Craigleith** stone of very fine grain. The strengths in crushing vary from 200 to 500 tons per sq. ft.

Limestones. These are usually softer than sandstones, but are equally as durable. The best known is the **Portland** stone from Dorset, of which there are three varieties in common use: the "whitbed" or best kind, of even texture and good weathering qualities; the base or so called "best" bed, similar in appearance but not so good in quality; and the "roach," a rough-grained stone not suitable for fine-dressed work, but of good weathering qualities. Bath stone is a limestone, very soft and easily worked. Purbeck stone is another kind, much harder, and used often instead of York stone where considerable resistance to crushing is required. Chalk is of the same chemical composition as a limestone, but it is too soft for engineering structures, although it is sometimes used for small buildings. There are other limestones which are composed not solely of carbonate of lime, but contain also a large proportion of carbonate of magnesia. These are called magnesian limestones or dolomites, and come from the Midlands. Some of them are of excellent quality, notably the Mansfield stones.

Artificial stone of various kinds is now made. It is practically a cement concrete, and may be obtained very cheaply in various moulded forms, thus obviating the need for carving. It is more used by architects than engineers, principally for dressings such as window heads, sills, etc., and for stone stairs.

METHODS OF WORKING

The methods of getting and working stone vary with its hardness and its disposition in the quarry. It is generally obtained in the first place either by **blasting**, or, if the stone is soft enough, by drilling holes 3 in. to 6 in. apart in rows as described in the chapter on excavation in rock, and then driving a series of steel **wedges** into the holes so drilled, with the result that the rock is split along the line of the holes. This is the method also adopted for splitting large blocks into the sizes required. Sandstones and limestones have originally existed in the form of sand or particles of carbonate of lime, deposited in layers at the bottom of a lake or ocean, and they usually lie in the quarry in **beds** corresponding with these layers. These beds are not necessarily horizontal (though they must have been so in the first instance), owing to subsequent upheavals in the earth's crust. The stones are more easily split along the bedding planes than across them, though both directions are possible by the method of wedging described.

In some stones, such as York, it is easy to see the bedding planes in each block, but in others, such as Portland, it is practically impossible. This matter is of importance, since the crushing strength of stone is greater across the **bedding planes** than along them, and therefore the blocks should be marked at the quarry so that there can be no mistake. The blocks can then be built into the work in the correct position, *i.e.* with the bedding planes horizontal if in ordinary walling, or radial if in an arch, the **edges** of the beds showing on the face of the wall in both cases. Other cases are shown in Fig. 25c, though it must be pointed out that columns are not often cut with the beds horizontal, owing to the high cost of obtaining long stones across the beds.

When the blocks have been split to a manageable size they are nowadays usually **sawn** nearly to the final dimensions required, even granite being thus worked. The saws are composed of blades of flat strip steel with either plain or serrated edges, usually worked by power. A short stroke to-and-fro motion is given to them, and a mixture of sharp sand and water is fed into the cut so produced. For hard stones, as granite and York stone, very fine chilled steel shot—" iron sand "—is substituted for the sand. Soft stones, such as Bath, can be sawn with an ordinary toothed hand saw.

After the stone has been thus reduced almost to its final dimensions, the surfaces are finished in different ways. For granite, the face may be left from the saw—called **half-sawn**—or it may be hammered over by the **axe,** a heavy steel sharp-edged hammer worked vertically over the surface, giving a definite number of short and shallow parallel channels per inch width, finer work being done by the patent axe, consisting of a number of blades held close together in one handle. Instead of the axe a pick may be used, giving a series of shallow holes at fairly regular intervals over the surface.

The cheapest form of face for granite is to leave it as it comes from the quarry after being split. This is usually called **rock** or **quarry face**, the larger projections being knocked off with a heavy " spalling " hammer. Blocks finished in this way are somewhat irregular in shape and, in order to facilitate accurate setting and to improve their appearance, they are usually " drafted " on the edges, that is, a plain flat border is worked around the face with the axe. The top and bottom beds of the stone must, of course, be flat, and should be axed or sawn and not too smooth. Another finish for granite, employed chiefly in architectural work, is the **polished face.** The sawn surface is rubbed over with iron sand under a heavy block of cast iron until a smooth surface is obtained ; then fine grit is substituted for the iron sand, and lastly polishing powder. A polished face is naturally expensive, but appears to be almost indestructible. Sometimes a rubbed face is produced without any final polishing. Mouldings may be worked upon granite, but they should be of simple outline in order to save expense.

Sandstones and limestones are quarried and split from the block and sawn in a similar manner. The final face is produced, however, by the mallet and chisel, and not by the axe. The sawn and rock faces are similar to those on granite, the margin around the rock face being produced in this case by dressing down with the **tool** or inch chisel. For large flat faces the **broad tool** or **boaster** is used. Limestones and sandstones are often **rubbed** smooth with iron sand and coarse or fine grit, but they do not lend themselves to polishing like granite, with the exception of hard limestones like Purbeck, which is then called Purbeck marble. Stones such as York, which split easily along well-defined bedding planes, are often used for paving. These planes are often so flat that no further work is required on them, and the stones are said to be **self-faced.** This, of course, saves much labour. Very soft stones, such as Bath, are sometimes finished by scraping with a toothed scraper. This is called " dragging."

Mouldings are cut with the mallet and chisel, a reverse template being first made in sheet zinc showing the full-size profile of the moulding, and applied from time to time by the mason to the stone as it is being worked (Fig. 25A). Hand work, such as moulding and carving, is done on a firm bench called a **banker.** Mouldings are often produced by machinery, either by placing the stone on a moving bed and allowing it to pass under a tool like a large plane iron of the required shape, or by passing the stone across a shaped revolving carborundum wheel, which grinds it down to the required form.

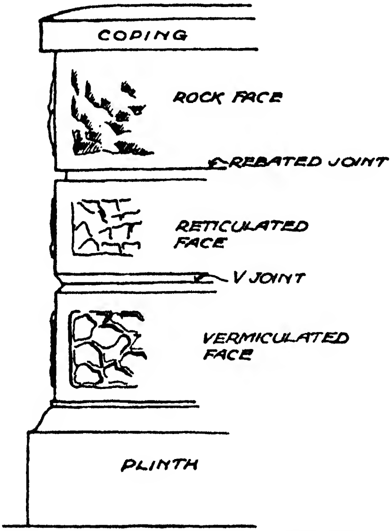

FIG. 23.—Ashlar stonework in wall construction.

One form of surface very often employed is that known as **rusticated.** The beds of the stone are sawn or tooled, and the exposed faces have a margin, say, 2 in. wide, tooled all round, the inner portion of the face being either left rock-faced or being cut into one of a numerous variety of fanciful patterns of a rough and picturesque character (Fig. 25).

Stone columns are now usually turned in a large lathe, although small ones may be cut out by the masons on the banker in the old-fashioned way.

Stonework, if in large quantities, is now usually done at the quarries, first, because carriage has then only to be paid on the actual weight of the finished stone, and not on the block out of which the stone is cut; and secondly, because the stone is softer and easier to work if freshly quarried, before the quarry "sap" or moisture has had time to dry out.

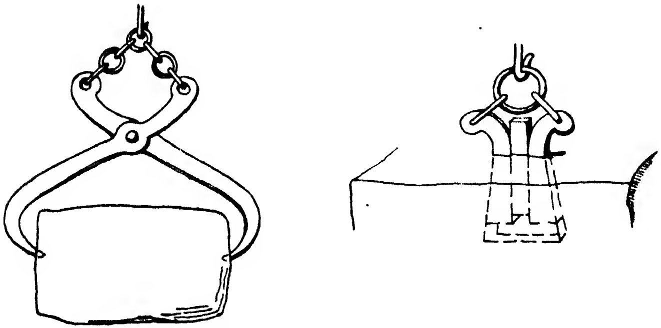

Fig. 24.—Nippers and lewis for lifting stones.

Setting and Inspection of Masonry

When the shaped stones have arrived on the works they must be hoisted into position, usually by a crane, and it is important to see that they are securely fixed to the crane hook. The ordinary expedient of a rope or chain sling around the stone is inadmissible, both because the edges of the stone would probably be damaged, and because of the difficulty of removing the sling when the heavy stone is lowered on to its bed. For this purpose, therefore, use is made of **lewises** of different forms (Fig. 24). These are iron wedges let into holes cut in the top of the block, of such a form that the weight of the block tends to keep them tight. If the ends of the block are to be covered up eventually, **nippers** may be used inserted into shallow holes picked in the stone a little above its centre of gravity.

It is usual to set the stone in position first dry, then to lift it, spread the mortar and set again. For some kinds of stonework a thin joint is considered to be best, and this means that the beds must be carefully worked perfectly flat—though not rubbed, as they should not be too smooth—and it is much easier to work the beds hollow so that the stones bear on each other at the outsides only. This causes the corners to "flush" or "spall," and should not be allowed (Fig. 25B).

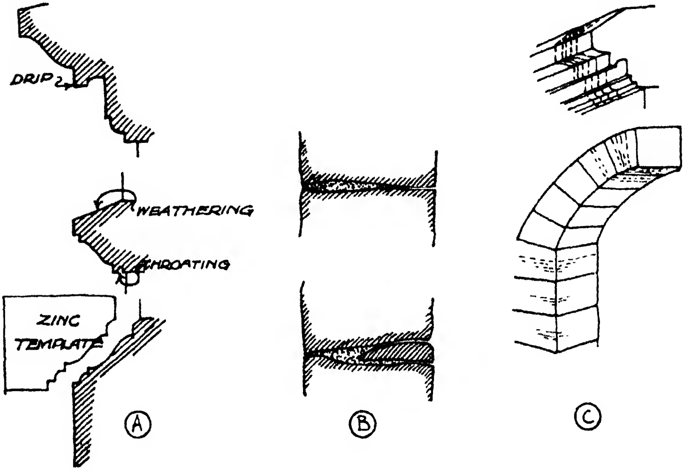

FIG. 25.—Stonework.
(A) Mouldings.
(B) Hollow bedding.
(C) Correct arrangement of bedding planes. Edges of beds shown by dotted lines.

Stone is usually set in Portland cement mortar, but in architectural work with light-coloured stones it is best to form the outside of the joint with a strip of white lime and sand, the Portland cement being kept well within the face of the stone, as it is likely to stain it. The face joints of the stonework are often rebated or V-jointed, both for the sake of appearance and to avoid any danger of spalling (Fig. 23).

When inspecting stone the **defects** to be looked for include splits or cracks, sand holes or soft places, and weak bedding planes. The dimensions and angles must, of course, be accurately worked to, and it is customary with stone which has been expensively worked to cover it in transit by means of a wooden framework fixed to protect its edges, which is, of course, removed when the stone is being set. The edges are often protected in the same way after the stone is set, until the scaffold is taken down and there is no fear of its being chipped. Masons sometimes cover up defects by means of pieces of stone stuck on by shellac varnish. This of course, should not be allowed.

Stone Walling and Dressings

Stone walling is generally divided into two classes, **ashlar** and **rubble.** Ashlar walling is composed of stones carefully worked all round, is set with thin joints, and is generally employed for dressings which will be described later. Rubble walling usually has the exposed surface quarry or rock-faced, however carefully the beds may be worked. Ashlar stones for walling are worked all to set dimensions, while rubble stones may be of different sizes in the same course, and the courses themselves may vary in height.

The cheapest form of rubble walling—seen only in districts where stone is plentiful—is **random** or **uncoursed rubble**, often built without mortar (Fig. 27). A skilful waller can build a substantial wall in this manner, but the stones must be carefully chosen to bond together well, and if the wall is thick there must be a number of stones going completely through from face to face. The easiest way to build rubble walls is always to build the two faces as neatly as possible, filling in between with odd pieces, and **bond** or **through** stones are very necessary. A usual requirement is one to every square yard of face. The coping of a " dry " stone wall is usually set in mortar.

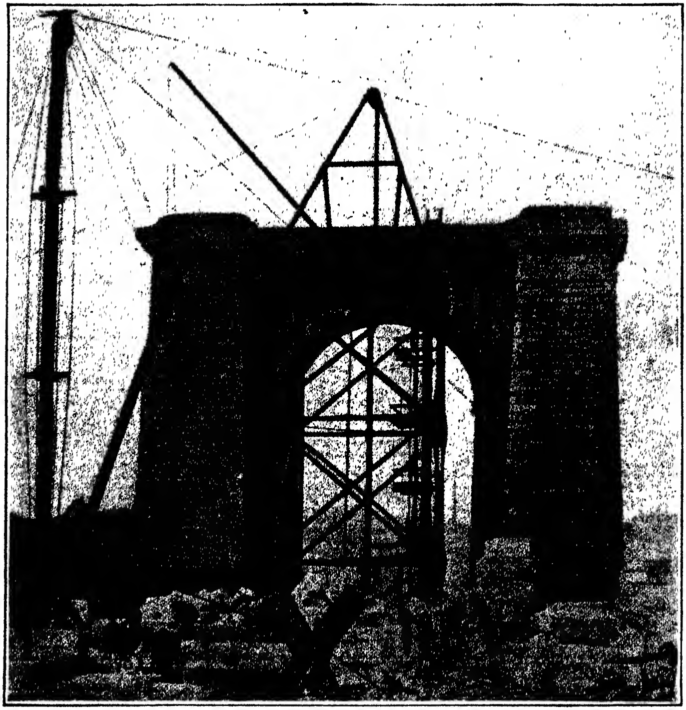

FIG. 26.—Masonry Pier of Blackwell's Island Bridge, New York.
[*Engineering*, 20th August, 1909.

When the stone is of a flat-bedded nature, so that by merely splitting it the top and bottom beds are parallel, by taking a little care in squaring the ends of the stones, a very substantial wall can be built in what is called **snecked rubble.** The stones are built into the wall as they come to hand, and no attempt is made to form complete courses of regular height. The skill of the mason is severely taxed to obtain adequate bonding, *i.e.* the avoidance of continuous vertical joints. The overlap should be at least 3 in. It is usually required that the stones should be above a certain minimum thickness, say 4 in., that the joints should be squared 4 in. back from the face, and that at least ¼ of the face should consist of stones reaching 24 in. deep. A rather better and more expensive class of walling is obtained when the stones are carefully sorted into heights, each course being composed of stones of one height only. This is called **coursed rubble.**

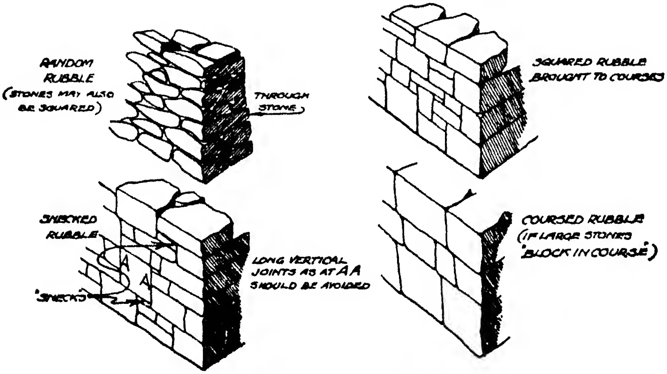

FIG. 27.—Rubble walling.

For heavy engineering work, such as large bridge abutments, retaining walls, etc., **block-in course** walling is often employed. This is simply coursed rubble, of which each stone is above a specified minimum size, say, not less than 7 in. deep and 18 in. × 12 in. on the bed, up to 14 in. deep × 4 ft. × 3 ft. on the bed.

The **mortar** used for stone walling is usually composed of hydraulic lime (lime which will set under water) and sand, in the proportions of about 1 of lime to 2 of sand. For strong work Portland cement is substituted for lime, and often ashes or crushed stone are used instead of sand. The stones should be kept well wetted when being laid if of an absorbent nature, as this causes them to adhere better to the mortar.

A special kind of masonry is sometimes used for massive works such as solid masonry dams, and is known as **rubble concrete.** It is composed of very large blocks as obtained from the quarry—usually near the dam, or stone excavated to form the foundation of the dam—which are set in fine cement concrete by means of a crane. The stones have also fine concrete packed around them by hand, great care being taken that there are no hollows left, the stones being about 6 in. apart. A system of " waggling " the stones on their bed is adopted sometimes to render the work more solid. The face may be finished in squared rubble or ashlar.

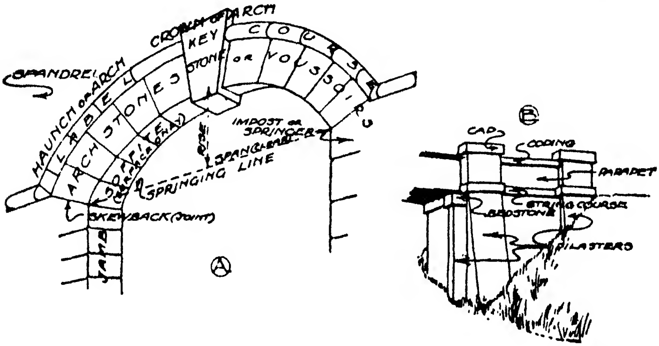

FIG. 28.—Stone dressings.
(A) Arch. (B) Bridge abutment.

Dressings are ashlar stones carefully worked to shape to suit special positions. Amongst them may be mentioned steps, window sills, window heads, arch stones of various shapes, string courses, labels, hoods, mullions, transoms, cornices, copings, etc. These can be better shown by sketches than described, and it is essential that the student should be familiar with their technical names (Fig. 28). Many of them will be further described in the later chapters dealing with the structures in which they are used. Those intended to throw off water are usually **weathered,** *i.e.* the upper surface is sloped, and they are also allowed to project

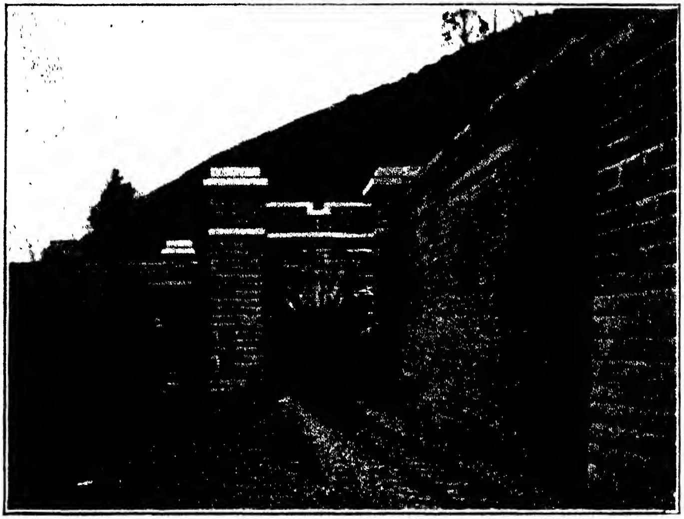

FIG. 29.—Tunnel entrance showing ashlar and rubble stone work, caps, pilasters and face of heavy retaining wall.

Engineering, 27th August, 1909.

over the main face of the work in many cases, the projection being **throated,** or a groove cut underneath to form a drip and to prevent the wet from running back on to the face of the work (Fig. 25A). Certain precautions are necessary in setting. Thus, window sills should be bedded hollow in order to allow for a slight settlement at the ends without danger of fracture.

JOINTING AND STRENGTH OF STONEWORK

Various forms of joint are employed besides the plain "butt" joint used in ordinary walling. Mullions are prevented from moving sideways by **dowels**, generally of slate, these being let into the upper surface of the sill and the under surface of the mullion. Coping stones are prevented from moving laterally relatively to each other either by **cramps** of copper or galvanized iron let into the stone and covered with cement, or by slate cramps of double dovetail shape—these cramps being capable of resisting tension—or by cement **joggles**, which are merely recesses cut into the adjoining faces of the coping stones and filled with cement which, when it sets hard, prevents lateral movement. This last method is also sometimes used for the abutting faces of arch stones.

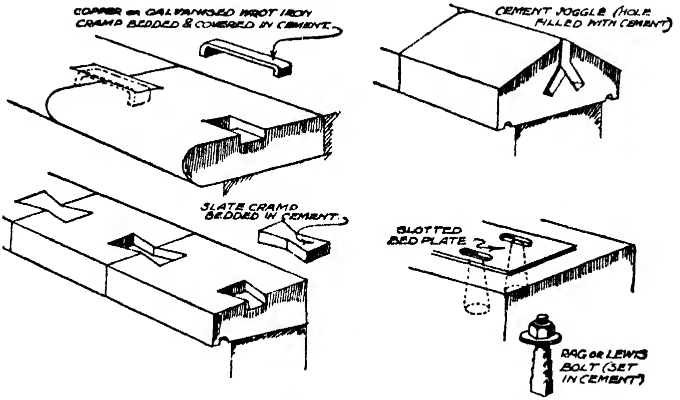

FIG. 30.—Stonework fastenings.

Elaborate dovetail joints are also used for the construction of lighthouses and other works exposed to the force of the sea. These are usually designed specially for each work, having due regard to the forces brought to bear on it. Iron should never be used unless it is well galvanized. If it rusts it expands and splits the stone.

The **strength** of stonework in compression is considerably less than that of single squared blocks, and decreases with the decrease in strength of the mortar employed. Little is yet known as to the amount of this decrease, and consequently engineers allow a very high factor of safety.

OUTLINE SPECIFICATION CLAUSES FOR MASONRY

The following items are among the more important for insertion in the specification :—

Stonework generally. All stones are to be of the full dimensions shown on the drawings, free from cracks, flaws, vents, sand holes, or other defects ; and laid on their natural bed in the case of walls, or with the natural bed perpendicular to the face and to the line of pressure in the case of arches. The granite is to be from .... or other approved quarry, properly axed to even and true surfaces. The face where exposed is to be fine axed (or axed, patent axed, rubbed or polished). No hollow bedding will be allowed, and all stones must be protected from damage before they are in place. No shellac or other cement is to be used for jointing broken pieces. All stonework is to be jointed in Portland cement mortar as specified for brickwork, and all vertical joints first pointed and then grouted solid with neat cement. No joint is to be more than ¼ in. in thickness. Care is to be taken to avoid any air holes in the bedding of large stones. Dowels, cramps, etc., are to be bedded solid in cement and sand 1 to 1.

Ashlar stonework. All ashlar stones are to be worked to details supplied by the engineer. Mouldings are to be cut accurately to templates.

Block-in course. No stone is to be less than 9 in. deep or 1½ square feet on the bed. All horizontal beds are to be square for the full depth, and vertical joints at least 6 in. from the face.

Snecked rubble. No stone is to be less than 5 in. deep or ¾ square foot on the bed. All horizontal beds are to be square for the full depth, and vertical joints at least 4 in. from the face. One bond stone is to be provided to every superficial yard of face, reaching at least 24 in. back.

Granite pitching. The setts are to be of granite as previously specified, bedded on 2 in. of fine ashes (or coarse sand) and grouted with cement mortar.

CHAPTER VIII

CONSTRUCTION IN BRICKWORK

BRICKS

MODERN bricks are made from clay—without straw—and are burnt after moulding. The engineer should be familiar with the process in outline, as it often pays on large works to use the clay which may be excavated, if this happens to be suitable. Just as the chemical composition of a stone is very little guide to its durability, so the chemical composition of a clay is to the engineer no criterion of the brick it will produce. It may be said that strong pure clays make a very hard brick, which, however, warps and twists a good deal in the burning, and that an admixture of sand improves it on the whole. So does a proportion of carbonate of lime, provided it is disseminated throughout the mass and is not in the form of lumps, which become quicklime in the kiln and slake afterwards, thus bursting the brick. The red colour of most bricks is due to iron in the clay.

The old process of **making by hand,** which is still carried on where it does not pay to provide the capital for machinery, is as follows. In the autumn the grass and earth are removed from the surface of the clay deposit, and the clay is dug and exposed in heaps to the weather during the winter. It becomes softer and more workable, and in the spring it is tempered by being mixed with water and well worked into a stiff pasty mass. It is then moulded into bricks, the moulder throwing a clot of clay into a wooden mould about 10 in. × 5 in., 3 in. high, resting on a wooden slip or "pallet." Dry sand is first dusted over the mould—in some cases water is used instead—to prevent the clay from sticking. The mould is lifted off, leaving the soft brick resting on the pallet, on which it is carried to the drying yard. Here the bricks are stacked so that air can circulate freely about them, being protected from the rain by light roofing.

Hand-made bricks are formed with a depression or **frog** on one side, its purpose being probably to lessen the amount of clay required.

After drying for a few weeks—the exact period depending upon the weather—the bricks are burnt either in a **clamp** or in a **kiln**. In the former, a dry level site is selected, floored with burnt bricks, over which a layer of fine coke breeze is spread, and the unburnt bricks are stacked on this in the form of a rectangular heap 9 or 10 ft. high, the bricks being placed a little apart and flues being formed among the lower layers. The external faces of the stack are smeared with clay and the coke breeze ignited at the windward end. The fire spreads steadily, burning many days, and the hot gases circulate amongst the bricks. When the fire has spread through and burnt out, the bricks are sorted out, those from the centre being well burnt and hard, and the outsides being softer. For clamp burning it is advisable to mix a little coke breeze in with the clay in moulding.

In kiln burning the unburnt bricks are stacked inside a brick kiln—the Scotch type is a very common one—and fires are ignited at the fireholes. Kiln burnt bricks are usually more uniform in quality, and less coke is consumed in burning. Modern brick kilns are now constructed upon the chamber principle, in which the air for burning is first drawn through a chamber of burnt bricks waiting to cool, where it is heated up, then through a chamber of burning bricks, where it combines with the fuel, and lastly, through a chamber of bricks waiting to be burnt, which it dries in parting with its heat. By this means much of the heat hitherto wasted in cooling the burnt bricks is utilized and fuel is saved.

Bricks are also very largely moulded by machinery, the commonest form being that of a **pug mill** in which the clay is cut up by revolving knives, then crushed between rollers and forced through an oblong die about 10 in. × 5 in., whence it issues as a solid band which is cut into rectangular slabs by a series of wires. These bricks are generally dried under cover in heated chambers, and a great saving in time is thus effected. Such bricks are known as **wire cuts.**

Pressed bricks are often used for superior work, generally for facing other brickwork. They are made from the unburnt wire cuts by putting them in a steel mould and pressing them top and bottom, then drying and burning in the usual manner. They have square faces and sharp edges or "arrises," and are usually a little larger than the wire cuts, so that they may bond well with the latter and at the same time only require a thinner joint. This increase in size is effected during the pressing by indenting the top and bottom surfaces with a depression or frog, the extreme dimensions of the brick being thus increased although the actual volume of clay is if anything slightly reduced under the pressure. It will be seen that in brickwork it is customary to allow what is condemned in stonework, viz. hollow bedding.

Many kinds of bricks are in common use in Great Britain.

For ordinary engineering work, apart from purely local kinds, the best known are:

Staffordshire blue, very hard, strong and durable, used for heavy pressures and where great wear is expected, under girder bedstones, for angles of walls, tunnel linings and facings.

Staffordshire brindles, somewhat similar to the above, but not so expensive; used for similar purposes.

Fire bricks, made from certain clays which will withstand a very high temperature without fusing or becoming shapeless lumps of glassy material. Used for furnace linings. They come from different parts of the country, for example from Scotland, Newcastle, the West Riding, and Wales.

Glazed bricks. These are usually made from fire bricks, and are of two kinds, viz. salt glazed, in which the glaze is produced by throwing salt on the kiln fire, the fumes from the salt combining with the clay to form a brown glass coating; and enamelled, which are first burnt, then coated with a special clay on one or two faces and reburnt. Enamelled bricks may be of any colour, but salt glazed are brown. The latter are the better for outdoor use.

Rubbers. These are made from carefully prepared clays, and are soft and of even texture throughout. They are larger than ordinary bricks, and are used principally for arches, for which purpose they are rubbed or filed down accurately to the proper wedge shape. They are usually of a pleasant bright red.

Moulded bricks, of many shapes and used for ornament. The commonest is the one with a single rounded corner, or **bull nose,** in ordinary red, Staffordshire blue, or glazed brick.

Terra cotta, made from special clays and burnt in special kilns. Although not strictly speaking a brick, it is often used for important features in a building in conjunction with ordinary brickwork, such as window heads, sills, string courses, keystones to arches, copings, etc. It is very strong, hard and durable, but owing to its cost is usually made in the form of hollow blocks with skins about 1 in. thick, which are filled with fine concrete when it is being laid. It should not be cut or chipped, in order to preserve the skin intact. Stock patterns may be obtained from the manufacturers, but if special designs are required which cannot be made up out of ordinary stock patterns, they may be made specially by the manufacturers if a full-size detail is supplied. This takes time, and is only adopted on large works.

BRICKWORK

There are many points to be attended to during the **laying** of the bricks. The usual size is nominally 9 in. × 4½ in. on the bed and 3 in. high, the actual size being about ¼ in. less than each of these dimensions, so that with mortar joints ¼ in. thick the full dimension is obtained. This will give four **courses** "rising" to the foot. In some parts of the country, principally in the north, four courses when laid are equal to 13 in. in height. It will be seen that each brick is twice as long as it is wide, and this is for the purpose of facilitating the regular arrangement in courses, known as bond.

The principal tools used by the bricklayer are the large laying trowel for spreading the mortar and, where the bricks are soft, for cutting them by striking with the edge, a broad chisel, called a **bolster**, being used for hard bricks; the **pins**, which are of iron and thrust into the joints of the brickwork and the **line** stretched between them as a guide to the bricklayer; and the **plumb rule** for ensuring the verticality of the face. The mortar is mixed by a labourer, who serves the bricklayer with it on a large board, from which it is scooped on to a small board fitted with a handle.

The corners of the wall are first built up several courses and kept perfectly upright, and the line stretched between them, the intermediate portion being then built up to the same level. If the **face** of the wall is exposed to view in the completed work, the outside bricks are either carefully selected from the main bulk, or special bricks are employed for this portion. These outside bricks, however, must be properly **bonded** to the rest of the work. Those bricks laid with their length parallel to the length of the wall are called **stretchers**, those at right angles to the length **headers.**

As in masonry, the bricks should be kept wet and the joints properly and solidly filled with mortar to the top. In thick walls the outside bricks are set in the usual way with the trowel, the inner ones laid dry but not quite touching, and over the whole is poured liquid mortar. This is called **grouting.** In order so far as possible to avoid cutting the bricks, piers between openings, and narrow projections should always be designed as some multiple of 4½ in. This is not necessary in lengths over, say, 6 ft., as the bricklayer can then work to the required length by slightly widening or narrowing his vertical joints.

The arrangement of bricks to produce a satisfactory **bond** needs careful consideration. There are two methods in common use, viz. **English** bond and **Flemish** bond. In the first, the facing courses are arranged in alternate rows of headers and stretchers. In order to avoid vertical joints, each corner header is followed along the course by a quarter-brick or **queen closer.** In Flemish bond each course consists on the face of alternate headers and stretchers, and the appearance is considered more pleasing. The corner header again is followed by a queen closer for the same reason as before.

If an attempt is made to bond a thick wall, in either English or Flemish bond, it will be found that if the vertical joints are broken—as they should be, since the object of the bond is to avoid them—then it will be impossible altogether to

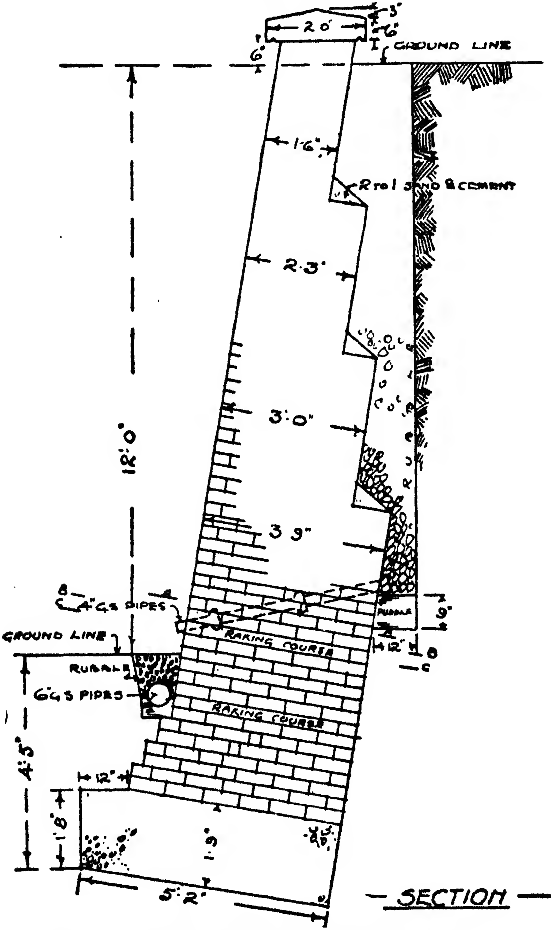

FIG. 31.—Brick retaining wall on concrete foundation.

avoid straight joints through the wall from back to front, and these consequently must be allowed. In thick walls, whatever bond may be adopted for the face, the interior is filled in with headers only. This weakens the longitudinal strength considerably, and in walls more than three bricks thick it is customary to build the inside of every sixth course with bricks laid diagonally, and solidly bedded in mortar (Fig. 31).

It is generally considered that English bond is stronger than Flemish, and English is consequently in common use for engineering work. The standard text-books on building construction give diagrams of bonding based on the principles stated above.

It is not often that the assistant is called upon to decide on the exact bond required, beyond what is laid down in the specification, but he should know the principles on which it is based, and be able to work it out in special cases. The general method is to draw the plans of two successive courses on tracing paper, place one over the other and see if it is possible to avoid any coincidence of the vertical joints, the face of the work always showing the orthodox queen closer next to the corner header.

The bricklayer must be careful to see that the vertical joints in alternate courses come exactly over one another. This is called "keeping the perpends." "Bats," which are bricks broken into halves across their length, interfere with the proper bonding of the work and are a source of weakness.

Where oversailing or corbel courses have to be built and where stepped footings are required, all the bricks are arranged as far as possible as headers.

ARCHES

Brick arches are built like stone arches, on strong timber centres covered with boarding, curved to the proper form (Fig. 39). In most engineering work ordinary bricks are used, the necessary wedge shape being obtained by making the joints between the bricks wider at the back (Fig. 32). The mortar is usually of Portland cement and sand 1 to 3. In arches consisting of several rings, there may be a tendency for the rings to separate, and they are consequently tied together by **lacing courses**, consisting of headers running through two courses inserted where the joints of two adjacent rings coincide; or in some cases solid blocks of brickwork like arch stones are built in as lacing courses. For small arches, the bricks are sometimes cut to a rough wedge shape by the bricklayer with the broad chisel or bricklayer's axe, and in architectural work arches are often formed of soft bricks, accurately rubbed to shape on a flat stone, and set with fine joints, the bricks in this case being usually hollowed on their beds and liquid cement poured into the recess thus formed, to act as a joggle and prevent relative lateral motion.

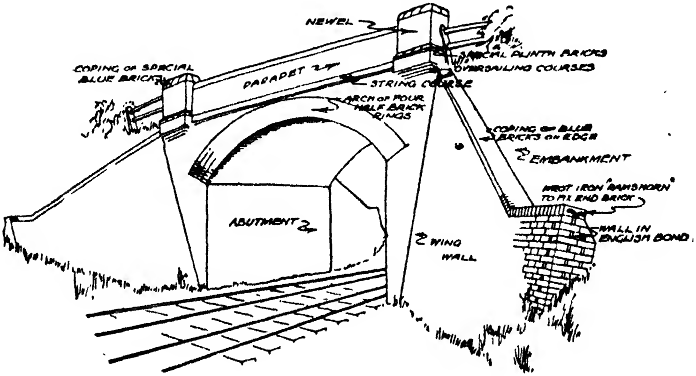

FIG 32.—Brick overbridge.

The **facing** of brickwork is generally done either with ordinary bricks selected specially, or with facing bricks. In addition, the mortar joints are "struck" with the trowel, generally with one of the joints shown in Fig. 33, in order to form a neat finish on the face.

If the work is being built in lime mortar—which requires some weeks to set—during the winter, it is usually inadvisable to strike the joints as the work proceeds, as a sudden frost will cause the unset mortar near the face of the work to fall out. In such cases the joints are left rough until the work is finished, then raked out $\frac{3}{4}$ in. deep and pointed with cement and sand, with which the face of the joint is formed.

Fig. 33.—Mortar face joints.

The **mortar** used for brickwork or masonry is made from lime or Portland cement and sand, generally in proportions about 1 of lime to 2 or 3 of sand, and 1 of cement to 3 or 4 of sand by volume. The lime is produced by calcining limestone, which is composed of carbonate of lime. In the process it becomes an oxide, called quicklime, which will combine with water to form a powder—still dry—called slaked or hydrated lime. This is mixed with more water and with sand to form lime mortar. Some limes are made from limestone which contains clay. It is found that such limes possess the property of setting under water, and they are thence termed hydraulic. Lime made from a lias limestone is of this character.

Strength of Brickwork

The **strength** of brickwork is a matter which has to be carefully considered by the engineer. It has been generally established by tests that—as in the case of stonework—the crushing strength of a mass of brickwork is always less than the crushing strength of the single bricks of which it is built, each being calculated in tons per sq. ft. The weakness of the mass of brickwork is more pronounced with weak mortar than with strong. Bricks themselves vary enormously in crushing strength—from 40 tons per sq. ft. for common bricks used in house building up to 400 tons per sq. ft. for the hardest blue bricks. Even ordinary house bricks may vary from 40 to 200 tons per sq. ft. in different parts of the country. It is, therefore, obviously impossible to lay down any standard working stress which shall be universally applicable.

A large margin of safety should be allowed if the working stress is to be deduced from the crushing strength of a single brick. As a rough guide to the working stress, a very common figure of 3 tons per sq. ft. for soft bricks in lime mortar and 6 tons per sq. ft. for the same bricks in cement mortar may be taken, the dry crushing strength of the bricks being about 50 tons per sq. ft. For Staffordshire blue bricks in cement mortar, the working stress may be taken as 12 tons per sq. ft., and for ordinary hard bricks in cement 8 tons per sq. ft. When testing bricks in a testing machine, it is necessary to observe the same precautions in bedding as in the case of stone, to ensure an even bearing. The pressure upon a bed of brickwork in an engineering structure is rarely evenly distributed unless it is due to dead weight alone, and the unevenness of distribution and consequent concentration along one edge must be allowed for in designing.

OUTLINE SPECIFICATION CLAUSES FOR BRICKWORK

The more important items for insertion in the specification are given below.

Bricks. The bricks for ordinary brickwork are to be sound, hard, well burnt, true to shape, free from cracks, lime, and flaws of any description, and equal in every respect to samples marked ...., to be seen at the engineer's office. Those for facing are to be of .... or other approved make (or carefully selected from those to be used for ordinary brickwork); p.c. £....................per 1000.

(Glazed bricks, blue bricks, rubbers, brindles, etc., may all be specified as facing bricks above, or alternatively they may be described as equal to samples to be seen at the engineer's office, and the p.c. amount omitted.)

Mortar. The lime mortar is to be composed of best greystone lime (blue lias, or any other kind easily obtained in the locality) properly ground in a mill with clean sharp sand (or crushed stone or ground clinker), in the proportion of 1 of lime before slaking to 2 of sand by volume. The cement mortar is to be composed of Portland cement as specified in concretor and clean sharp sand, thoroughly mixed in the proportion of 1 of cement to 3 of sand by volume, and used while fresh. No cement mortar is to be "knocked up" after it has commenced to set.

Brickwork. All bricks are to be well wetted before laying, and the joints thoroughly flushed up. Old English bond is to be used throughout the work, and no bats are to be used. In .... walls, the interior of the wall is to be filled in every sixth course with bricks laid diagonally. Bricks in footing courses and corbels to be laid so far as possible as headers. No joints are to be more than ¼ in. in thickness, and the outside faces are to be struck as the work proceeds with a neat weather-struck joint cut in on the lower edge (or for internal work with a neat flat joint). No brickwork is to be carried out during frost, and brickwork exposed to frost is to be protected by bags or otherwise. All mortar joints damaged by frost are to be raked out and pointed in cement mortar at the contractor's expense. All perpends are to be kept, and walls built truly vertical or to the batter shown on drawings. No part of the walls during erection is to rise more than 3 ft. above an adjacent part to which it is bonded.

Arches. All arches are to be built in cement mortar of half-brick rings properly bonded, and laid as stretchers along the axis of the arch, except where lacing courses are shown. Centres are to be eased slightly when the arch is completed, but not struck until at least three weeks after completion.

CHAPTER IX

CONSTRUCTION IN TIMBER

TIMBER

THE world's timber supply is being gradually depleted, and the price is consequently rising. New kinds are occasionally brought into the market from the tropics, but those in general use at the present may be divided into the two commercial classes of **hard** and **soft** woods, which correspond —with some exceptions—to the broad-leaved trees and needle-leaved trees respectively. Of these, the soft woods are the cheapest, the weakest, and the most common. The most important of them are :—

Red deal, obtained from the Scotch fir, and imported into England from Scandinavia, Finland, Russia, Prussia and North America. It is the commonest soft wood, and although of a light yellow colour is often called **red wood** in the North of England. It is in general use for timber piles, trench timbering, heavy framing, house joinery, floors, match-board and other purposes.

White deal, from the spruce fir, imported from the same countries as the red deal, and often called **white wood.** It is whiter in colour, but otherwise possesses similar properties.

Yellow pine, imported from Canada and sometimes called **Canadian white pine.** Very soft and of even grain. Useful for joinery, but not for engineering works.

American white wood—sometimes called **bass wood**—is very soft and of even grain, greenish white in colour, and only used for models, pattern making and indoor work.

Columbian, Oregon or **Douglas** pine or fir, imported from the Pacific Coast of North America, is similar to red deal, but is free from knots, and used principally for internal joinery, or for framing where very large sizes are required.

Pitch pine, imported from the south of the United States, is really a hard wood to the workman, although a true pine. It is heavy and strong, and contains much resin, which imparts to it a distinctive smell. It is in common use by engineers for piles and heavy framing generally, and also for internal joinery owing to the beauty of its grain when varnished.

Of the hard woods the most important for constructional purposes are :—

Oak, which may be either English grown, or imported from the Baltic ports, from Austria, or from Japan or America. It is tough, strong and heavy, and is one of the most durable of timbers where exposed to the weather. It is in common use where its expense is not too great, for piles, heavy framing, dock gates, timber bridges, and for internal and external joinery such as doors and windows.

Beech is English grown and used by the engineer principally for piles in the unsquared log. It is hard and dense and fairly durable.

Elm is English or American grown, used for the same purposes and in the same way as beech, and for rough framing.

Jarrah is a dense and deep red wood from Australia, used for piles, heavy framing, and wood paving blocks.

Karri is similar in appearance, from the same locality, and used for the same purposes as jarrah.

Blue Gum is a brownish-coloured, strong timber, also from Australia, used in the same way.

Greenheart is a yellowish-green timber from South America, extremely strong, expensive, and used principally for piles and under-water work. It resists the attack of the "teredo"—or shipworm—better than any other timber.

Mahogany comes from the West Indies and West Coast of Africa. There are many varieties, of varying degrees of hardness; some of the African kinds are probably not true mahogany at all, and are very light and open in texture. The best is that known as Spanish or Cuban. It is used for internal joinery on account of the beauty of its grain and colour.

There are many other timbers of infrequent use by civil engineers, but in common use by boat-builders, joiners and cabinetmakers, which it is not necessary to mention here.

Strength of Timber

The **strength** of timber is an important property to the engineer. There is a great variation between different specimens cut from the same log, and the published results of tests should be used with great caution and a large margin of safety allowed to arrive at the working stress. Tests are usually carried out either on a short prism, to obtain the crushing strength per square inch along the grain, or on short beams, to obtain the cross breaking strength on a specimen 1 in. wide, 1 in. deep and with a span of 12 in., loaded in the centre. These tests are always made on specimens without flaws and selected to some extent, and in applying the results to actual construction it should be borne in mind that large pieces of timber are likely to contain weak spots, and that timber which is unseasoned, or timber which is seasoned but wet, is weaker than if dry. For these reasons it is unusual to employ a working stress of more than $\frac{1}{8}$ of the test figure.

SEASONING AND DEFECTS OF TIMBER

Timber is usually felled either in winter or during midsummer, when it contains least sap and is therefore most easily seasoned. **Natural seasoning** is effected by allowing the green timber to remain stacked under cover, so that it is protected from the rain but exposed to a circulation of air. It thus loses weight and gains strength. Before it is stacked it is cut while green into balks or square " whole " timber, or, if it is designed for use in building, into planks, deals or battens, which are squared timbers of 11 in., 9 in. and 7 in. widths respectively, by about 4 in. to 2 in. thick. Timber less than 2 in. thick is called boarding. Being cut up in this way it seasons more quickly than if left in the round log. A further advantage is that round logs as they dry invariably split, owing to the reduction in circumference due to shrinkage. This shrinkage, which takes place across the grain and not along the grain, is one of the troubles with which the carpenter has to contend, and must be borne in mind in designing joints if they are not to become loose (Fig. 34).

When a section is made of a log there will be seen a number of roughly concentric **annual rings**, and in some woods—as oak—there are visible radial lines known as **medullary** rays. When a log shrinks the annual rings contract in the direction of the circumference, but the radius of the log shrinks much less, and balks or planks which are square when sawn out become distorted in section as they dry. The outside layers of a log when tested are found to be weaker than the inside.

In some timbers, such as red deal, there is a distinct division between the outside layers or **sap**—not to be confused with the liquid sap or juice of the tree—and the inner layers or **heart wood.** Most specifications stipulate either for no sap wood, or for a certain limited proportion. It is extremely difficult to ensure such clauses being carried out, not only because in many timbers there is no apparent distinction between sap and heart, but also because much of our timber is now cut from young and immature trees, and none of it in that case will be free. In many cases this is shown by the edges of squared timber being **waney** or showing the outside circumference of the log. Other defects in timber are **shakes** or splits running down the log, and large loose or dead **knots.** Except for internal joinery, ordinary fixed knots are not considered a defect. The inspection and acceptance or rejection of timber is always a difficult and onerous task owing to the practical impossibility of obtaining it absolutely free from defects. Slight shakes or a certain proportion of sap are not very detrimental to a pile, for example, and judgment—based on experience—must be used before ordering its rejection.

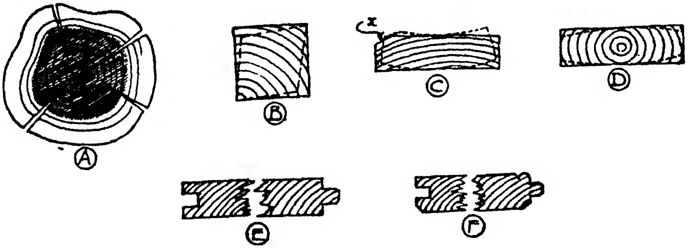

FIG. 34.—Timber.

(A) Log showing heart and star shakes and sap wood.
(B), (C), (D) Showing shrinkage in dotted lines.
(E) Floor board, tongued and grooved.
(F) Match board, tongued, grooved, beaded and V-jointed.

Timber, as is well known, is not everlasting, and is particularly liable to decay where it is alternately wet and dry, as at mean tide level in marine work. This is due to a process of oxidation and consequent destruction of the fibres. Below permanent water level, or if permanently embedded airtight in mud, timber will last many hundreds of years.

Similarly in perfectly dry situations—which are impossible to secure in the climate of Great Britain—it is almost everlasting. Its liability to decay, however, is leading to its supersession in outdoor work by the more permanent material, reinforced concrete. The kind of decay already referred to is known as **wet rot.** Timber which is in confined situations which are both damp and warm and not exposed to a circulation of air is also liable to that insidious disease known as **dry rot.** This is due to the growth of a fungus which lives on the wood and destroys it. This fungus is particularly liable to attack timber built into a wall or under a floor, and once it gains a footing spreads very rapidly. The chief remedy is to ventilate around the timber.

Marine timber structures are liable to attacks from the *Teredo navalis,* a marine worm which bores into the timber and eats out a cylindrical passage along the grain inside the outer skin, its presence being frequently unsuspected. Another much smaller animal, a species of shrimp, the *Limnoria,* also bores into the timber and eventually causes its collapse. It is extremely difficult to protect timber against these enemies. Sometimes the timber is sheathed in copper at about mean tide level, or the surface is covered with broadheaded nails driven in close together. Reinforced concrete is immune.

PRESERVATION OF TIMBER

Various methods have been adopted to protect timber from destructive agencies. **Paint** is one of the oldest and best known. It preserves by keeping moisture and air out of the interior of the wood. Coal tar and oil tar are used in the same way, and also wood tar (known as **Stockholm tar**). The commonest method now in use for timber which will remain out-of-doors, when the odour and appearance are no objection, is that of **creosoting.** Creosote is a dark brown oily liquid obtained in the distillation of coal. It contains a large proportion of carbolic acid and also a solid white substance known as naphthalene, both of which probably aid in the preservative action. The timber to be creosoted may be immersed in a bath of the liquid and soaked for some days, but a better plan is to force the liquid in under pressure. The timber is loaded on to a trolley which runs into a long steel cylinder, in shape and construction like a Lancashire or Cornish boiler without flues. The end of the cylinder is bolted on with an airtight joint, and air is pumped out from the interior by means of a steam pump. This causes a partial vacuum and draws out the moisture from the timber. Liquid creosote is then pumped into the cylinder until it is full, where it is allowed to remain under a pressure of from 30 to 100 lbs. per sq. in. It is thus forced into the fibres of the wood for a considerable depth. After remaining for some hours, the pressure is released, the creosote drained away into tanks, the door unbolted, and the trolley run out.

It is usual to run into the cylinder with the wood to be creosoted a sample piece which has been weighed dry. After the creosoted timber has been taken out, the sample is reweighed, and from these figures the amount of creosote absorbed per cubic foot can be ascertained and checked if necessary with the specification requirements. The usual requirement for red deal is 10 lb. per cubic foot. Hard woods absorb much less, but they are rarely creosoted.

The process is used largely for railway sleepers, timber piles and marine framing.

CONVERSION

Carpenters' tools are probably familiar to all. The most important are the **saw** of different degrees of fineness, from the coarse rip saw for cutting along the grain, down through the ordinary hand saw to the fine-toothed tenon and dovetail saws. **Planes** are of different kinds, the jack plane for rough work, and the trying and smoothing planes for finishing. For heavy framing a two-handed cross-cut saw is often used, worked by a man at each end ; and the **adze,** a sharp axe with the cutting edge across the line of the handle. This is used for pointing piles, and for dressing down the heads to take the circular wrought iron rings to prevent splitting. For boring holes in heavy timbers the **shipwrights' auger** is used, a tool like a large gimlet two or three feet long. For small holes the **brace and bit** are employed.

Timber is sawn out of the log by power, either by a circular saw, or by a band saw, consisting of a thin steel endless band running over two pulleys, one of its edges being cut into saw teeth.

Practically all timber used in Great Britain is imported, and it is necessary to know the usual sizes in order to avoid waste when designing. Hard woods are imported in the **log** or large squared **balk**, and will be sawn to any size required. Soft woods are also imported in the balk, of various sizes according to the trees, and if required may be cut in the same way. By this means an engineer may make certain that his timber is from large and mature trees. It is cheaper, however, to use the usual imported sizes, of which perhaps the commonest are 3″ × 2″, 4″ × 2″, 5″ × 2″, 7″ × 2″, 9″ × 2″, 11″ × 2″, 4″ × 3″, 9″ × 3″, 11″ × 3″, 4″ × 4″, 9″ × 4″, 11″ × 4″, the 9″ and 11″ timber being more expensive per foot cube than the narrower widths. Planed **boarding** is also imported, of various thicknesses, with square edges or tongued and grooved. This is used principally for flooring. Other boarding known as match-board has the edges tongued and grooved, and either V jointed or beaded in addition.

It should be noted that *timber is rarely of the full size specified;* it is the custom of the trade to take off roughly $\frac{1}{32}$ in. from each face for the thickness of the saw-cut, and $\frac{1}{16}$ in. if the face is planed.

JOINTS

Timber **joints** and **fastenings** may be classified in various ways, but we will here consider the commonest forms only, in connection with the iron fastenings and straps which are nowadays used to strengthen most of them, indicating where possible in what structures they are met with. **Nails** in common use are of various forms, best described by sketches. These include cut clasp, flat brads, oval brads, round French or wire nails, spikes, wooden trenails, flat-

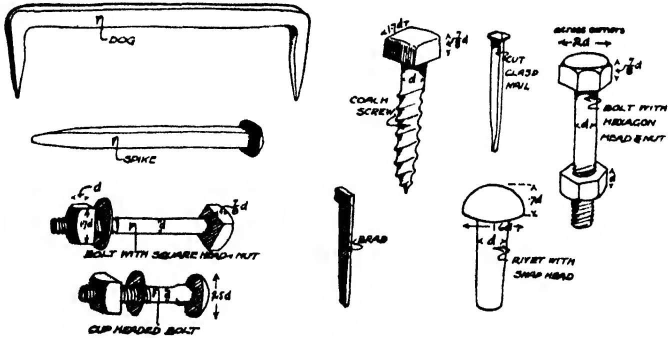

FIG. 35.—Timber fastenings (including also a rivet).

headed and round-headed wood screws of iron or brass, coach screws to be turned by a spanner, and bolts and nuts.

Cut clasp, flat brads and oval brads if driven with the width along the grain do not tend to split the wood. Trenails are used on some railways to fix the iron rail chairs down to the sleepers. Dog spikes have a head projecting on one side for gripping the flange of a rail, and are to be distinguished from dogs, which are made of $\frac{5}{8}''$ or $\frac{3}{4}''$ bar iron, pointed at each end and bent over into a wide U shape. These are used for connecting heavy timbers in temporary work. They can be withdrawn by inserting a crowbar under the shank. Wood screws of brass are used where they are exposed to wet and may have to be withdrawn. Bolts for timber construction have usually square heads and nuts, and may be obtained of almost any required length and diameter. Flat, circular or square washers are used under the head and nut to prevent too much indentation into the timber.

Iron straps are often used for strengthening joints as shown in Fig. 36C, generally $1\frac{1}{2}'' \times \frac{1}{4}''$, $2'' \times \frac{3}{8}''$ and $2\frac{1}{2}'' \times \frac{1}{2}''$ section, with holes drilled as required for coach screws or bolts. In dry or indoor situations the bolts should be tightened up again after the timber has shrunk. Occasionally cup-headed bolts with square necks are used for the sake of appearance and where the nuts will be hidden. The square neck prevents the bolt from turning when the nut is tightened.

Joints in timber are required for various purposes. Where a beam in tension is in two pieces, the separate portions may be connected by lapped, fished or scarfed joints (Fig. 36). **Lapped** joints are described by their name, and involve the use of bolts. **Fished** joints are those with strengthening plates, either of iron or timber; and **scarfed** joints are cut away and fitted so that the jointed portion is only the same thickness as the rest of the timber. In important work these joints are carefully designed to

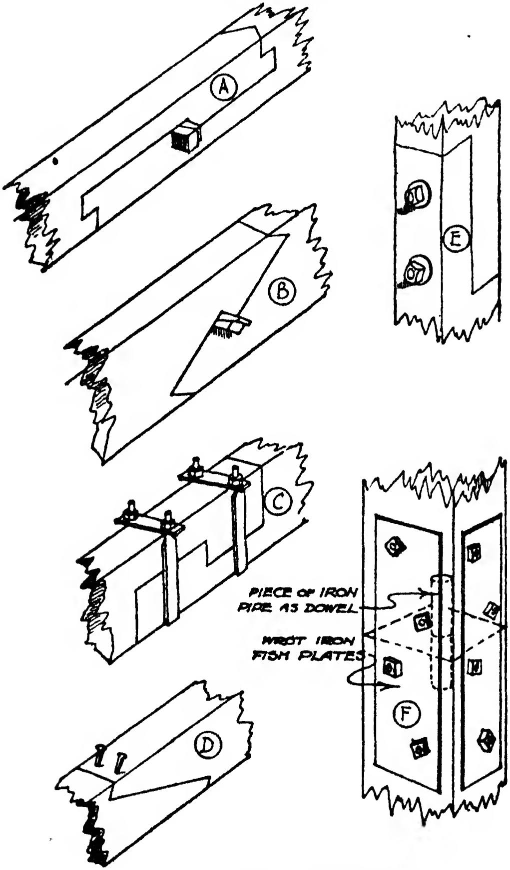

FIG. 36.—Scarfed joints in timber.
(A), (B), (C) Tension scarfs.
(D) Common form possessing no strength in tension.
(E), (F) Compression scarfs.

withstand definitely calculated loads, the methods of failure to be provided against being pure tension across the weakest section of the beam, shear of bolts, shear of timber, and the cutting of the bolts into the timber or bearing pressure. For small works the carpenter usually designs the joint, and in doing so follows tradition, with the result that often the joint is much weaker than it need be.

Four common forms of **tension scarf** are shown in Fig. 36. They are used in the beams of roof trusses, or trusses for temporary bridges. Fig. 36B shows a very common form, which may be strengthened also with iron fishplates and bolts. It is easily fitted, and the length is usually made three times the depth of the timber. The oak folding wedges—which are simply ordinary wedges in pairs driven from opposite sides—enable the joint to be tightened up before the holes for the bolts are bored. Fig. 36A is usually made in length equal to six times depth of beam, and is best where bolts are considered unsightly. Fig. 36C shows a joint strengthened with straps, which are best let into the timber with the surfaces flush on the sides.

A very common form of joint is shown in Fig. 36D. It is used only where two timbers are to be joined over a bearing, as two "purlins" in a roof truss, and has no appreciable strength in tension.

Compression members which require lengthening, such as long pillars in temporary scaffolding, or piles, are usually joined by one of the methods shown in Figs. 36E and 36F.

Where a compression member abuts on another—as at the foot of a roof truss or end of a bridge truss, or foot or head of a "king" post—the **inclined tenon** is used as shown in Fig. 37. The proportions shown are a rough guide only, and in important cases should be determined by direct calculation. The **bridle** joint is for the same purpose; it is not so common, however. A very common form in heavy framing is that of the **plain abutment and cleat block** (Fig. 38). Where timbers cross one another they are often **halved to** keep the crossing the same thickness. This is usually done where the horizontal sills or heads of framing intersect. Where timber floors are required, consisting of small beams or joists resting on larger ones, the cheapest method is to fix the small joists by **skew nailing**. They may be, and often are, **notched**, however, a piece about 1½ in. deep being cut out of the joist; or they may be **cogged**, in which case two pieces are cut out of the main beam in addition. This prevents the joist from moving sideways. The three methods just given are also used for the bearing of a rafter on a purlin.

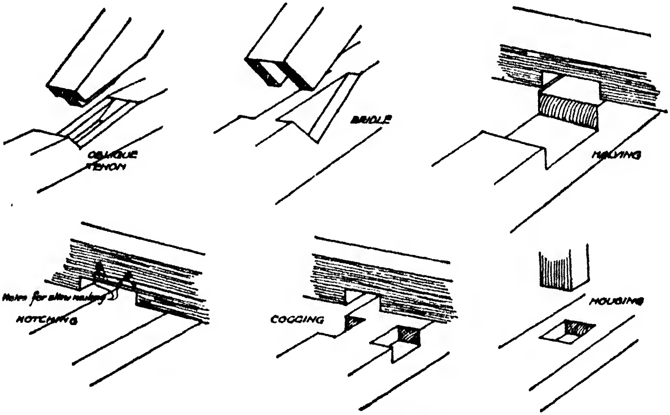

FIG. 37.—Timber joints.

Where one timber is let bodily into another for a short depth the joint is called a **housing**. This is often done where a small post rests on a large beam. If the hole to be cut out of the beam is thought to be too large, a small **plug tenon** is cut on the end of the post, and a correspondingly small **mortise** cut out of the beam, which is thus not weakened to the same extent (Fig. 38). The common mortise and tenon of the joiner and cabinetmaker is not much used by the carpenter on heavy framing, owing to its tendency to shrink in width and slacken as the timber dries. The keyed or wedged **dovetail tenon** shown in Fig. 38 is, however, useful for temporary framing which will have to be dismantled, and should not be confused with the glued and wedged tenon used by joiners. The ordinary tenon is fixed by a hard wood peg, the hole for the peg in the tenon being bored a little nearer the root of the tenon than the holes in the sides of the mortise, so that when driven it draws up the shoulder of the tenon tightly against the side of the mortise. This is called **drawboring.** The joiner's mortise is usually cut wedge-shaped, and small wooden wedges dipped in glue are driven. This is the joint used for doors, and it is obvious that as it depends on glue it should be kept well painted if used externally. For such situations paint is sometimes used instead of glue. Where horizontal beams carrying floors run into one another, the **tusk tenon** is employed (Fig. 38), in which the main

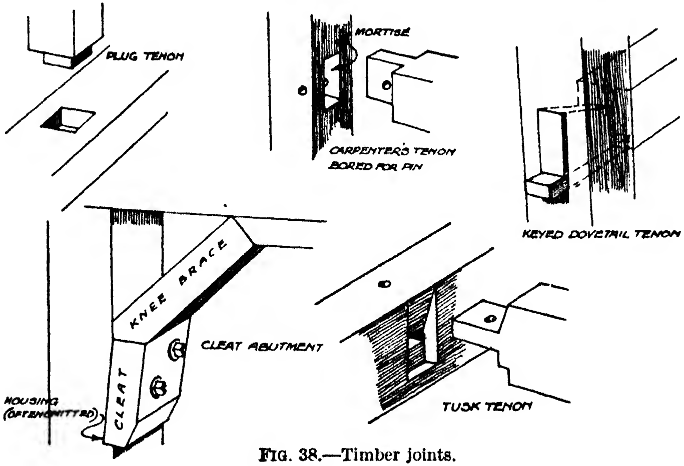

FIG. 38.—Timber joints.

beam is not seriously weakened by cutting away any top or bottom fibres, while the secondary beam obtains a good solid bearing.

The orthodox king and queen post trusses are not much used nowadays, king and queen posts having been superseded by **wrought iron rods** with screwed ends, nuts and washers.

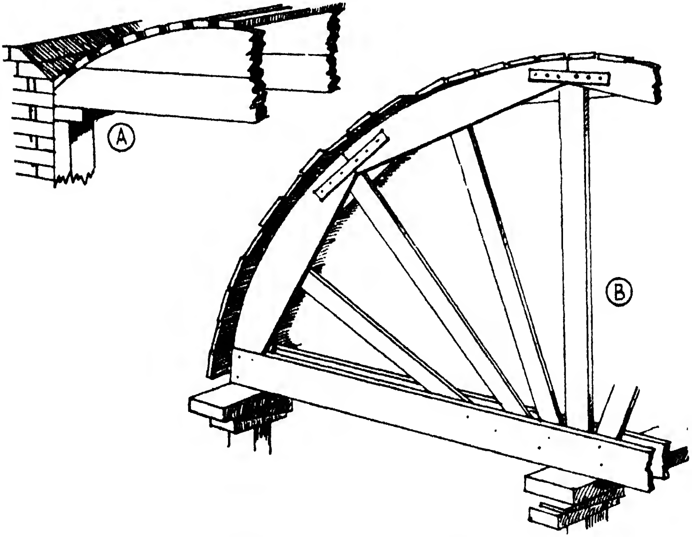

Fig. 39.—Simple arch centres.
(A) Up to 6 ft. span. (B) Up to 15 ft. span.

Arch centres are also a form of timber construction often required (Fig. 39). They must be so designed as to withstand the weight of the arch stones or bricks, and are made in the form of ribs covered with strips or laggings, and supported on wedges, which can be eased slightly when the arch is built, and taken right away when the mortar has set to allow of the removal of the centre.

OUTLINE SPECIFICATION CLAUSES FOR TIMBER CONSTRUCTION

The following specification clauses are typical of those required for construction in timber :—

Timber. All timber is to be die square, of the full sizes specified, except where wrought, $\frac{1}{16}$ in. being allowed for each wrought face, sound, free from sap, shakes, large loose or dead knots, and thoroughly seasoned. (In some cases the port of shipment is specified, particularly for deal.)

(A short description may be given here of the kinds of timber to be used for the various parts of the work, *e.g.* fenders of American elm, framing of pitch pine, etc.)

Creosoting. The timber for .... is to be impregnated with creosote oil under pressure, after being dried in a partial vacuum, to the extent of 10 lb. per cubic foot if deal, or 5 lb. per cubic foot if pitch pine. The amount absorbed is to be tested by weighing sample blocks in and out of the creosoting chamber ; the samples being provided by the contractor, and being similar in all respects to the timber required to be creosoted.

Framing. All joints for heavy framing are to be carefully cut to bear throughout their full width. Bolts are to be screwed to Whitworth standard thread, and heads and nuts to be provided with large washers. From time to time they are to be drawn up as the timber dries and shrinks.

CHAPTER X

CONSTRUCTION IN STEEL AND IRON

MANUFACTURE

EARTH, stone, bricks and timber have been used for construction for many thousands of years. They are all of very variable composition, liable to hidden flaws, and the problem of design in these materials is based largely on past experience with a large margin of safety. With structural steel, however, the case is different. The material itself has not been in common use for more than about thirty years, but it is of very uniform quality, its properties have been thoroughly studied, and it therefore lends itself to scientific design with a comparatively small margin of safety.

The metal iron is used by engineers in the three main forms, **cast iron, wrought iron** and **steel.** They are all combinations or alloys of pure iron and carbon, cast iron containing most, wrought iron least (it is almost pure iron), and steel occupying an intermediate position. In the modern processes of manufacture cast iron is made first from the iron ore, then wrought iron or steel are each made direct from the cast iron.

Great Britain contains large deposits of iron ore in Scotland, Cumberland, Yorkshire and South Wales, and in addition ore is imported, principally from Spain. The ore may be an oxide as in the case of the red haematite of Cumberland or the brown haematite of Wales, or it may be a carbonate as in the case of the clay ironstone from Yorkshire. The sulphide, iron pyrites, is not used. The ore is first roasted with coke to drive off moisture and, in the case of a carbonate, carbonic acid gas. It is then tipped into the top of a **blast furnace** together with measured quantities of limestone and coke. The blast furnace is a tall structure built of firebrick with a sheathing of steel, becoming narrower as it reaches the top. A fire is kindled at the bottom—and kept burning often for years—and the charge of coke ignites. Hot compressed air is blown in through nozzles near the bottom, and the whole mass becomes white hot. The carbon in the coke combines with the oxygen in the ore, releasing the metallic iron which melts and sinks to the bottom as a white hot liquid. The limestone combines with other impurities and forms a slag, which also melts, sinks down and, as it has a less specific gravity than the iron, rests as a second white hot liquid on it, like oil on water. After a time a small hole in the base of the blast furnace which has been plugged with fireclay is freed, and the molten iron rushes out along channels which have been carefully made in a large bed of sand, where it solidifies into the form of "pigs." The slag is drawn off through another hole, solidifies into a greenish glassy stone, and is then usually broken up for road metal. The **pig iron** thus produced is the basis of most of our structural iron.

STEEL

Dealing first with the most important material, **structural steel**, the pig iron is converted either by the **Bessemer** or the **open hearth** process. In the former the molten iron is run into a Bessemer converter, a huge iron bottle lined with fireclay or other fire-resisting composition. There it has a blast of air blown through it. Most of the carbon which the cast iron contains is burnt off, and this leaves almost pure iron in the converter. A certain definite quantity of cast iron rich in carbon is then added and, as this mixes with the molten iron, steel is produced. The steel is now poured out into large ladles, and from these into moulds, where it cools until it is a soft white-hot solid. It is then passed through iron rolls, which gradually squeeze it out into the shapes required, such as rails, girders, angles, etc., before it cools finally and becomes hard.

The original Bessemer process was only successful with non-phosphoric ores (phosphorus is a very harmful ingredient in iron or steel), and the lining of the converter was of what chemists call an " acid " composition. It was discovered later that if the lining were made of " basic " materials, phosphoric ores could be used, as the lining then combined with the phosphorus to form a slag

The first process is known as the Bessemer Acid, and the second as the Bessemer Basic; steel made by these processes being often marked B.A. and B.B. respectively. Phosphoric ores are cheaper than non-phosphoric, and this tends to cheapen B.B. steel; but many engineers fear that in B.B. steel the phosphorus may not have been entirely eliminated, and they consequently specify B.A.

In the open hearth process of converting cast iron to steel, the molten iron is run into a special furnace where air is blown over it. The same change takes place as in the Bessemer converter, carbon is burnt off; a sample of the molten metal is taken from the furnace and analyzed, and the required quantity of cast iron rich in carbon is added. Steel is thus produced, which is cast into ingots and rolled as in the former process. In the same way also the lining of the furnace may be " acid " or " basic," to deal with non-phosphoric or phosphoric ores respectively. The open hearth is often called the Siemens-Martin process, and steel made by it is marked S.M.A. or S.M.B., as the case may be. It is rather slower than the Bessemer process, but owing to the possibility of analysis during conversion, the steel is considered to be more certain and trustworthy in composition.

The quality of structural steel in Great Britain is governed usually by the requirements of the British Standard Specification for structural steel for bridges and buildings, which is amended from time to time. The present requirements are, roughly, for structural steel a tenacity of 28 to 33 tons/sq. in., with an elongation of 20 per cent. on a length of test piece of 8 diameters[1]; and for rivet steel a tenacity of 25 to 30 tons/sq. in., with an elongation of 25 per cent. on a length of 8 diameters. In addition, certain bending tests are stipulated to ensure toughness, either on the steel as it is sent on to the works, or, if preferred, after heating to a dull red and quenching in water. The steel must then be capable of being bent over a round bar of a diameter three times its thickness without cracking. For rivets, the steel must be capable of being bent double, cold, without cracking.

It often falls to the lot of an assistant to test and see tested samples of steel from a consignment, in order to find out if the specification requirements are satisfied. Care must be taken to see that the dimensions of the specimen, and particularly the ratio of the length between gauge marks to sectional area, are as specified; otherwise the results will not be correct, the percentage elongation being particularly affected. There are other specifications in common use for special work, viz. the Admiralty requirements and Lloyds Registry and Bureau Veritas specifications for shipbuilding.

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[1] The slenderness of the test piece affects the percentage elongation of a ductile specimen.

The forms in which structural steel are supplied to the market are now standardized to a large extent, and are contained in the British Standard List of Rolled Sections. They comprise **rolled steel joists**—sometimes called H or I sections—**angles** with **equal** legs, **angles** with **unequal** legs, **tees** with height equal to width, **tees** with height less than width, **tees** with height greater than width, **channels, zed** bars, and various **bulb** sections used in shipbuilding.

The British Standard List, referred to in Appendix I, which is amended from time to time, gives the dimensions of all the sections and their principal properties, such as sectional area, moments of inertia, moments of resistance (section modulus), weight per foot run, and radii of gyration about various axes. These figures are, of course, indispensable in designing.

Sections in common use, besides those in the above list, are **flats**, which are plain strips of steel from $\frac{1}{2}$ in. to 24 in. wide, and of thicknesses from $\frac{3}{16}$ in. upwards; plates, over $\frac{3}{16}$ in. thick; and sheets, under $\frac{3}{16}$ in. thick. For economical design it is necessary to know not only the lengths or areas easily obtainable, but also the commonest sections which are usually kept in stock. Some of the sections contained in the British Standard List are rarely rolled, and it is an expensive business to roll a few for one particular order. The best way of ascertaining this is to write direct to the steel merchants from whom it is proposed to obtain the sections. These will quote a " basis price " for each section at per ton, and will then charge extra over this basis price for sections of unusual length or area. Thus joists, angles, tees, etc., can be easily obtained up to 30 or 35 ft. long, and plates up to certain areas. Angles and tees when rolled are usually curved in length if delivered direct from stock, and a charge is made for straightening. Joists are supplied straight at the basis price. If a price is required from the steel merchants for the whole of the steelwork ready prepared for erection, upon receipt of detailed drawings they will quote per ton, this price, of course, including all straightening, etc., and also one coat of paint if required.

Where the steel sections are ordered separately, they are cut at the works with a saw while hot, and the length cannot be guaranteed within $\frac{1}{4}$ in. over or under. If an " exact " length is required, the section must be cut cold, and an extra price is charged. Extras are also charged if the ends of a section are to be machined square, as in the case of stanchions.

STEEL FRAMING

Framed structures are built up from detailed drawings, generally blue prints, fully dimensioned. A template is first made out of flat board of the full length of each member, and these templates are nailed lightly down on a large floor in their actual positions on the structure. Thus a full-size elevation in wood is constructed in the flat. The templates are so arranged that the structure is of the exact shape and size required, including the slight **camber** which is usually given—in the case of bridges, about 1 in. in 40 ft. span—but which is not drawn on the blue prints, although its amount may be figured on them. The templates are then drilled through in position to show the positions of the rivet holes, and in this way the fitting of the holes is ensured.

Each template is then taken to the shops, where it is used to mark off the exact length and shape of the member, and also the position of the rivet holes. Previous to this, however, the steel has been straightened in rolls. It is then cut off to the length marked from the template—if a joist tee, zed or similar section by a saw, if an angle by shears, and if a plate it is cut to the shape required by shears also. The edges of the plate are further planed off to the exact line, thus removing the distorted portion which is always slightly damaged by the shear. The holes are then punched through the members separately in the positions marked from the template, the punched hole being $\frac{1}{4}$ in. less in diameter than the size required, after which it is reamed out with a drill to the full size to remove the metal around the hole which has been damaged by the punch. In modern work, however, it is now becoming usual to drill the holes

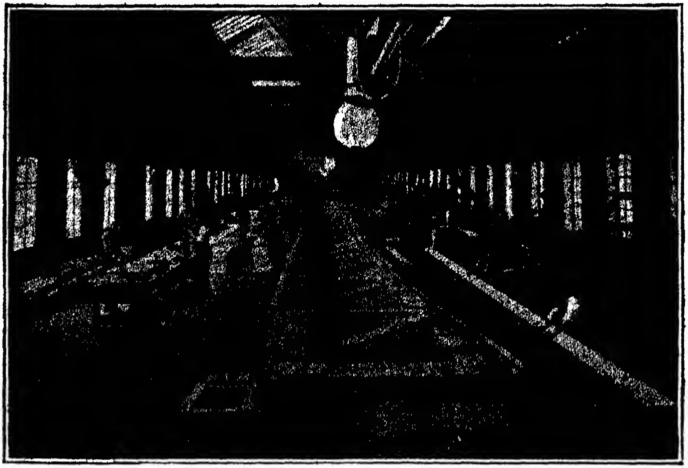

FIG. 40.—Laying out templates for girder work.
[*Engineering*, 20th March, 1908.

without previous punching. Punching a row of holes in a member has the effect of slightly lengthening and curving it, and it is often difficult to get the holes to coincide exactly with those in other members, however carefully the setting out has been done.

The separate members are then assembled in a yard and temporarily bolted together with service bolts; holes which do not coincide properly have a taper pin driven through them to bring them together. The structure is then dismantled, given a coat of paint, and the members marked to correspond with an erection drawing before being sent away for final erection. Many structures are riveted in the yard in sections not too large for transport, these sections being finally riveted together on the site.

Riveting in the yard is generally more trustworthy than that done on the site, owing to the use of powerful hydraulic or pneumatic presses for closing the rivets. Hand riveting on the site, called **field riveting,** is usually done by gangs, each consisting of two men and a boy, furnished with a small portable forge. The rivets, which are made in the first instance by a press, are chosen of the required diameter and of a length sufficient to pierce all the plates and allow about 1¼ diameters beyond, and are dropped on an iron plate pierced with holes and resting on the forge fire. The shanks of the rivets pass through these holes and are heated white hot. The rivet boy then lifts one out with the tongs, inserts it into the hole while one of the men places a heavy hammer with a cup-shaped depression in it against the head, and the other beats down the protruding shank and so closes it, finishing off with a cup-shaped tool.

The rivets in most common use for ordinary structural steelwork are nominally ¾ in. and ⅞ in. in diameter. Their actual diameter before heating is a shade less than this, while the holes are always $\frac{1}{16}$ in. larger in diameter. There is therefore no difficulty in inserting the white-hot rivet, which, of course, has expanded in heating. The final diameter of the rivet is thus the nominal diameter plus $\frac{1}{16}$ in., but it is not usual to take account of this increased diameter in designing.

The kinds of rivets in common use are the "snap head" for ordinary work, and the countersunk for flat-bearing surfaces where the heads must not project. Field rivets are usually increased in number by 25 per cent. over those required for shop riveting, to compensate for possible weakness due to the more difficult conditions under which they are driven. In small structures the field connections are made by bolts which are often lightly burred over the nuts with a hammer to prevent them from working loose. The exact position of the field joints is best left to the manufacturer, as it depends on the appliances available for carriage, but a clause should be inserted in the specification providing for the necessary increase in the number of rivets. In important joints, where bolts are to be used and much vibration or impact is expected, the bolts should be turned to the exact size of the holes and driven into position.

Fig. 41.—Structural steelwork, showing heavy stanchions, plate girder runways for travelling cranes, and roof trusses.
[*Engineering*, 3rd May, 1907.

The following precautions should be observed in designing a riveted joint, apart from those depending on the mechanics of the loads, which are given in the usual text-books. The diameter of the rivets (d) which are generally of soft rivet steel according to the British Standard Specification, is usually determined as $\frac{3}{8}$ in. more than the thickness of the thickest plate (t), or by Unwin's well-known rule ($d=1{\cdot}1\sqrt{t}$), and is based not on considerations of the strength of the joint, but is really a guide to the size of the hole which can be conveniently punched, a small hole being impossible in a thick plate. The outside rivets should be about $2d$ from the edge of the plate (to the centre of the rivet hole), not less than $1\frac{1}{2}d$ and not more than $8t$, where d and t are the nominal diameter of the rivet and thickness of the outside plate—where several are being riveted together—respectively. These rules provide against the plate bursting in the punching and springing off the other plates, thus allowing water to enter and rusting to begin. Holes should not be nearer together than $3d$ centre to centre, nor further apart than $16t$. In girder and bridge work, if 4 in. pitch centre to centre satisfies all the above rules and at the same time the calculations for strength, it is generally adopted. In roof work a pitch of 3 in. is often used in the same way.[1]

Flats and plates used for structural work vary in thickness by sixteenths from $\frac{3}{8}$ in. to $\frac{3}{4}$ in., being rarely thinner or thicker than these limits, though $\frac{1}{4}$ in. and $\frac{5}{16}$ in. may be used for work protected from the weather. Where cover plates are employed at a joint, the total thickness of both if two are used, or the thickness of the one with a single plate, should be 25 per cent. greater than the thickness of the members to be joined; but in roof work double cover plates are often made, each of the thickness of the members to be joined.

Care should be taken that the centre of gravity of the group of rivets lies on the axis of each member joined, though in small roofs and girders this rule is often broken for the sake of economy in the size of the joint, with the result that bending stresses are set up in the members. In

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[1] It is probable that in the future some method of welding steel work joints will take the place of riveting. The British Standards Institution now publishes a specification for welded joints.

the same way, in small roof design joints are often so made that the load in the compression members is not truly axial. It is not usual to allow members in roof design to be less than ¼ in. thick, although in many cases the loads on the members are extremely small, and the theoretical size of the member consequently below such a limit.

The load on a roof is due to the dead weight of the roof covering and to the pressure of the wind. Very little is known yet of the actual pressure due to the wind and its distribution on a roof, the usual figure taken being 40 lbs. per sq. ft. against a vertical surface, reduced where the surface is inclined. There is no doubt that wind pressure on roofs is of the nature of an impact load, but the allowance for impact is generally made in a rough manner by allowing a working stress of from 6½ to 7½ tons per sq. in.

In bridge design, on the other hand, a definite allowance is made for the "impact" effect of the live load by means of one of the various well-known "impact" formulae, such as the Launhardt or the Pencoyd formula. See Appendix II.

Steel is also used in structural work in the form of **castings** for such purposes as bridge rollers and bed plates. These are usually required to comply with the British Standard Specification for steel castings for marine work. **Steel forgings,** such as pins and eyebars, should comply with the corresponding specification for forgings.

Steel alloys are now being produced and put on the market; they have high tensile strength and elongation percentages. Their cost is greater than that of ordinary mild steel, but it is probable that in the future some of them, especially the nickel alloys, will be used for bridge building, in view of the fact that much higher working stresses can be employed, and therefore the weight of the structure itself, which is considerable in the case of large spans, can be reduced.

WROUGHT IRON

Wrought iron is not much used by structural engineers, mild steel having now almost superseded it. It is made by melting cast iron in a furnace called a "puddling" furnace, in which a current of hot air blows over the molten metal. This is constantly stirred, and as the carbon burns off, the remaining iron becomes pasty instead of liquid, owing to the fact that the melting point of wrought iron is much higher than that of cast iron. The pasty white-hot mass is drawn out of the furnace and taken to a steam hammer, where it is squeezed and beaten into a rectangular "bloom," which is then rolled to the required section similarly to mild steel.

Wrought iron is usually known as "merchant bar," "crown," "best," "best best," and "triple best," in ascending order of quality. There are in addition certain well-known brands, such as the Lowmoor Yorkshire iron, of high quality and price, used principally in situations liable to sudden shocks, such as coupling bars for waggons, chains, etc.

Wrought iron is used also for **pipes** and **tanks**. These are described later. For ordinary purposes the tensile strength of wrought iron may be taken as about 21 tons per sq. in. and its elongation 25 per cent. on 8 diameters. The working stresses usually allowed are 5 tons per sq. in. in tension, 4 in compression and 4 in shear. See Appendix II. The latter figure refers to wrought iron rivets, which have been practically superseded by mild steel. They are, however, less liable to injury during "field" riveting through overheating, and are occasionally preferred by engineers for that reason.

Cast Iron

Cast iron is used by civil engineers principally for pipes and tanks, and its use will be described in more detail in the section devoted to these articles. It is made by remelting pig iron in a "cupola"—which is really a small blast furnace—different kinds of pig being mixed to give the quality required. The iron when melted is run into moulds formed of a coherent sand in the floor of the foundry, where it is allowed to solidify. The moulds are formed around a "pattern," generally of wood, of the exact shape of the article required, but a little larger to allow for contraction in cooling. The interior of hollow castings is filled during the process of pouring the metal by a shaped "core" of sand, which is afterwards withdrawn or in some cases broken down and shaken out through a hole in the casting. Care is required in casting to ventilate the moulds so that gases may escape, and to prevent the occurrence of blow-holes or blisters and defects due to the sand breaking away from the mould.

Castings should be true in shape, of the required dimensions, and free from warping, cracks, blow holes or sand holes. They are usually tested by ringing all over with a hand hammer, the variation in sound showing the presence of defects. The metal itself is usually tested by running a portion of it at the time of casting into a special mould to form a bar 42 in. long, with a rectangular section 2 in. × 1 in. When cold this is placed on supports 36 in. apart with the 2 in. side vertical and loaded at the centre. Good cast iron will sustain 28 cwts. when thus loaded and will be deflected ⅜ in. The best cast iron is made from pig which has been produced in blast furnaces where the air blast is not heated before being blown into the furnace, but this quality is expensive.

Cast iron has already been described as an alloy of iron and carbon. In some forms the iron and carbon are chemically united, and if the resulting mixture when cold be broken, the fractured surfaces are **white** and glittering in appearance. In other cases the iron and carbon are not—for the most part—chemically united but only mechanically mixed, and fractured surfaces are then dark **grey**. The grey cast iron is the kind used for structures. It is softer, tougher and more easily melted than the white. The best cast iron is composed of mixtures of different pigs which have been melted several times to ensure thorough mixing.

When designing castings, care should be taken that the several parts are of approximately the same thickness. Thin webs joining thick parts cool first and set up serious internal stresses when the casting is cold. Internal angles should be rounded to a radius. Cast iron may be tested in tension, when it should sustain about 9 tons per sq. in. The elongation is practically nil. In compression its strength is about 40 tons per sq. in. Owing to the possibility of flaws occurring in castings, the working stresses are rarely allowed to rise above 1½ tons per sq. in. in tension and 8 tons per sq. in. in compression for a steady load, and about ⅔ of these for a fluctuating load. See Appendix II.

TANKS

Cast iron **tanks** are usually constructed of flat plates, ½ in. to ¾ in. thick, about 4 ft. square, with flanges all round and stiffening ribs crossing the centre. The flanges may be either inside the tank or outside, and the abutting surfaces are planed to ensure a tight fit. The joint may be made with red lead paint before the flanges are bolted up. In another form of joint, the flanges are so shaped that a groove is left when they are bolted together. This groove is filled with a mixture of iron filings and sal ammoniac caulked tightly in after moistening. The iron filings rust and expand and form the well-known rust cement. For large tanks some of the plates have lugs cast on to their internal faces, which enable wrought iron tie rods to be carried across the tank from side to side in order to brace it against the liquid pressure inside. The tanks are usually supported by a series of rolled steel joists, one under each joint across the width of the tank, these being supported in turn by a steel substructure if the tank is elevated above the ground, or by walls of brick or concrete if near ground level. The detailed design of such tanks is usually undertaken by specialist firms, who often supply their own drawings and an outline specification with their tender.

Connections to and from the tank are arranged for by having certain of the plates cast to a special pattern, with holes through them of the required size, fitted with flanges for bolting on the pipes. Corner plates are also cast to special shapes.

Cast iron is usually preferred for tanks owing to its greater resistance to corrosion than wrought iron or steel. For very large tanks where high pressures have to be sustained, or where the cost of carriage of plates is an important item, iron or steel plates are employed, generally from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. thick. The plates are lapped as in boiler construction and riveted together, the joint being made watertight by "caulking" the edges. Large tanks of this kind are usually circular in plan—as with this shape there is no tendency for the thin side plates to bulge—and rest upon a flat concrete base which supports the tank over its whole area.

Connections to steel tanks are formed by riveting on flanges of the proper size.

Pipes

Cast iron **pipes** are made of all sizes from 2 in. internal diameter upwards, and in many forms, according to the purposes for which they are to be used. By civil engineers they are employed for conveying water, sewage, gas, oil and steam. There are three forms of joint in common use. The first, for ordinary water or sewage, is called the **lead joint** (Fig. 42A). Each pipe is cast with a **spigot** and a **socket** end—for the shape of which there is now a British Standard specification.

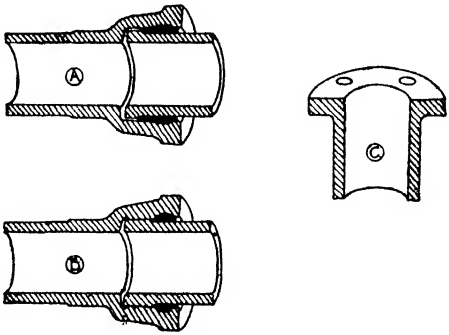


Fig. 42.—Cast-iron pipe joints.
(A) Spigot and socket run with lead. (B) Turned and bored, also run. (C) Flanged.

The pipes are usually laid underground in a trench specially dug for them to the required depth. The spigot end of one pipe is inserted into the socket end of the next—the socket ends facing " upstream "—and a ring of rope yarn is rammed into the joint hard to the bottom of the socket. The jointer takes a pat of clay, rolls it into a long sausage, which he fits around the mouth of the socket leaving a small opening at the top, into which he pours melted lead from a ladle. The lead fills the annular space of the socket and when it has set the clay is taken away.

Sometimes a special flexible band of asbestos is used instead of the clay. The contraction of the lead in cooling loosens it a little, and the jointer then " sets it up " by driving into the socket a flat-ended chisel which compresses the lead and causes it to wedge tightly in the socket.

Occasionally there are situations in which it is impossible to pour the lead into the socket, as in the case of vertical pipes with the socket downwards. In such cases "lead wool," formed of thin threads of metallic lead, is forced into the socket and caulked cold.

Another form of joint for quick laying is the **turned and bored joint** (Fig. 42B). In this case part of the socket and spigot are turned in a lathe to an accurate fit on a slight taper. They are smeared with thin Portland cement or red lead and forced together, thus making a tight joint, which in some forms may be afterwards run and caulked with lead as well. These joints are rigid, and will not give to slight settlements of the ground as the ordinary lead joint does. This may lead to fracture of the pipes.

A third form of joint used for steam pipes and in situations where it is anticipated that pipes may require to be taken out and renewed is the **flanged joint** (Fig. 42C). In some forms the flange is cast on the pipe, in others it is a separate casting screwed on. The adjacent flanges are bolted together with jointing material between, usually red lead or sheet rubber for water, and asbestos sheet for steam.

Cast iron pipes are usually supplied in 9 ft. lengths up to 12 in. diameter and 12 ft. lengths beyond. They should be cast vertically when possible with the socket downwards, and it is essential, of course, that the core of the mould be exactly central to ensure an even thickness of metal. The thickness is tested by callipers of a special form—double-ended, since ordinary callipers cannot be withdrawn over the beads at the ends of the pipes ; and the bore is tested by drawing a circular disc through, of a diameter ⅛ in. less than the nominal bore. Small percentage variations in weight are usually allowed—from 2 to 4 per cent., on the condition that percentages *over* the correct figure do not count when payment is made by weight. The pipes should be tested by hydraulic pressure, rubber-packed discs being cramped on to each end and water allowed to fill the pipe at 300 ft. head, defective pipes being rejected. Practically all cast iron pipes are dipped in a hot bath of Angus Smith's composition, a mixture of pitch, resin and linseed oil, which forms a hard protective black varnish, in order to guard against rusting.

Wrought iron and **mild steel** pipes are made for the same purposes as cast iron pipes, but are much thinner. They are made for export, but their use in Great Britain is confined to small sizes. They may be butt or lap welded. Tubes are also manufactured by rolling out solid steel ingots without joints, but these latter are expensive and are not used for the ordinary purposes given above. The small tubes are made in different thicknesses for gas, water, steam and hydraulic pressure, with fittings to match, and most of them may be obtained either black (unpainted) or galvanized. The tubes and fittings are usually priced according to a standard tube list, and quotations are made by adding to or taking from the list a certain percentage, which applies to both tubes and fittings equally. The tubes are screwed at the ends with an outside thread, and the joint is made by means of a socket with an inside thread, the end of one of the tubes being smeared with red lead paint. The socket is screwed on for half its depth, and the next tube is screwed into the socket for the full depth of its own thread, after being similarly painted with red lead paint. Bends are connected in the same manner.

Elbows and tees are made of the same diameter as sockets, that is, larger than the plain pipe, and threaded inside so that they may be screwed direct on to the pipe. At certain points on the pipe line " connectors " are provided. This simply means that on one of the pipe ends a thread is cut for a greater length than usual, so that if a disconnection is required in the pipe, at that point the socket may be screwed back entirely on to one pipe leaving the other pipe clear. A small back nut is also required to butt tightly up against the socket when it is in position to prevent water leaking down the long thread. Usually a few strands of hemp are wound round the thread of the pipe after painting with red lead, and before screwing on the socket, to ensure watertightness.

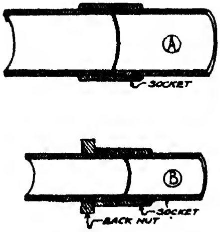


FIG. 43.—Wrought-iron and steel pipe joints

(A) Ordinary socket joint.
(B) "Connector" joint with back nut and long thread.

Provision must be made in pipes laid and fixed above ground in long lengths for expansion and contraction due to changes in temperature. With steam pipes special joints are employed. With other pipes it is usual to introduce sufficient bends in order by their springiness to take up the movement.

When the end of a pipe line is approached, a special exact length of pipe is generally required to join up. In steel or iron tubes this is cut from an ordinary length on the spot by pipe cutters, and screwed by a stock and die. With cast iron pipes a length can be cut in the same way and the joint at one end made by a double socket, or with flanged pipes, the pipes may be cut and threaded and a loose flange screwed on to the exact length. In many cases, however, it is more satisfactory to take exact measurements and send these to the foundry so that a special pattern may be made and a casting obtained.

Valves, etc., may be obtained from the manufacturers with flanged, socketed or screwed ends as required for insertion in the pipe line.

OUTLINE SPECIFICATION CLAUSES FOR STEEL AND IRON WORK

The following specification clauses which deal with the more important points in steel and iron construction are intended to apply only to small contracts. For large ones practically everything is covered by the British Standard Specifications referred to in Appendix I.

Structural steel. The structural steel (rolled sections) is to be of the full sizes and weights shown on the drawings. Its tenacity is to be between 28 and 32 tons/sq. in., with an elongation of not less than 20 per cent. on 8 diameters. It is to be capable of being bent cold round a mandril of a diameter of three times the thickness of the test piece without cracking.

Rivet steel. The rivet steel is to have a tenacity of between 25 and 28 tons/sq. in., with an elongation of not less than 25 per cent. on 8 diameters. It is to be capable of being bent double on itself while cold without cracking.

Steel castings. Steel castings are to be sound in every part and free from cracks, blowholes or distortion. The metal is to be capable of withstanding 35 to 40 tons per sq. in. in tension, with an elongation of not less than 15 per cent. on 8 diameters. All castings are to be annealed.

Steel forgings. Steel forgings are to be perfectly sound, worked at a high temperature, and afterwards annealed. The metal is to be capable of withstanding at least 28 tons/sq. in. in tension, with an elongation of 29 per cent. on 8 diameters.

Iron castings. All castings are to be sound, free from blowholes or other defects. The metal is to be capable of withstanding 9 tons/sq. in. in tension, tested on bars run from the same metal as the casting. Castings are not to be run from the first melting. Pipes are to be cast either vertically or in an inclined position with the sockets downwards, and not less than 12 inches is to be cut from the spigot end after casting.

Wrought iron. All wrought iron is to be capable of withstanding a tensile stress of 21 tons/sq. in. without breaking. All welding is to be done only by skilled smiths, and is to be carefully inspected before it leaves the shop.

Structural steelwork. All riveting, where possible, is to be done by pressure machine. No forging or working of the steel is to be done at blue heat. Holes for rivets and bolts if punched must be reamed out to the size required at least $\frac{1}{8}$ in. all round. Where turned bolts are specified they must be a driving fit. Other bolts may have $\frac{1}{32}$ in. clearance all round. Bevelled washers must be provided where necessary. The ends of stanchions must be machined true and square. Where sheared plates are used instead of flats with rolled edges, the sheared edges must be planed off. All parts must be assembled before final riveting, and the rivet holes must fit without drifting.

Painting. All structural steelwork is to receive one coat of boiled oil (or one coat of red lead paint, or one coat bitumastic paint) before being assembled or before leaving the shop and two more coats after erection. All pipes are to be coated inside and out with Dr. Angus Smith's composition applied by dipping.

CHAPTER XI

CONSTRUCTION IN CONCRETE

MATERIALS

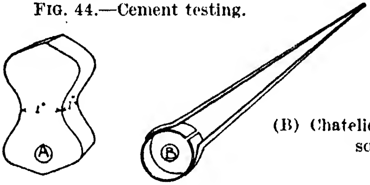
CONCRETE as used by civil engineers is composed of an aggregate such as broken stone or gravel, mixed with sand and Portland cement. Other cements have been used in the past, such as the quick-setting but weak Roman cement —Roman is a trade name only—and even hydraulic lime which will set under water.

PORTLAND CEMENT

Portland cement is, however, far superior to these, and, as far as we are aware from our knowledge of it during the past hundred years, it does not deteriorate under ordinary conditions. It is made by mixing together carbonate of lime in the form of limestone or chalk with silicate of alumina in the form of clay, mud or shale, and then burning the mixture at a very high temperature. The raw materials are usually mixed by being ground together with water to a "slurry," and the burning is nowadays usually done in a "rotary" kiln formed of a long inclined cylinder, like a steam boiler, lined with refractory material. The slurry is introduced at the top end of this kiln, which is rotating very slowly. At the lower end a spray of powdered coal is injected through a nozzle, which is ignited and sends a sheet of flame up the cylinder. The slurry meeting this is dried, and crumbles up owing to the continuous motion of the cylinder, travels slowly down, becomes white hot, and finally drops off the lower end in the form of granules of black coke-like material about the size of peas. This is the Portland cement clinker, and when very finely ground it forms the Portland cement of commerce, changing in colour from black to grey in the process of grinding.

The quality of Portland cement has improved largely during the past thirty years and is now governed by the British Standard Specification. The testing of Portland cement is much more difficult than that of iron or steel and is a very important part of the duties of a resident engineer or of his assistants. The tests to be carried out are those for tensile strength, fineness, soundness and setting time. The chemical composition, although specified, is not often tested. When it is required, the analysis is carried out by a qualified chemist, as it is a somewhat intricate business. The **tensile test** [1] is carried out by mixing the neat cement powder with water to a stiff paste, pressing into a mould of brass made in two halves fastened together with thumb screws, and of the shape shown in Fig. 44A. The paste is allowed to set twenty-four hours, when it becomes as hard as a soft stone; then the mould is taken apart and the "briquette," as the cement is now called, is immersed care-

FIG. 44.—Cement testing.



(A) Tensile briquette.

(B) Chatelier ring for testing soundness.

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[1] This method of testing will probably be superseded in the future by the cement and sand test given on the following page. It is still allowed, however, as an optional test by British Standard Specification No. 12.

fully in a vessel of water and allowed to remain six days more. At the end of that time it is like a hard stone, and is taken out and, while wet, inserted into the jaws of a testing machine where it is broken by tension across the narrow waist.

In gauging up the cement with water in the first instance certain precautions must be observed. The usual method is to weigh out 20 oz. of dry cement powder—rather more than enough for three briquettes—form a conical heap with it on a slate or glass slab, make a crater in the heap, and pour in a measured quantity of water—usually 4 oz., or 20 per cent. by weight—from a chemist's measuring glass. The mixture is then chopped up, turned over and patted with an ordinary bricklayer's trowel until in about 30 seconds it becomes a dark moist powder—not a paste—when it is inserted in the three moulds, which have been cleaned, very slightly oiled, and laid out on three small iron plates. The cement is pressed into the moulds by thumb pressure alone, rammers being forbidden in order not to obtain a fictitious strength, and is finally finished off with a few pats from the trowel. During this process the cement will appear to become wetter, and will finally finish as a paste which can be trowelled off smoothly at the top of the mould. The correct percentage of water is not standardized, and can only be judged by the behaviour of the cement as described. If the cement remains dry in the mould, and will not become pasty, that particular mixing must be discarded and a fresh one made with a slightly higher percentage of water. For ordinary Portland cement the amount varies between about 19 per cent. and 22 per cent. If too much water is used, the cement becomes liquid in the mould and its strength will be reduced.

The test for tensile strength is also carried out on cement mixed with sand. The sand used must be "standard" sand, obtained from Leighton Buzzard, graded by sieves to pass twenty and be retained on thirty meshes to the lineal inch. It can be obtained from manufacturers of testing apparatus. The sand and cement are thoroughly mixed dry, in the proportion of 3 of sand to 1 of cement by weight, and water is then added as described above in the proportion of about 8 per cent. of the total weight of cement and sand.[1] The briquettes are made in the same moulds and in the same way, and kept twenty-four hours in air and two days under water.

The British Standard Specification, referred to in Appendix I., requires neat cement to withstand 600 lbs. per square inch in tension seven days after gauging, or cement and sand 300 lbs. three days after gauging, with a certain definite increase in strength when seven days old. The machines used for testing the cement are of different forms, the commonest being, perhaps, one in which the load is applied by means of lead shot run into a container, the force being increased by several levers mounted on steel knife edges. Other forms use a travelling weight on a long lever arm, or a container holding water instead of shot.

The test for **fineness** is carried out by weighing in a delicate balance 100 grams of cement, and sieving this through very fine sieves of brass wire of a definite gauge, giving respectively 72 and 170 meshes to the lineal inch. The sieving is carried on for 15 minutes, the sieves being arranged in a nest, the coarse one at the top, then the fine one, then a container to hold the finest powder. The British Standard Specification requires a residue of not more than 1 per cent. on the 72 sieve, and not more than 10 per cent. on the 170 sieve, of the original weight of the

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[1] The correct amount of water to be used is obtained by a preliminary trial with a "Vicat plunger," as explained in British Standard Specification No. 12. See Appendix I.

cement. This is obtained by weighing the residue on the 72 sieve, and adding that on the 170 sieve and weighing again.

The test for **soundness** is that known as the Chatelier test. Cases have been known in which Portland cement, to all appearances perfectly sound when first gauged up and put into work, has after a few weeks expanded and cracked. It is impossible to keep a sample sufficiently long to test this directly, so a small pat is gauged up as for tensile testing and filled into a split brass ring fitted with pointers (Fig. 44B). Small glass plates are squeezed on to the ends of the ring in order to enclose the cement, and the whole is put carefully under water to set for twenty-four hours. At the end of that time the ring, glass plates and cement are immersed in a vessel of cold water, the exact distance between the pointer ends is measured, and the whole warmed up over a gas flame and boiled gently for three hours. It is then allowed to cool and the distance between the pointer ends measured again. The effect of the boiling is to cause the cement to " age " much more rapidly than in ordinary circumstances. If the cement has any tendency to expand, this will be shown by the pointers. Over 10 millimetres expansion, measured at the pointer ends, is considered unsafe.

The test for **setting time** is performed by gauging up a pat as for tensile testing and allowing a weighted needle to rest gently on the surface of the pat. The standard needle is 1 millimetre square in section and has a weight of 200 grams. If the needle penetrates completely through the pat, setting has not commenced. When it just fails to do so is the time of " initial " set. Final set is considered to have taken place when a needle of a special form encircled by a sharp edged " bell " of brass just indents the pat, the bell itself making no impression. The time is measured from the moment of adding the water during gauging. The initial set should occur in not less than 30 minutes, and the final set in not more than 10 hours.

Cement testing must be carried out with great care, as the results of a test may be used to reject a large consignment. In such cases the contractor usually takes a sample in the presence of the engineer, which is sealed and sent to an independent testing engineer, who with his expert knowledge frequently obtains a rather higher tensile strength than that obtained by the engineer's assistant. This leads to disputes.

Cement in England is usually sold by the bag of about 200 lb., 11 bags to the ton. It must be kept perfectly dry before being used, and it has until recently been customary on large works to erect special cement sheds where the cement can be spread out in thick layers to aerate or cool before being used. This makes it slower in setting, and consequently more convenient for general use, but many engineers now consider the cost of doing so outweighs any possible advantage. Quick setting cement can be obtained from the manufacturers when required for special purposes, such as jointing sea walls between tides.[1]

CONCRETE

Concrete has already been described as a mixture of cement and aggregate. The aggregate may consist of

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[1] It is now possible to obtain Portland cement which is slow setting but rapid hardening—*i.e.* its strength increases rapidly after setting, so that a three-day test may be made to equal a twenty-eight-day test on ordinary Portland cement, the final strength after six months being about the same. This property is valuable in the case of concrete piles and similar work, where the casing may be taken off and reused at short intervals.

Another rapid hardening cement known as " high aluminous cement " or " Ciment Fondu " is sometimes used. It is of a different chemical composition from Portland cement and is more expensive ; hardens very rapidly ; and should not be mixed with lime or Portland cement, which act on it chemically.

broken stone—sandstone, limestone, or granite, blast furnace slag, hard clinker, coke breeze, broken brick, gravel dug from a pit or shingle from the sea-shore or a river bed—the latter often called ballast. The aggregate is broken up to a size convenient for the purpose in view, usually to pass a 2 in. square mesh for ordinary foundation work, and a $\frac{3}{4}$ in. square mesh for fine concrete or for reinforced concrete.

The strength of concrete varies to some extent with the kind of aggregate, soft bricks and coke breeze forming a relatively weak concrete. These aggregates and clinker are generally used for concrete exposed to fire, for which the other kinds are unsuitable. It is often said that angular aggregates form stronger concrete than rounded ones, but this does not seem to be borne out by tests, shingle undoubtedly forming a very good concrete. It is essential that the aggregate should be free from sulphides—which may be present in clinker and coke from pyrites in the coal—as these are liable to oxidise and expand in setting, thus disintegrating the concrete. It should also be clean and free from any clay or organic matter which is often present in pit gravel. In such a case the gravel is washed in a sieve, water being poured on and the clay carried off in suspension.

In order to form a good concrete the aggregate should contain sand. This is usually defined as material which will pass a $\frac{3}{16}$ in. square mesh, and is often present naturally in dredged shingle and other aggregates. The proportion of sand should, however, be controlled and this is usually done by sieving the aggregate in order to separate out the sand, and then remixing in the required proportions. The sand itself should be clean and free from any organic or loamy matter. In some circumstances with " lean " concretes—those containing a small proportion of cement—a small amount of clay may be present in the sand without harmful effect; but this should not be allowed on any important work without careful testing and experiment.

PROPORTIONING AND MIXING

The proportions in which the aggregate and sand are mixed are often determined by experiment. A tank of known capacity is filled with aggregate. Water is then poured in until it just rises to the edge of the tank. The quantity of water is measured as it is poured in, and its volume gives the volume of the interstices between the fragments of aggregate, or voids as they are called. This volume plus, say, 10 per cent. is the volume of sand which is required to form a dense concrete. In the same way the voids in the sand may be found and the volume of cement required to fill those voids ascertained. The volume of cement is, however, usually specified from considerations of strength—the larger the volume of cement the stronger the concrete.

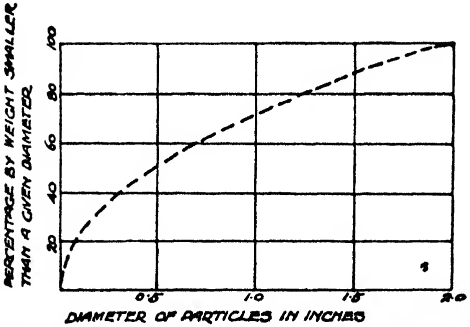

FIG. 45.—Fuller's curve for maximum density of aggregate.

On important works the aggregate proposed to be used is sieved through successive meshes of decreasing size, and the results are plotted in the form of a curve, giving on one axis the size of the mesh, on the other the percentage of aggregate retained on that mesh. It is possible in this way to see at a glance if the aggregate contains an abnormal amount or lack of any particular size of grain. There is some difference of opinion as to what may be considered as a normal curve, but Fuller, who has carried out investigations on this subject in America, recommends the curve shown in Fig. 45. For important work it is thus possible to combine two aggregates in the proper proportion to obtain a "normal" aggregate. Although the strength of concrete varies with the proportion of cement, yet with a given proportion of cement the strongest concrete is that made with the densest aggregate, which is one with a "normal" sieve analysis curve.[1]

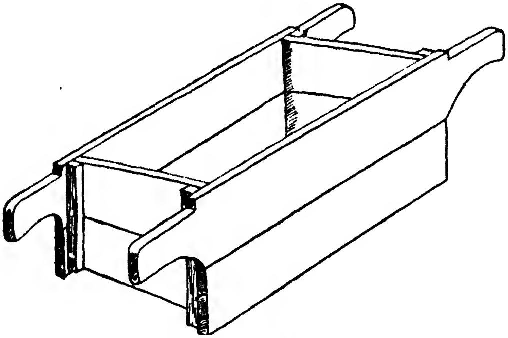

FIG. 46.—Gauging box.

Where it is impossible to carry out a definite series of tests to determine the proportions of aggregate, sand and

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[1] An alternative method of proportioning concrete propounded by Professor Abrams of Chicago, and now often used, depends upon the well-known fact that very wet concrete, though more easily deposited, is weaker than that which is merely moist. Abrams deduces from any given sieve analysis the minimum proportion of water to cement which will make the concrete "workable". (See *Concrete and Constructional Engineering*, 1923, p. 253.)

cement, they are usually specified from past experience, an almost standard figure for small foundations being 6 of aggregate (including sand) to 1 of cement by volume. It should be noted that this is not the same as the common proportion for reinforced concrete, viz. 4 of aggregate, 2 of sand and 1 of cement. If the 4 of aggregate and 2 of sand in the latter be mixed, the resulting volume will only be about 4½, due to the sand being lost in the interstices of the aggregate, a fact which may be used by an unscrupulous contractor to his benefit.

The **mixing** of concrete for small works is carried out by hand. A boarded platform is laid on the ground, and a hose pipe fitted with a rose led to it. The aggregate is first filled into a large bottomless box fitted with handles, placed on the platform, until it is full to the top. The box is then lifted up by two labourers, and the aggregate falls through the bottom and forms a conical heap. This is levelled off at the top and a smaller bottomless box placed on the levelled surface. This is filled with sand and lifted off. The cement box is of the same form, but usually with a bottom; it is filled with cement and upturned over the sand. The boxes are made to hold the required relative volumes—the aggregate box being often 3′ × 3′ × 1′ 6″ high, the sand box 3′ × 1′ 6″ × 1′ 6″ and the cement box 1′ 6″ × 1′ 6″ × 1′ 6″ for a 4 : 2 : 1 mixture. The dry heap is now turned over with shovels at least twice, and then water is sprinkled on through the rose, while the turning over is again repeated twice. If the water is added from a bucket or nozzle, there is a tendency for the cement to be flooded away over the edges of the platform. The amount of water is regulated by the ganger until the required consistency is obtained. The wet concrete is then filled into barrows, wheeled away, and deposited where required.

On large works the concrete is mixed in machines, of which there are many types on the market, generally in the form of a revolving drum into which the ingredients are tipped in the proper proportions—including a measured quantity of water—the mixed concrete being delivered through a shoot into trucks waiting to receive it. The final volume of concrete is, of course, by no means the sum of the volumes of its constituents. In order to arrive at the approximate volume, it may be taken that the voids in ordinary aggregate amount to about 40 per cent. of the total volume of aggregate and voids, and the same with regard to the sand. The dry cement shrinks in volume a little when mixed with water, so that the resulting volume is much less than the combined volumes of the ingredients.

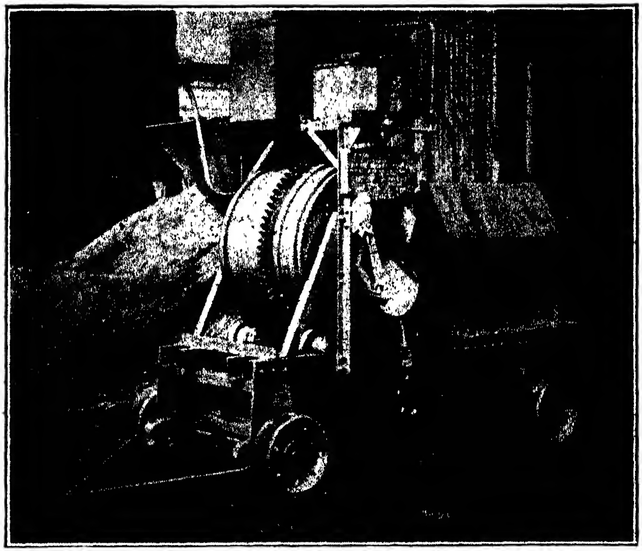

FIG. 47.—No. O Mixer (1920 type), petrol engine drive, fixed hopper.
[*By courtesy of the Ransome Machinery Co.* (1920), *Ltd.*

The proportion of **water** used for mixing the concrete affects its strength. There is little doubt that concrete mixed rather dry and well rammed is the strongest, particularly a short time after mixing, but a wet concrete is usually preferred where bars are to be embedded as in reinforced concrete, owing to difficulty in packing dry concrete solidly round the reinforcement.[1] In important works it is usual to make test cubes of 4 in. side in small wooden moulds from the concrete being deposited, which are tested in compression as a check on the quality—though when the test is made—often twenty-eight days after the concrete is deposited—it is usually too late to have the original concrete cut out if unsatisfactory. In testing the cubes in compression they should be bedded as described for bricks to ensure even pressure. It is essential that concrete should be deposited as mixed, and not allowed to set on the mixing platform during the night if more is mixed than can be put in place at the end of the day. There is often a tendency among the workmen to " knock up " the partially set concrete the next morning with water and treat it as if freshly mixed. Its strength is, however, very much reduced by this process.

On important works where the concreting is stopped for the day, the junction is brushed over with liquid cement grout next morning before adding the new concrete to form a strong and solid joint. When depositing new concrete against old, it is usual to hack the old concrete with picks in order to roughen it, wash it with clean water, and brush over with grout.

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[1] The wetness of concrete is often measured in the works by means of a "slump cone," a truncated conical mould without a bottom, 8 in. diameter at the base, 4 in. diameter at the top, 12 in. high, which is filled with concrete and then carefully lifted, leaving the concrete behind as a heap which " slumps " or flattens more or less under its own weight according to its wetness. For ordinary mass work a 2 in. slump and for reinforced concrete a 6 in. slump are often specified.

In massive concrete work, such as large dams, concrete is often saved by embedding large stones as they come from the quarry, called **plums**, care being taken that the plums do not touch each other. A variety of this, called rubble concrete, has been described in the chapter on masonry.

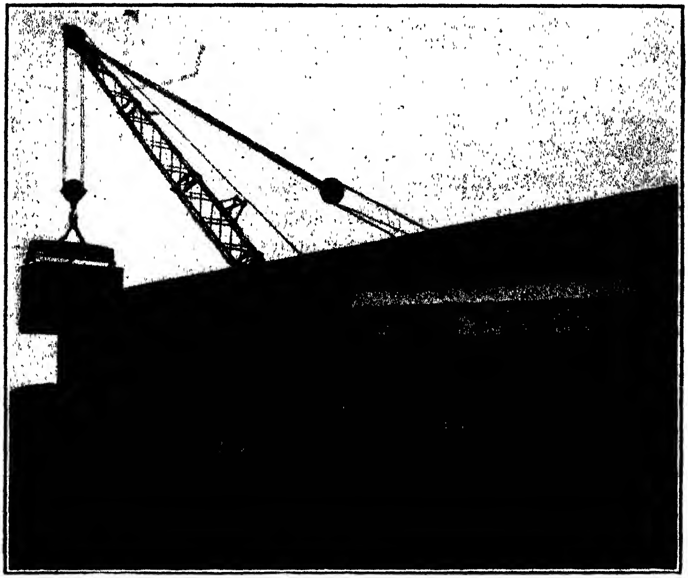

FIG. 48.—15-ton block setting crane with skip for depositing concrete in water.
[*By courtesy of Messrs. Stothert & Pitt, Ltd.*

DEPOSITING

Concrete is usually deposited from skips slung from a crane, tip waggons, or wheelbarrows. There is generally a clause in the specification forbidding its being tipped from a great height, owing to the tendency of the stones to force themselves through the layer of fresh concrete through their momentum and range themselves in layers on the concrete previously deposited.

Cases arise where concrete must be deposited in water. It is only possible to do this in comparatively still water, and even then the operation is troublesome. It is usually carried out in boxes with hinged bottoms. These are filled with concrete and lowered carefully through the water by a crane. When they are near the bottom a pin is pulled out by a cord and the bottom of the box allowed to fall open. The concrete slips through, but often loses a proportion of its cement in the process, particularly on the surface.

Mixed concrete is sometimes deposited in bags, which are allowed to remain. They are of open texture, and as they bed down on one another the cement oozes through the fabric and keys the bags together. This is a useful method for building work between low and high tide level. Another method is to form a shoot of boarding from above water level to the place where the concrete is to be deposited, down which the concrete is shot, the mouth of the shoot being moved as required. A good deal of underwater work is, however, carried out by forming the concrete into large blocks in moulds in the dry, the blocks having usually carefully designed joggle joints to key them together when set. They are lowered by large cranes, directed by helmet divers so that they may be set accurately.

For concrete foundations, trenches are dug the exact width of the concrete required, which is simply thrown in and takes the form of the trench. Where the concrete is to be narrower than the trench or is above ground, it is deposited behind shuttering or casing formed usually of boards. These act as a mould, and are allowed to remain until the concrete is quite set, when they may be removed, usually after about a fortnight. If the boards are thoroughly wet when the concrete is deposited there is not much danger of its sticking; but to make sure, the casing is often whitewashed or painted over with mineral oil, soft soap or clay.

While the concrete is setting it should be shaded from the sun, generally by laying empty cement bags on it, and it should be sprinkled daily to keep it moist. Frosty weather stops the setting but does not otherwise damage the concrete after it has taken its initial set. Fresh concrete, however, should not be deposited in frosty weather. When the frost is ended, the setting goes on as before.

Concrete has, within ordinary limits, a temperature coefficient of expansion about equal to that of steel (0·0000065 per degree F.) and long concrete walls if made in warm weather crack sooner or later. This is sometimes obviated in concrete buildings by constructing the walls with some form of tongued and grooved joint at intervals where the cracks can take place and open without being unsightly. Very fine hair cracks often appear also on the surface of a concrete wall, due to the unequal contraction of the surface and the core. They are, however, not harmful, and do not penetrate deeply. The face of a concrete wall is usually blotched and unsightly, and shows the joints of the shuttering if this is not carefully constructed of planed boarding. To overcome this defect, the concrete may be plastered with a ½ in. coat of cement and sand, trowelled smooth with a steel trowel, or finished with a wooden float which leaves a surface like rubbed stone. The surface may alternatively be roughened by hammering with a " bush " hammer having many sharp points, or it may be washed over with dilute hydrochloric acid and then with clean water to give it a granular texture.

Concrete is often used in positions where it must be watertight, as in tank walls. Ordinary concrete well proportioned and rich in cement is watertight—although not damp-proof—but it is possible to improve a poorer concrete by mixing with it one of the patented powders now on the market for that purpose. A small percentage of fine hydrated lime has the same effect, although some engineers maintain that extra cement to the same value would be more efficacious. If the concrete is to be absolutely dry the only way is to coat the outside with a layer of asphalt.

REINFORCED CONCRETE

The strength of concrete in compression is considerable; but its strength in tension is very small, and it is consequently unsuitable for use as a beam, the underside of which is usually in a state of tension. By embedding steel rods in the underside of a concrete beam its strength is increased enormously. The concrete in setting grips the steel very tightly, and as both materials expand equally with temperature, there is no tendency for this grip to be loosened. Concrete thus strengthened is now rapidly superseding timber and even steel in many cases for structures of moderate size, and is known as **reinforced concrete.** If the steel is properly embedded in and covered by the concrete, it is found to be perfectly protected from corrosion and rusting, probably owing to the fact that rusting is started in the first place by carbonic acid in the air, and that the alkaline nature of the concrete neutralises this. The minimum amount of **cover** is generally taken as ½ in. in slabs, 1 in. in beams, and 1½ in. for all outdoor work, in piles, framing, etc. For work exposed to sea water it is advisable to allow 2 in. The steel reinforcement may be in the form of plain round bars complying with the British Standard Specification for structural steel or some similar specification, or one of the many forms of patented bars now on the market may be used at a slightly higher price per ton. Most of these bars are corrugated, twisted or in some way roughened to enable the concrete to grip them with more certainty, while others have patented arrangements for attaching to the main bars other smaller members to take the shear stresses which are set up in a beam.

The proportions of the ingredients in the making of the concrete, the amount of steel and the methods of calculation may be carried out according to the official regulations of the local authority where such regulations exist (as in London) ; or the *Handbook on the Code of Practice for Reinforced Concrete* recommended by the Building Research Board may be followed. (Concrete Publications Ltd., 20 Dartmouth Street, S.W. 1.)

The concrete is usually mixed in the proportion 4 : 2 : 1, aggregate, sand, and cement by volume ; and its crushing strength twenty-eight days after mixing, kept in air, should be 1800 lb. per sq. in. A working stress of 600 lb. per sq. in. is then allowed in compression, and its strength in tension is neglected in the calculations. The working stress on the steel in tension is 16,000 lb. per sq. in.

The **designing** of reinforced concrete structures is more complicated than that of similar steel structures, owing principally to the various proportions of metal to concrete used, and the need for close and efficient supervision of the work is very great, as once the concrete is deposited, it is impossible to check any error in the position or amount of the steel. Reinforced concrete is used to a large extent for upper floors and the beams supporting them. A casing is first constructed of boarding into which a layer of concrete is first deposited about 1½ in. thick. The reinforcement is then laid on this in the proper position, and more concrete filled over it and rammed around it until the upper surface is reached.

The **shuttering**, which should be stiff enough not to deflect under the weight of the wet concrete, is left up for periods varying from a few days to a fortnight, the sides of beams being removed first and the bottoms last, and is generally made so that it can be easily taken down and used again

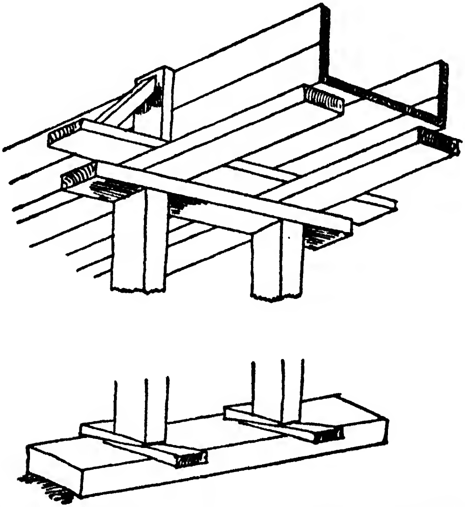

FIG. 49.—Casing and supports for a reinforced concrete beam in an upper floor.

(Fig. 49). Vertical columns are boarded up on three sides with vertical casing. On the fourth or open side, after the reinforcement has been placed in the casing, a few short boards are nailed across at the bottom and concrete thrown in and well rammed. More boards are then nailed across and more concrete thrown in, until the necessary height is reached. The reinforcing bars are not cleaned before being embedded in the concrete, as it is found that a small amount of red rust is not detrimental to the adhesion of the concrete. Most of the bars are bent to shape or hooked at the ends before being placed in position, and this is best done cold to template—except in the case of heavy bars, which must be heated.

Concrete piles are made in the same way in boarded horizontal moulds, the shoes being concreted in. It is a good plan to place in the corners of the moulds a small triangular fillet, so that the resulting beam or pile has chamfered edges. Square edges are liable to be broken off during handling and the reinforcement exposed. Where "hard" driving is expected it is also a good plan to construct the top 3 ft. of the pile of richer concrete. When concrete piles are driven to the required level and a reinforced superstructure is to be erected, the concrete at the upper end of the pile is broken away with steel wedges and sledge hammers, exposing the reinforcement, which can thus be allowed to overlap that of the superstructure, the whole being concreted up together inside casing fixed around it.

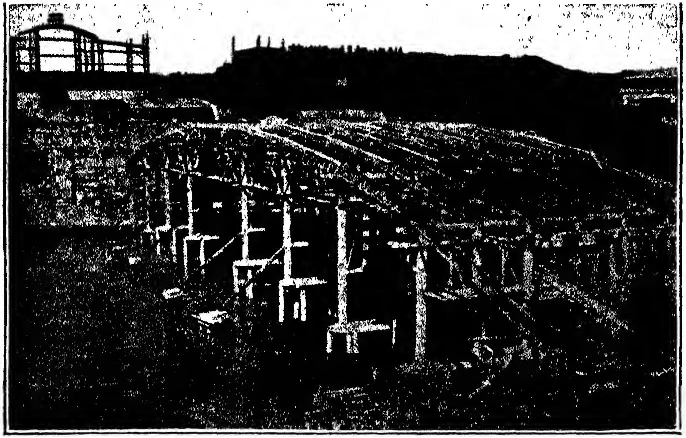

Fig. 50.—Reinforced concrete bridge under construction, showing centering and casing for concrete ribs.

[*Engineering*, 1st December, 1911.

Much, perhaps most, of the reinforced concrete work carried out in Great Britain is designed by specialist firms who are usually interested in some form of patent bar which they work into the structure. This, of course, increases the cost of the structure if one such firm is employed since competition is eliminated, although on the other hand such a firm can often save through its detailed knowledge of design. If competitive designs are asked for from several such firms, there is a tendency for the cheapest design to be selected, which often means the one designed with the lowest factor of safety. In fact, the position is similar to that in the case of steelwork required by those architects who are not competent to design such work in detail, and who therefore employ specialist firms to do it for them, such firms being usually manufacturers as well.

OUTLINE SPECIFICATION CLAUSES FOR CONSTRUCTION IN CONCRETE

The following specification clauses may be taken as typical for construction in concrete.

Cement. The cement is to be pure Portland from an approved maker, capable of withstanding a tensile stress of 600 lb. per sq. in. when gauged neat, after maturing one day in air and six days in water. Its fineness must be such that the residue on a standard sieve of 72 meshes to the lineal inch shall not be more than 1 per cent. by weight, and on a sieve of 170 meshes to the lineal inch not more than 10 per cent.

(These two requirements would probably ensure a fairly good cement, but the alternative clause given below is far better for works of any magnitude.)

The cement is to be pure Portland from an approved maker, and is to comply in all respects with the latest British Standard Specification for slow-setting cement. It is to be stored in dry, watertight sheds, in layers not more than 3 ft. deep, and is not to be used on the works within three weeks of the date of manufacture. All cement which has been damaged in transit will be rejected.

Aggregate. The aggregate for mass concrete is to be composed of clean broken stone, ballast, shingle, gravel or hard burnt clinker or other approved material, broken to pass a 2 in. circular ring, and containing an approved proportion of clean sand which will pass a $\frac{3}{16}$ in. square mesh. The aggregate for reinforced concrete is to be composed of clean broken stone, ballast, shingle, gravel, hard burnt clinker or other approved material which has been screened through a $\frac{3}{4}$ in. square mesh, and refused by a $\frac{3}{16}$ in. square mesh.

Sand. The sand for concrete must be clean and sharp, entirely free from loam, clay or organic matter, and capable of wholly passing a $\frac{3}{16}$ in. square mesh.

Mass concrete. The mass concrete is to be composed of six parts by measure of aggregate as specified above to one of cement, turned over twice dry and twice wet on a boarded platform, water being added through a rose, or mixed in an approved mechanical mixer. No concrete is to be tipped from a height of more than 10 feet except through a shoot. "Plums" may be used where approved, but must be separated by at least 6 in. of concrete when in position.

Reinforced concrete. The reinforced concrete is to be composed of four parts by measure of aggregate as specified above, two parts by measure of sand, and one of cement, all measured in suitable boxes, turned over three times dry and twice wet on a boarded platform, water being added through a rose, or mixed in an approved mechanical mixer.

The concrete is to be deposited in the casing and carefully rammed around the reinforcement. The amount of water used in gauging is to be to the approval of the engineer.

Protect concrete. All concrete while setting is to be protected from frost or the direct rays of the sun and watered daily if necessary. No concrete is to be mixed during frosty weather, and none is to be deposited which has been gauged more than three hours. No concrete is to be deposited under water until the arrangements have been inspected and approved by the engineer.

Facing concrete. The concrete in.................... is to have a facing 2 in. thick of richer concrete, gauged two of fine gravel and sand and one of cement, deposited at the same time as the backing and well pinned against the casing, the two kinds of concrete being separated by a board which is to be pulled out immediately the concrete is in place.

Casing, etc. All casing is to be strong enough to withstand the pressure or weight of the wet concrete without appreciable distortion. No casing is to be removed until the expiration of the following periods from the time of depositing: viz. mass concrete 7 days, reinforced concrete columns 7 days, beams 14 days, piles and blockwork generally 7 days. The contractor, however, is to be responsible for any damage which may occur through casing sticking to the concrete [1] or through its being removed too soon, and he will be required to render the face in cement and sand if necessary at his own expense. No piles are to be driven or blocks set in position until at least six weeks after mixing. All the above periods are to be extended during frosty weather. Where concrete has to be joined to other concrete which has been gauged more than 48 hours, the junction must be thoroughly cleaned and grouted with neat cement before the new concrete is deposited.

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[1] The use of oil, soap or limewash for coating the casing must be subject to the engineer's approval.

CHAPTER XII

CONSTRUCTION OF BUILDINGS

DESCRIPTION OF SMALL COTTAGE

CUSTOM and tradition play a large part in the design and construction of small buildings. In this chapter a description of the building of a small house (Fig. 51) will be given, and such variations as are required for pumping and generating stations, offices, and other buildings which are often designed by civil engineers will be indicated.

FOUNDATIONS

The first work is to clear the site of grass, weeds, trees, bushes, etc., and then to dig the **foundations.** These are set out on the ground from the drawings by means of pegs, the width of each trench being the width of the concrete foundation, usually twice the thickness of the wall plus 12 in. These trenches are dug out with vertical sides about 2 ft. deep, the bottoms of the trenches being kept level and stepped where the ground is sloping. Before they are dug to the final depth, the architect decides on the level of the surface of the ground floor in relation to the surrounding ground, and has a stout peg driven, from which the builder can work his levels. This gives the actual level of

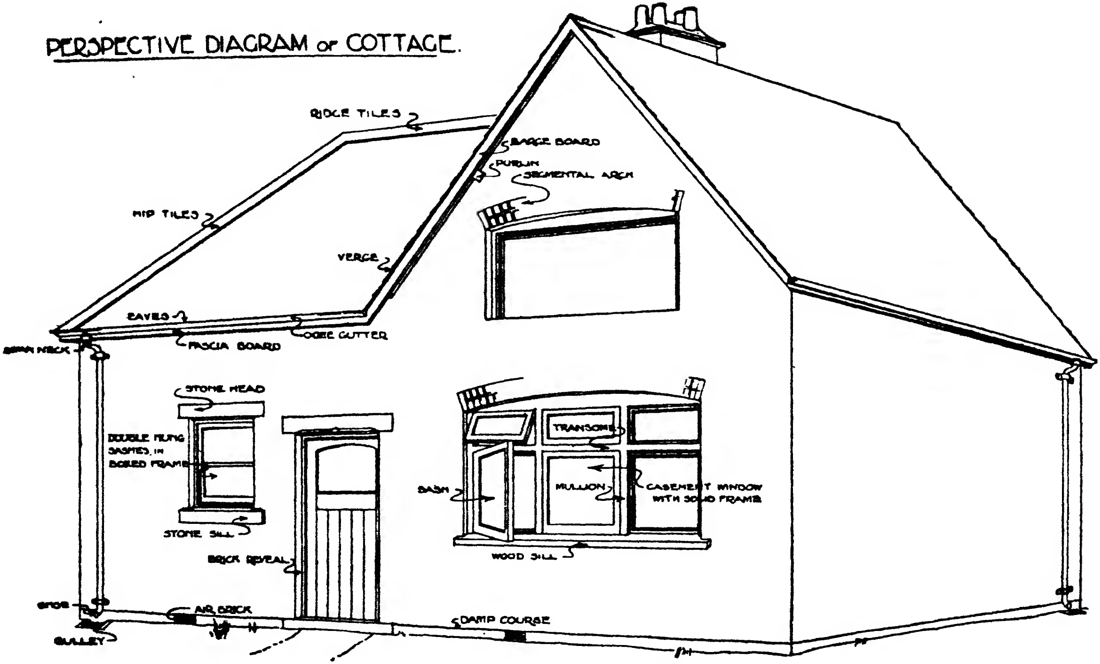

Fig. 51.—External view of cottage.

the bottom of the trenches as measured below the floor level on the drawings, but in any case this should not be less than 1 ft. 6 in. below the actual ground level in order to be free from the effect of frost, which in a clay soil might upheave the ground. **Concrete** is then mixed, usually 8 of aggregate to 1 of cement, and deposited to a depth of about 12 in., the surface being carefully levelled by patting with the back of a shovel.

WALLS AND FLOORS

When the concrete has set for about a week, the bricklayer lays his lowest course of bricks, measuring carefully to see that his **walls** come in the exact positions shown on the drawings. The bricks are laid as far as possible in the lowest or footing courses as headers, that is, with the longest dimension across the wall, and the width of the bottom course is twice the thickness of the body of the wall above. The next course is laid with the vertical joints over the middle of the bricks below, and its width is 4½ in. less, *i.e.* 2¼ in. on each side. Other courses are laid, diminishing successively 4½ in. until the thickness of the body of the wall is reached. At the same time the ground between the wall trenches is levelled to the depth shown on the drawings, and a layer of concrete 6 in. thick is deposited over it and carefully levelled. This prevents subsoil air from being drawn up into the house.

The **ground floors** are of boards nailed to wooden joists resting on small brick walls called **sleeper walls**, which themselves rest on the 6 in. surface concrete (Fig. 52). The sleeper walls are generally spaced about 4 feet apart, across the direction in which the timber joists are to run, and therefore in the same direction as the floor boards. They are only 4½ in. thick, and have generally the vertical joints of the bricks left open in order to allow a circulation of air through them. Those outside walls of the building which run parallel to the sleeper walls are built up to the level of

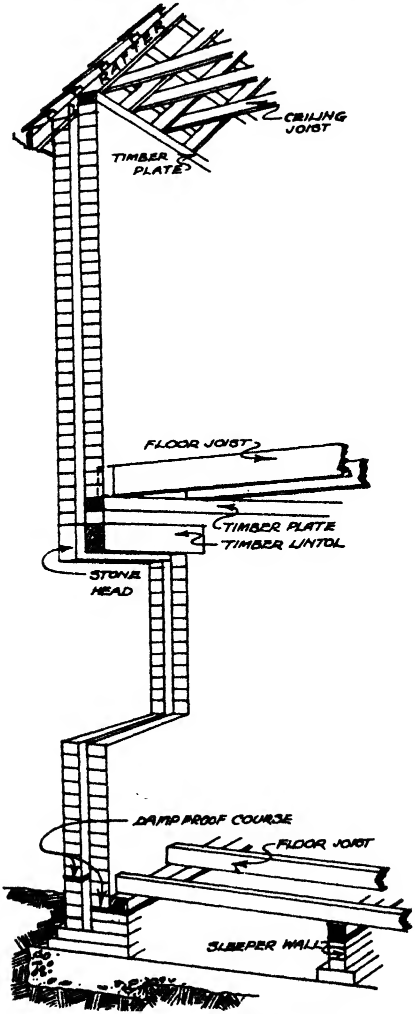

FIG. 52.—Dissected section of cottage wall viewed from inside.

the top of the sleeper walls with an extra 4½ in. thickness —**offset**—on the inside.

On the top of this and of the sleeper walls are bedded **plates**, pieces of timber 4½ in. wide, 3 in. deep, and extending the whole length of the sleeper walls and offsets. These plates are not bedded direct on the brickwork, but on a **damp course**, which may consist of special slates 4½ in. wide laid flat on the wall in cement mortar in two courses, or it may be formed of bituminized felt, or one of the patent damp courses now on the market. At the same time, this damp course is carried right through the thickness of all walls, internal and external, whether they carry plates or not. Its object is to prevent damp from being drawn up the walls—bricks being porous—by capillary attraction from the earth so as to reach the timber plates or the main body of the wall. The plates are simply bedded on the damp course in mortar, and not bolted down in any way. Across them are laid the **floor joists**, usually 4 in. × 2 in. on edge in section at 14 in. centres, "skew" nailed to the plates. Openings are left in the external walls under the floor level, 9 in. × 3 in., and fitted with iron or terra-cotta pierced gratings—called **air bricks**—so that a through current of air is possible under the floor as a preventive of dry rot in the timber. Eight such bricks would suffice for a small cottage.

Where **fireplaces** occur, extra foundations are provided to take the increased thickness of brickwork, carried down to the same depth as the ordinary wall foundations, and in addition a small 4½ in. wall is built on the 6 in. surface concrete to contain the **hearth**, which is usually 18 in. wide from the front of the fireplace brickwork, and 12 in. longer than the fireplace opening, damp courses being built in as before described.

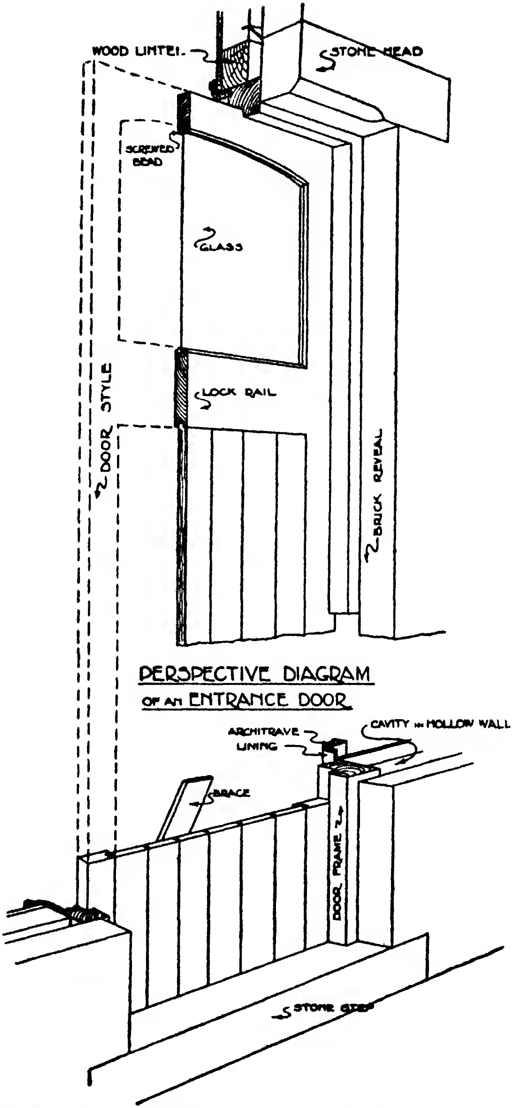

Fig. 53.—Dissected drawing of common external glazed door in solid frame, viewed from outside.

WOODWORK

The bricklayer builds in stone steps for external doorways where required and sets the **door frames** (Fig. 53). These are oblong frames of wood, generally of 4½ in. × 3 in. section forming a head and two side posts which have been previously made by the joiner and painted one coat. The lower ends of the posts—or **jambs**—may be fixed to the stone step, or if there is no stone step they may be tenoned into an oak threshold, which rests on the brickwork. The bricklayer builds up the brickwork neatly against the posts of the frame, generally forming a projecting tongue or **reveal**, which partly protects the frame from the weather. When the level of the windows is reached, the sills of

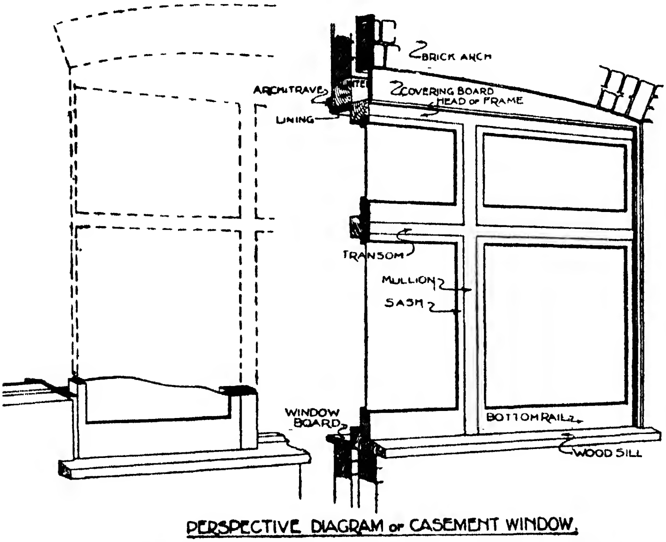

FIG. 54.—Dissected drawing of common casement window in solid frame, viewed from outside.

the **window frames** are bedded on the brickwork at the correct levels (Fig. 54). These may be of stone, and the wooden sills of the windows are bedded upon them with a galvanized iron **water bar** to prevent water from driving in the joint. If stone sills are not used, the wooden sill of the window frame—which is attached to the jambs and head—is bedded direct on the brickwork, which is built around and against the frame in a similar manner to that around the door frames.

Meanwhile the interior walls, which in a small house would be 4½ in. thick, are carried up course by course, openings being left where **internal doorways** occur. These openings are spanned at the top by wooden lintels of 4½ in. × 3 in. section placed flat, and usually over these lintels the bricks are arranged in the form of a rough "relieving" arch to take off the pressure due to the weight of the wall above. In the case of the openings in the external wall, the external 4½ in. of the opening is spanned by a **stone head** or **brick arch**—segmental or flat—and the internal portion is bridged by wooden **lintels** as in the case of internal openings, of a depth usually 1 in. for every foot of span, and of a width equal to the thickness of the whole wall less the 4½ in. occupied by the outside head or arch. "Relieving" arches are turned over the internal lintels as before.

Near the chamber floor level, wooden plates similar to those for the ground floor joists are bedded on the inner 4½ in. of the external walls which are to take the ends of the chamber floor joists, and on those internal walls which are crossed by the same joists. The joists themselves, 2 in. thick and of a depth from 7 in. to 10 in. according to the span, are spaced at about 14 in. centres, being arranged in this case as in that of the ground floor joists, so that there is a joist against each wall to take the ends of the floor boards. They are skew nailed to the plates, and the brickwork is built up and over the plates and between the joists, so that both plates and joist ends are surrounded by it.

ROOF

The walls are continued up to the level of the roof, door and window openings being dealt with as on the ground floor. At the roof level a third set of plates is bedded on the brickwork to take the **ceiling joists**, which are usually 4 in. × 2 in. spaced as on the ground floor, but in this case—as they have to span from wall to wall—they are often supported by cross beams—called **binders**—9 in. × 3 in. laid *above* them, on edge, to which they are skew nailed. The roof itself is constructed of sloping timbers called **rafters**, usually 4 in. × 2 in. in section, fixed to plates at the bottom—often the ceiling joist plates are in a convenient position for this—and running up to the apex of the roof or **ridge**, which is formed of a vertical board about 9 in. × 1½ in., against which the rafters are simply butted and nailed. The rafters are also supported at points intermediate between the plate and the ridge by horizontal girders of timber called **purlins** of stout scantling (cross section), often 7 in. × 3 in., and these in turn are supported on struts of 4 in. × 4 in. scantling, carried up wherever possible from the tops of the internal walls, thus avoiding the expense of trusses, such as are required for large buildings.

Across the rafters are then nailed the **slating battens** of 2 in. × ¾ in. section, laid horizontally at the proper distance apart to give the required lap to the slates, which is usually 2½ in., and the slates are nailed down to these battens with galvanized nails with thin flat heads. It should be noted that the lap of the slates mentioned above is not that of one slate over the next below it, but over the next but one below, so that every part of the roof is covered by at least two thicknesses of slate, and, where the lap occurs, by three thicknesses.

Where there are **valleys** in the roof, the rafters have to be cut and nailed against a valley rafter, about 7 in. × 2 in., and up the angle between the two slopes two boards are nailed on the rafters to form a gutter. This is covered with sheet lead weighing 5 lb. per sq. foot, nailed at the top to prevent it from slipping down the slope, and then dressed by the plumber on each side over small triangular fillets 3 in. × $1\frac{1}{2}$ in., called **tilting fillets**, and nailed on the edges also. The lead is dressed at the lower end into the **eaves gutter**. This is a cast-iron gutter, either of half round section or of ogee flat back section, screwed either to the feet of the rafters, or to a 6 in. × 1 in. planed **fascia board**, which is itself nailed to the feet of the rafters. The slates at the eaves project about an inch over this gutter, which is fixed not perfectly horizontal in order that the water may run towards the outlets. These are lengths of gutter with nozzles cast in the bottom, which discharge into cast-iron round rain water pipes with "ears" cast on, which are nailed to the walls, and these discharge in turn at the foot over a gulley grating communicating with the sewer.

Where **hips** are formed in the roof, the rafters are cut and nailed to a "hip" rafter of the same section as the ridge. After the slates are laid, the ridge and hips are covered with ridge or hip tiles, made to a suitable angle, and bedded in cement mortar.

An opening has previously been left by the carpenter when fixing the rafters for each chimney which comes up through the roof, by cutting off certain rafters where required and tenoning their ends into cross rafters or **trimmers.** The brickwork of the chimney is brought up above the roof, and a damp course—in this case often of sheet lead—is laid just above the roof level over the whole area of the chimney, with holes cut through for the flues. This is to prevent wet from soaking down the brickwork of the chimney into the rooms below. The brickwork is then carried up and finished with two courses of red roofing tiles laid to project, and red earthenware chimney pots are then bedded on the tiles in a mass of cement mortar, which is " flaunched " up against their sides to hold them firmly. The plumber fixes his lead " flashings " at the spot where the slates abut against the chimney, and the roof is thus rendered weather tight.

STAIRS, DOORS, AND WINDOWS

When the roof is covered in the internal work can proceed. The chamber floor joists, which have been trimmed around the upper fireplaces to keep them at least 18 in. away from the fronts of the fireplace openings, are stiffened by having rows of **herring-bone strutting** nailed across them, and then the floors are laid. These are of " inch " boarding—really $\frac{7}{8}$ in. thick only—the edges being either square or tongued and grooved, cramped up as tightly as possible, and well nailed. Landings on the staircase are done in the same manner.

The **stairs**, which have been constructed as far as possible in the joiner's shop, are brought in and fixed in position, by nailing the **wall string**, as the inclined skirting against the wall is called, to the wall, and by tenoning the outer string to upright posts or **newels**. The stairs in a small house are usually about 2 ft. 9 in. wide, and the steps themselves about 9 in. on the tread and 7 in. rise each, the actual boards of which they are composed being wider to allow for tongueing. The wall string and outer string are $1\frac{1}{2}$ in. and 2 in. thick respectively, and the ends of the treads and risers are let into them bodily—or " housed "—for $\frac{1}{2}$ in. and glued and wedged there. Blocks are also glued underneath to strengthen the angles between the heads and risers, which are 1 in. and $\frac{3}{4}$ in. thick respectively. The front edge of each tread projects 1 in. over the face of the riser and is rounded. To obtain the height of each riser the vertical distance between the floors is divided into the required number of equal parts, each about 7 in., and the treads are calculated in the same way as equal divisions of the horizontal distance available. When the stairs are fixed, the sides of the landing joists, which are of sawn wood and exposed to view, are covered with a $\frac{1}{2}$ in. planed board called an **apron lining.**

The frames for the internal doors would now be fixed, those for the external doors having been built in with the brickwork. Internal door frames—usually called **linings**—are much lighter in section, being merely stout planed boards, 1 in. thick, and consisting of two jambs and a head. They are of the same width as the thickness of the wall in which the opening occurs—that is, the brickwork, plus $\frac{3}{4}$ in. on each side for plaster—and they are nailed to small pieces of $\frac{3}{8}$ in. board which were previously built into the joints of the brickwork around the opening, say three on each side, the head being nailed upwards to the lintel. On the face of these linings door stops are nailed, of planed timber 2 in. × 2 in. The external door and window openings have now to be finished inside. Linings of $\frac{3}{4}$ in. planed board are fixed around the openings inside, their edges being tongued into grooves previously made in the inside faces of the door and window frames. These linings are nailed as before to $\frac{3}{8}$ in. wood slips built into the joints of the brickwork, and their edges project into the room beyond the internal face of the brickwork $\frac{3}{4}$ in. They go around the window and door openings on the sides and head only, the floor taking the place of the lining in the case of the doors, and a thicker board being fixed along the bottom of each window openings, called a **window board**—often, but wrongly, called the window sill, which is really part of the window frame itself.

INTERIOR WORK

The **plasterer** can now commence work. **Laths** are nailed up against the underside of the ceiling joists over the bedrooms and against the underside of the chamber floor joists over the ground floor rooms. The laths are 1 in. wide and about $\frac{3}{16}$ in. thick, nailed $\frac{3}{8}$ in. apart until all the ceilings are covered. The plasterer then mixes up his first coat stuff, in the proportion of two parts of clean sharp sand to one of lime by measure, and sprinkles into the mixture cow-hair which has been well beaten to separate the hairs. When this has been well mixed, it is applied to the underside of the laths by means of an oblong laying trowel and squeezed well between them, so that it obtains a key which prevents it from falling again. The walls are also plastered with the same mortar—often without hair in this case—and when the first coat has dried a few days, it is scored over with a pointed lath in order to roughen it, and a second coat is plastered on and carefully flattened with a wooden trowel called a float. Finally, a third coat is applied very thinly, and the whole ceiling and wall carefully levelled off with the float. The plaster now finishes flush with the edges of the internal door linings and the window linings, and the joiner covers the joint between the wood and the plaster—which is bound to open as the building dries—with a moulded slip of wood about 2 in. × 1 in., called an **architrave.**

The underside of the stairs is lathed and plastered similarly to ceilings. The first coat of plaster on walls is known as **rendering,** the second coat as **floating,** and the third coat as the **setting coat.** In some cases the second coat is omitted. The lime for plastering should be slaked some weeks before it is required, in order that no unslaked particles may get into the plaster, and cause it to "blow" by slaking afterwards.

The **skirtings** are now nailed on the face of the plaster. They are usually formed of 6 in. × 1 in. boards with the upper edge moulded. They butt against the edge of the architrave. The **doors** are brought into the building and hung by means of butt hinges, and the door locks and "furniture" fitted and fixed. The sizes of the doors vary slightly according to the importance of the building, but for a small cottage 2 ft. 6 in. × 6 ft. 6 in. is often used, 1½ in. thick for internal doors, 1¾ in. for external. Doors are often imported from abroad ready made, and may be obtained 2 ft. 8 in. × 6 ft. 8 in., and 2 ft. 10 in. × 6 ft. 10 in. The window sashes—for which there is no standard size—are then hung on hinges and the fasteners fixed if the windows are of the casement type, or they are fitted into their grooves and the beads screwed on if they are of the sliding sash type.

The **water supply** is laid on by the plumber. From the nearest water main a ½ in. or ¾ in. lead pipe is taken in a trench 2 ft. deep to the house. The connection of the lead pipe to the iron main is done by the water authority, which also prescribes the strength of the lead pipe to be used and the type of fittings, such as taps. In some districts galvanized iron pipes with screwed collar joints may be used. Near the entrance to the premises a stop cock is fixed on the lead pipe, surrounded by a small dry brick chamber with an iron lid. This is for cutting off the water supply to the house in case of a leak inside. The lead pipe is taken underground until it reaches the building, where it passes through the wall and is then taken to the sink, where it is fitted with an ordinary brass "bib" tap. Branches are led as required to the bath, lavatory basin, and water closet.

DRAINS

The W.C. consists of a glazed **fireclay pedestal pan**, resting on the floor and fitted with a polished seat. The flushing cistern is fixed on brackets at least 5 ft. above the pan and holds 2 gallons, and is connected to the pedestal by means of a vertical lead or galvanized steel pipe of 1½ in. bore. The water service is connected to the cistern through a ball valve, which closes the supply pipe when the cistern is full. There is also a short ¾ in. overflow pipe, which discharges through the wall into the open air if the ball valve fails to close. If the W.C. is on the ground floor, the outlet from the pan is cemented into a 4 in. stoneware pipe which bends under the floor, through the wall, and runs to the sewer. The pan is made in such a form that liquids and solids may pass down the drain, but that gases cannot come back into the room. This is called **trapping**, and is an essential part of any modern drainage system. If the W.C. is on an upper floor the outlet from the pedestal is cemented into the socket of a 4 in. heavy cast iron pipe, which is taken through the wall where it enters a vertical pipe of the same kind running down to the stoneware drain at the foot, and upwards to the roof where it is left open to the air.

This iron pipe is called a **soil pipe**, and its junction with the drain at the foot is effected by merely inserting the lower length of iron pipe into the socket of a stoneware bend and making tight with Portland cement and sand 1 to 1. There is no trap at this point, and consequently no obstruction either to the downward flow of sewage or the upward flow of sewer gas, which can thus escape into the air near the roof. The soil pipe thus acts as a ventilating pipe to the drains. The other sanitary fittings in the building, such as baths, lavatory basins and sinks, are all fitted with lead **waste pipes**, usually 1½ in. diameter in the case of the bath, 1¼ in. in the case of the lavatory basin or sink. These waste pipes are also fitted with traps, and then discharge through the wall into the open air over a gulley if they are on the ground floor, or into a large cast iron funnel at the head of a length of rain water pipe, called a **rain water head**, if they are on an upstairs floor, the rain water pipe itself discharging at the foot over a **gulley**. These gullies, which are generally of glazed stoneware fitted with galvanized iron gratings, are formed with a trapped outlet, which is cemented into the socket of a 4 in. drain pipe

The drains consist of 4 in. pipes, 2 ft. long, of glazed stoneware—or in the North and Midlands they may be of glazed fireclay, which is not quite so hard—laid in trenches dug to the proper depths and levels, so that the pipes may be in perfectly straight lines with an even fall from end to end of each length, of not less than 1 in 40. The joints are made of cement mortar. Where two drains join they are run into the two sockets of a junction piece, and the combined drain carried on as before.

Near the boundary of the premises a **manhole** is built of 9 in. brickwork on a cement concrete foundation, through which the drain passes in the form of an open half-round channel. At the outlet of this channel through the wall of the manhole is fixed a glazed stoneware trap—called an **intercepting trap**—which is to prevent gas from the main sewer—into which the drain eventually runs—from passing up the house drains. At the same time a stoneware pipe is taken horizontally through the wall of the manhole near the top, then vertically through the earth until it projects two or three feet above the ground, where it is fitted with a mica flap **inlet valve**, which will allow the air to pass down into the manhole, but will not allow the gases from the manhole to discharge into the external air. The air which enters the manhole passes up the house drain and makes its exit at the top of the soil pipe near the roof, thus keeping the whole drain constantly flushed with fresh air.

When the cement joints of the drain pipes have set hard, and before the trenches are filled in, the drain is tested by plugging up the lower end where it enters the intercepting manhole with a bag of clay or a patent "drain stopper," and then filling the whole drain with water until it overflows at the lowest gulley. It is left for an hour, and if the drain is tight the water level at the gulley will not sink appreciably. If it does, the pipes must be examined and the leak stopped with cement, unless it be due to a cracked pipe, in which case two or more pipes must be broken out and new ones inserted. It is impossible to take out and insert one pipe alone owing to the form of the joints. When satisfactory the trench is filled in and the ground surface levelled.

PAINTING AND GLAZING

When the interior plastering is fairly dry, the painter commences work. He first paints the knots in the exposed woodwork—which must be planed before being painted—with **knotting**, which is a shellac varnish, and then he gives the whole one coat of **priming paint** mixed with red lead. When this is dry he fills the nail holes and cracks in the joinery with putty, pressing it well in and smoothing off. This is known as stopping, and the wood is then ready to receive two coats of paint in addition. The window sashes have been given one coat of priming paint at the joiner's shop, and the glass is now fixed by filling the wooden rebate or groove with putty, which sticks to the painted surface, and then pressing the glass into it, cutting off the surplus putty which is squeezed out and forming a fillet on the outside. The putty is formed of whiting and linseed oil, and the glass is usually ordinary sheet glass of a thickness specified by its weight per square foot, 15 oz. being used in the cheapest work, 21 oz. being stouter and better.

For bathrooms, etc., some form of obscured glass is used, fixed in the same way. In glazed doors, the glass is usually fixed in place by thin slips of wood, called beads, being screwed against it. These are easily removed when required for repairs. The fireplaces, which are purchased complete at the builders' merchants or ironmongers, are fixed in position by the bricklayer, and the plaster made good around them. The hearths are laid, usually of tiles in cement, a neat joint being made against the floor boarding. The painter whitewashes the ceilings, and if the walls are dry either distempers or papers them, though it is usually wise to defer this for at least six months. Further details of cottage design are given in Appendix V.

The foregoing description is an outline of the common practice in the South of England. In other parts, building varies according to the local traditions and materials. Thus, where stone is plentiful the foundations may be formed of large flat stones instead of concrete, and the outer walls of the house may be formed of stone, generally backed inside by brick. The roof may be covered with thin slabs of stone. In other districts flat tiles may be used instead of slates, either nailed on to the battens in the same way or merely hung by projecting nibs.

Almost all the sizes given in the preceding account apply to the cheapest class of cottage, and if they are varied on any particular work this should be in the direction of better—and more costly—work. For example, for a larger building, such as a set of offices, the following sizes might be adopted: external door frames 5 in. × 4 in. scantling; window frames 4½ in. × 3 in., or steel casements selected from a manufacturer's catalogue; internal door linings 1¼ in. thick; skirtings 9 in. × 1¼ in.; architraves 4 in. × 1¼ in.; chair and picture rails fixed against the walls at any convenient height; these and the skirting and architraves being nailed to flat "grounds" of timber 3 in. × ¾ in. fixed to the face of the brickwork in convenient positions, the face of the grounds being level with the face of the plaster. The mouldings may either be obtained of stock patterns, or worked to a special shape designed by the architect. Stair treads 1¼ in.; risers 1 in.; strings 2 in.; doors 2 in. thick (really 1⅞ in.); sashes 2 in. thick. Joists and rafters would be the same size for any buildings, as they are governed by the bye-laws, which prescribe sizes ample for any class of construction.

A copy of the **local bye-laws** should always be obtained by anyone who has to design a building. In most parts of England such bye-laws apply, and even where they do not—as in the case of railway buildings—they are a useful guide in many ways. They may be obtained from the local surveyor. Before a building is commenced plans must be deposited in duplicate with the surveyor to the district, and approved before the work can be started. The bye-laws prescribe the levels, widths and construction of new streets, the construction of footings, walls, damp courses, thicknesses of walls, construction of chimneys and fireplaces, sizes of floor and roof timbers, air space around buildings, construction of drains, water-closets, earth-closets, ashpits and cesspools, and the height of rooms. As a guide to the sizes of timbers, etc., in common use, the following rule may be adopted in the absence of bye-laws: the width of joists carrying floors should be 2 in., and the depth in inches should be half the span in feet, plus 2. Thus, a 12 ft. span requires an 8 in. × 2 in. joist. Rafters, as already stated, are usually 4 in. × 2 in. with a clear span of 8 ft. between supports.

Appendix VI gives the conventional method adopted in drawing small scale plans of a simple building, together with a few details and an outline specification.

Pumping Station

The buildings which a civil engineer has to design are often of a different character from ordinary dwelling houses, and a few of the many points of difference will here be noted, taking as a typical example a **sewage pumping station.** The walls will be built of hard bricks, and an attempt will be made to give some architectural character to the exterior, usually by introducing projecting plinths, bands of blue or moulded brick, keystones into the arches, etc. The walls inside will probably be faced with glazed brick bonded into the other brickwork, or with glazed tiles set in cement. The roof may be lined with planed boards stained and varnished. As there will probably be no ceiling, the roof timbers where exposed to view will be planed, and supported upon steel roof trusses.

The windows may be of the factory type, consisting of steel frames of light section with projecting lugs built into the brickwork, the sashes—where these are required—being of steel also. These frames are made by various firms and are selected from a catalogue, being inserted in a contract as prime cost sums. Projecting angles will be finished in bull nose bricks. A plan of the machinery and piping to be erected in the building will be obtained as early as possible from the manufacturers of the machinery in order to decide on the position of such accessories as pipe ducts under the floor, support for overhead cranes, concrete engine beds, etc., which must obviously be arranged for before the machinery is installed.

Chimney Shafts

Chimney shafts are often required in connection with such schemes. The area of the shaft and the height are first calculated from considerations of the horse-power to be supplied by the station. The actual construction is usually based on certain empirical rules for thickness and diameter, such as those issued by the London County Council which prescribe the minimum thicknesses and external diameter. This diameter must be worked to if the horse-power calculations give a less amount.

The foundations must be carefully prepared. If there is time to obtain them or to have them manufactured, it is well to build the chimney of specially made radiating bricks to avoid wide outside joints. The top is finished either with a hollow cast-iron cap in segments, bolted together, or a stone coping cramped together, to avoid any danger of fragments dropping off. Such chimneys are usually lined inside with a separate skin of firebrick carried up about fifty feet, the connection with the flues being formed through heavily arched openings at the foot of the stack. Lightning conductors of copper tape are also fixed. and carried to an earth plate.

CHAPTER XIII

GENERAL DESCRIPTION AND PURPOSES OF CIVIL ENGINEERING WORKS

I. RAILWAYS

TRACK

ORDINARY railways in Great Britain are of standard gauge, *i.e.* 4 ft. 8½ in. measured between the inside edges of the head of the rails (slightly more on curves). The **rails** themselves are of *bull headed*—or double bulb—section, and weigh from 80 to 100 lb. per yard, the cross sections now being standardized in the British Standard Specifications.

The steel is somewhat similar to that for bridges and buildings, but with a rather higher percentage of carbon and, consequently, a greater hardness and tenacity. The rails are generally laid in 30 to 60 ft. lengths, and are supported in cast-iron **chairs** weighing 30 to 60 lb. each, which in turn rest on creosoted fir **sleepers** 8 ft. 10 in. × 10 in. × 5 in., to which they are spiked and bolted in various ways, according to the practice of each railway (Fig. 55).

The sleepers are spaced about 3 ft. apart—a little closer near the ends of the rails—and are bedded on **ballast** formed of about 12 in. of broken stone in large lumps or similar material, which in turn rests on the surface of the earth levelled off to receive it. The level of this earth is called **formation** level, and is thus about 2 ft. below the rail level or top surface of the rail. Between the sleepers is packed a layer of ballast broken to smaller size called the **boxing**.

The rails are fixed to the chairs by means of **keys** of hard wood or creosoted soft wood driven in as wedges by a special sledge hammer. The joint between the adjacent lengths of rail is kept open about $\frac{3}{8}$ in. to allow for the expansion of the rails in hot weather, and it is the English practice to make the joint between two sleepers and not over one of them in order to give it more elasticity. The ends are connected by **fishplates**, one on each side, bolted through the rail, the holes in the rail being slotted out oval to allow for the expansion and contraction due to changes of temperature. The rails, although bulb-shaped, are not intended to be reversible.

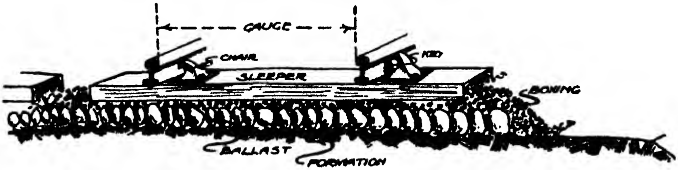

FIG. 55.—Part section of railway track on embankment.

In many countries the rails are of the **Vignoles**, or flat-bottomed type, laid direct on the sleepers. A flat bed is adzed for them, giving them a slight cant inwards, and they are spiked or bolted down, the ballast being sometimes omitted in pioneer railways. This is a cheaper form of construction, but the base of the rail does not spread the pressure on the timber to the extent which an ordinary chair does, and the rails are not so easily renewed.

Where rails are laid on a curve the sleepers are tilted down towards the inside of the curve to counteract the centrifugal tendency of the train. This is called superelevating the outer rail, and its amount is greatest for curves of small radius.

Where one track joins another a set of **points and crossings** is necessary, and these often become complicated where there are many tracks. The point itself consists of a pair of special movable rails, which are shaped down to a thin tongue, and pivoted at the heel. They are moved by a horizontal bar attached to a series of rods which run alongside the track to a signal box, where they are controlled by the signalman. They are also connected to the signal wires in such a way that when the points are closed against any particular track the signal for that track cannot possibly be set at "clear."

In designing a line of railway it is usual to specify **limiting gradients**, which must not be exceeded owing to the high working costs involved with steep gradients; and also limiting radii of curvature—for the flatter the curves the easier the running. At the same time, the formation width—the bed for the ballast—is decided. This is usually about 28 ft. in cutting and 30 ft. in embankment for double track, or 18 ft. and 20 ft. respectively for single track. When a new line is to be constructed the centre line is set out on the ground by pegs one chain apart, the curves being carefully set out by tape and theodolite to the required radii, the junction between curve and straight being eased off by a **transition curve** carefully calculated and set out. At the same time, pegs are put in showing the position of the fence on each side of the line, and also the top of the cuttings and the toe of the embankments, which must, of course, be inside the line of fence, usually about 6 ft.

The level of the line has been decided from a series of levels taken previously, in order to equalise the amounts of cutting and embankment as much as possible, paying due regard at the same time to the limiting gradient and the avoidance of tunnels. Where it is impossible or inadvisable to equalise the cutting and embankment, extra material if required is obtained from " borrow pits " opened near the line, and surplus material is dumped into " spoil banks." It is often cheaper, however, to tunnel rather than carry on an open cutting more than 40 ft. deep, though each case must be judged on its merits. The methods of carrying out **cuttings, embankments** and **tunnels** have already been given in Chapter VI. As a general rule the line will be laid out as direct as possible between the two points to be connected, but detours may be necessary to avoid obstacles.

BRIDGES

An important part of the engineer's duty is the location and design of the **bridges.** These are of two kinds, **underbridges** to carry the track over rivers, ravines, roads, etc., and **overbridges** to carry roads, canals or other railways over the projected line. In the case of underbridges, the requirements as to load to be supported are based on the weight of rolling stock employed, two of the heaviest engines followed by a train of coaches being usually taken for each track, this being in English practice reduced to an " equivalent " uniform load which will cause at least as severe stresses as the actual engines. This equivalent load is easier for calculation than the actual axle loads. Some allowance is always made for the " impact " effect of the load at high speed by means of one of the well-known " impact " formulae, and the stresses due to the load thus increased are calculated (see Appendix II). To these stresses are added the stresses due to the weight of the bridge itself, comprising main girders, cross girders, rail bearers, flooring, ballast, sleepers, chairs and rails. In addition, there are extra stresses to be allowed for, due to the pressure of the wind sideways on the bridge, not only on the girders but also on a passing train.

The type of bridge to be built is determined by various considerations. Where the span is less than 75 ft., solid web plate girders are generally employed; for spans greater than that, open web or lattice girders are usually cheaper.

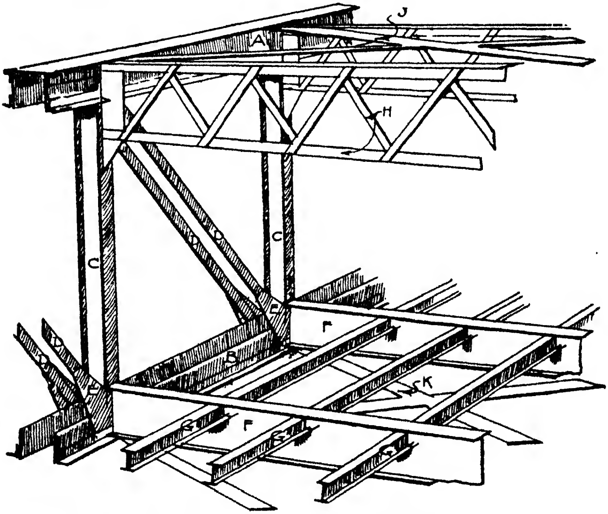

FIG. 56.—Perspective diagram of large through bridge.

(A) Upper boom.
(B) Lower boom.
(C) Strut.
(DD) Ties.
(E) Gusset plates.
(F) Cross girders.
(K) Lower lateral bracing.
(G) Rail bearers.
(H) Portal bracing.
(J) Upper lateral bracing.

Where the bridge comes over a road or river it is generally important to obtain as much headroom as possible under the bridge, and at the same time to keep the rail level low in order to avoid steep approach gradients. This means that the bridge must not be deep, and the best form is the **through bridge** (Fig. 56), in which the flooring and track rest on the lower flanges of the main girders. Where the question of headroom is not important, the flooring may rest on the upper flanges of the girders, this giving the cheaper form of **deck bridge** (Fig. 57), although with this form light parapets must also be provided. Over a wide river the cost of a long bridge, which increases very rapidly with the span, may be reduced by introducing one or more intermediate piers, the actual design depending on the relative costs of piers and girders. The abutments are of brickwork or masonry, and "wing walls" are sometimes necessary to keep the approach embankment from falling forward under the bridge.

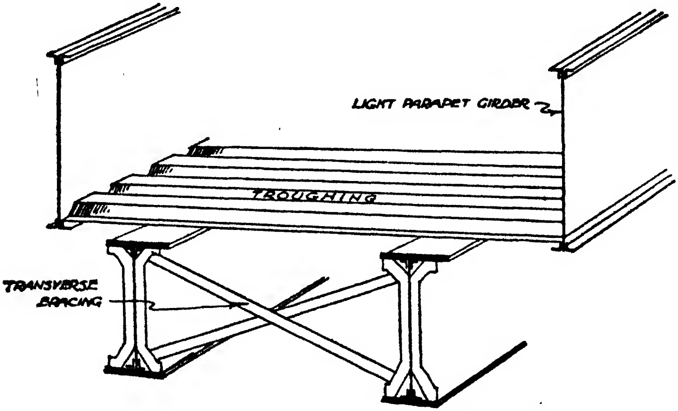

FIG. 57.—Perspective diagram of small deck bridge.

The bearings of the girders on the abutments are usually formed of cast-iron bed-plates bolted down to girder **bed-stones** of granite or York stone. The bed-plates are planed smooth and lubricated, to allow for the change in length of the girder due to an alteration in temperature, the sliding taking place between the bed-plate and a flat steel plate riveted on to the lower flange of the girder, called a **bolster plate.** In large spans the bed-plate is formed of a steel casting provided with a knuckle which will allow of the surface tilting a little as the girder bends under the load. Without this knuckle, when the girder is deflected, the pressure on the bed-plate, and so on the bed-stone, becomes concentrated severely on the inside edge. Bed-stones are usually chamfered on that edge, the actual bearing in that case being nearer the centre of the stone. In large spans the bed-plates at one end are made to rest on rollers to allow for expansion and contraction.

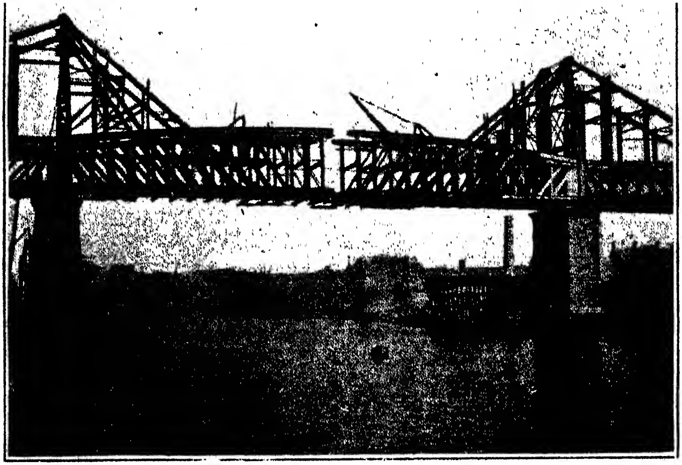

FIG. 58.—Open web through bridge over River Wear, at Sunderland, before completion, showing temporary inclined ties used for erection only.
Engineering, 23rd October, 1908.

The construction of the flooring varies according to circumstances. The cheapest form is to lay cross girders between the main girders, spaced about 8 ft. apart, and on these to fix longitudinal rail bearers of rolled steel joists, one under each rail. The rails are bolted on to longitudinal sleepers, which in turn are bolted to the rail bearers. This, which is known as a skeleton floor, is not in favour in Great

Britain, and the more usual practice here is to cover over the whole floor by means of steel plates riveted to the tops of the rail bearers. These plates may be either flat, or slightly arched between the rail bearers, or "buckled," *i.e.* dished in two directions like an inverted saucer. The flooring is then covered with ballast, the lowest three inches being mixed with asphalte to form a watertight concrete, which protects the upper surfaces of the plates from corrosion. On this ballast the sleepers are laid in the usual way. There is thus no interruption in the continuity of the track.

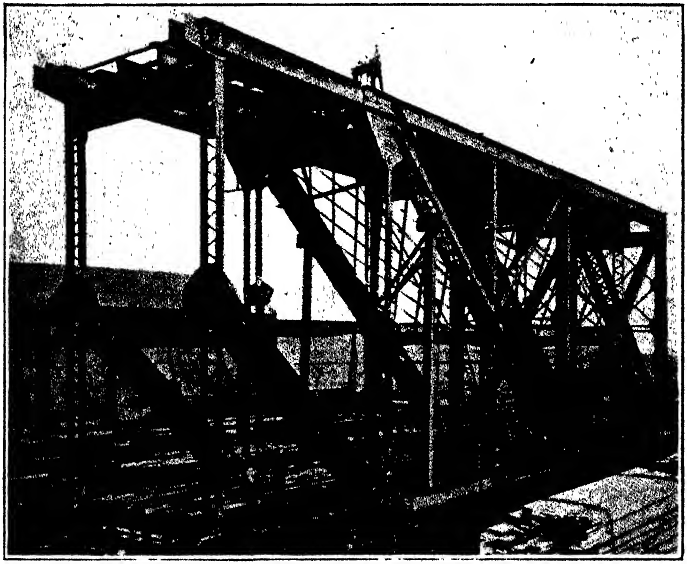

FIG. 59.—Large through bridge in course of temporary erection and fitting in yard, showing pin and riveted joints.

[*Engineering*, 22nd February, 1907.

Abroad, where timber may be obtained cheaply, railway bridges are often constructed of such material framed up with steel tie rods into various forms of truss, the flooring being also constructed of timber beams.

Where the span is more than 150 ft. it may become more economical to employ an **arched truss** if good abutments can be found to resist the outward thrust, and for very long spans suspension bridges or cantilever bridges are common. **Suspension bridges** are unsuitable for small spans on account of their flexibility; in large spans the total dead-weight is so large that the moving load has little effect. **Cantilever bridges** have most of the weight of the steelwork itself concentrated over the piers where it does not cause severe bending stresses, and this reduces the total weight of the bridge.

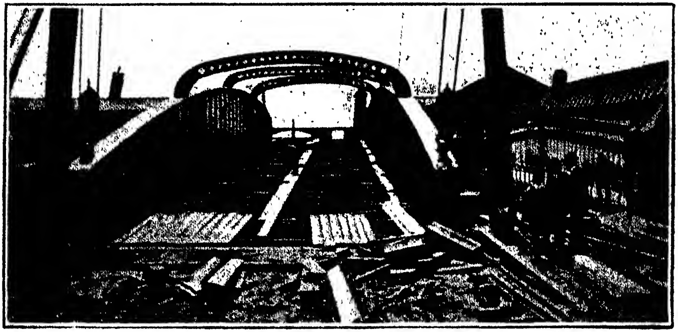

FIG. 60.—Hog backed plate girder through bridge with decking removed.

[*Engineering*, 20th February, 1914.

Continuous girders are sometimes used over a series of spans. They are so constructed that they can resist the tendency to arch themselves over the piers, and they may then be made lighter than would be necessary for a series of detached girders merely abutting at the piers without any connecting members. Their greatest disadvantage is that any slight settlement in one of the piers entirely alters the distribution of stress in the girders, and they are not much favoured in consequence.

The erection of bridges is often a troublesome problem, and is usually arranged by the manufacturers in Great Britain. Girders are often erected on shore at one end, and either rolled forward over temporary piers into position, or floated out on pontoons until they are against the piers, and then jacked up to the required level. Suspension bridges are obviously easy of erection. Cantilever and large arch bridges are usually built out from the piers member by member until they meet at the centres of the spans. The stresses caused in the members during erection are often quite different from those caused by the dead and live load when completed, and they have to be carefully computed and allowed for (Figs. 58-64).

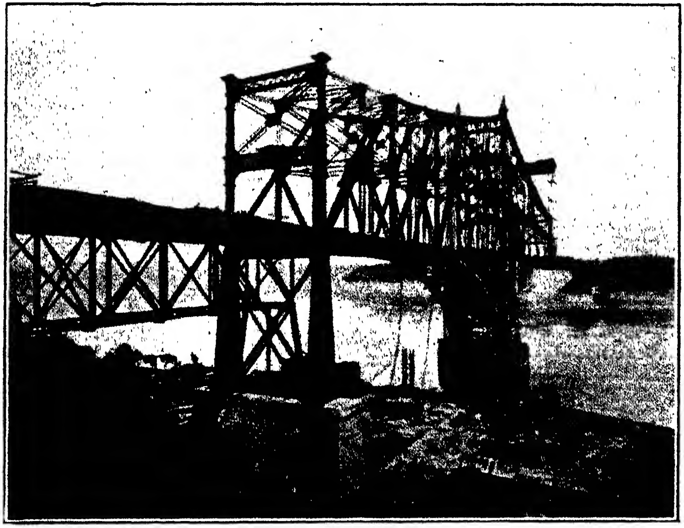

FIG. 61.—Cantilever bridge over the St. Lawrence during erection.
[*Engineering*, 6th September, 1907.

Railway bridges over rivers are often required to provide for the passage of ships under them, by means of opening spans. The commonest form is the **swing bridge** with a central pier on which is balanced a double cantilever. This is rotated horizontally by electric or hydraulic machinery, the pivot consisting of a large steel pin, the weight of the bridge being taken by a circular track of hard steel rollers. Other forms are the **bascule bridge** with one or two leaves rotating on a horizontal pivot like the mediaeval drawbridge, one modification of this being the **rolling lift bridge**, in which each leaf rolls back on a quadrant instead of rotating on a pivot. **Floating bridges** are simply large flat boats in principle which are hauled across the river by power, leaving a clear passage except for a guide cable which lies on the bed of the river. **Transporter bridges** are built with a high tower on each side of the river. These towers are connected near the top by a girder or a stiffened

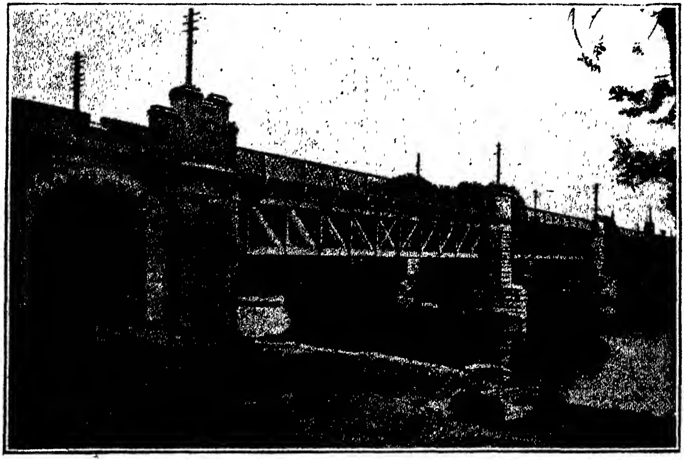

FIG. 62.—Open web deck bridge, Caledonian Railway.
[*Engineering*, 4th December, 1908.

suspension bridge, on which runs a carriage. From this carriage is suspended a small platform at the ordinary road level, and this is caused to travel backwards and forwards over the river, leaving a clear passage for vessels up to the height of the supporting girder. Floating and transporter bridges are, however, only used in exceptional cases for railways. They are more suitable for road traffic.

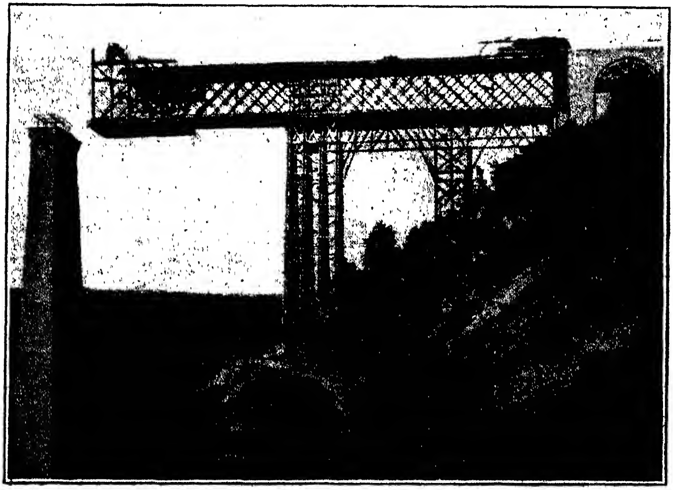

FIG. 63.—Erection of tall viaduct girder on Paris–Orleans Railway, showing tall masonry pier and temporary trestle piers for erection.

[*Engineering*, 31st December, 1909.

Where a railway crosses a wide and deep valley embankments are sometimes formed up to a depth of about 50 ft. Beyond that depth it may be more economical to carry the line on a **viaduct**, that is, a series of small bridges on masonry or brickwork piers. These small spans may be brick or concrete arches, or steel or reinforced concrete girders. The commonest type is perhaps the brick arch of 40 to 50 ft. span, with six to eight rings of brickwork on brick piers of a thickness between $\frac{1}{6}$ and $\frac{1}{7}$ of the span, every sixth pier being sometimes made thicker to resist the thrust of the arches, if one should give way or be taken down to be repaired. In some countries a very common form for deep valleys is the trestle viaduct (Fig. 64). The piers are composed of skeleton trestles built of tees, angles and flat bars connected at the top by ordinary plate girders.

Bridges over a railway are, as already stated, called overbridges, and their chief points of difference from underbridges are that the span is usually small, but that the loads they have to sustain vary largely according whether they are for roads, canals, or other railways. The commonest form is the brick arch or brick abutments to carry an ordinary highway. The loads to be carried are determined by the highway authority—town, county, or rural council—and the bridge is designed accordingly. If the road crosses over the railway at right angles the span will be about 13 ft. over single track, 24 ft. over double track,

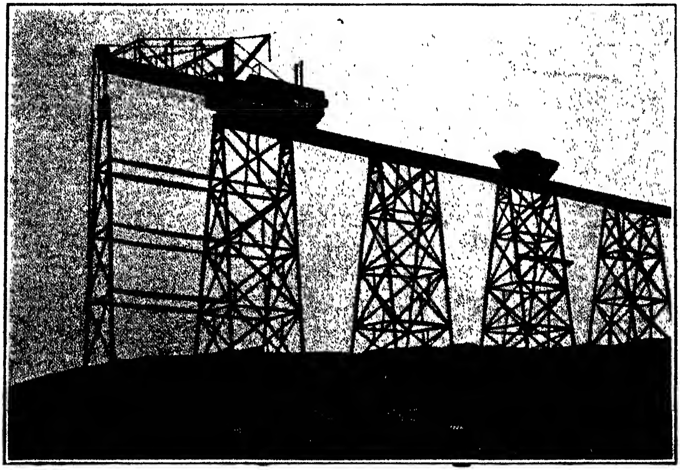

Fig. 64.—Canadian trestle viaduct in course of erection.

[*Engineering*, 24th September 1909.

and the clear headway about 16 ft. at the centre, above rail level. The arch is usually segmental, of a rise about $\frac{1}{8}$ span, the thickness of the arch being $\frac{1}{18}$ of the span.

Where the road crosses the railway at an angle a **skew bridge** is necessary, and the span is increased. A skew arch is rather more difficult to build than a square one. The courses of bricks or stones are necessarily perpendicular to the face of the arch, as otherwise the end brick of each course would have only a partial abutment, and since the courses must be parallel and of even width it will be found that they take a spiral curve over the inner surface of the arch, and come down to the springing at an angle (Fig. 65). There they are cut off to fit the level springing, or special spring stones are laid—called **skewbacks**—which are shaped to receive the ends of the courses fairly. The arch is built in the usual way on close boarded centres, on which the lines of brickwork, or masonry, are carefully set out before it is begun, as a guide to the bricklayers or masons.

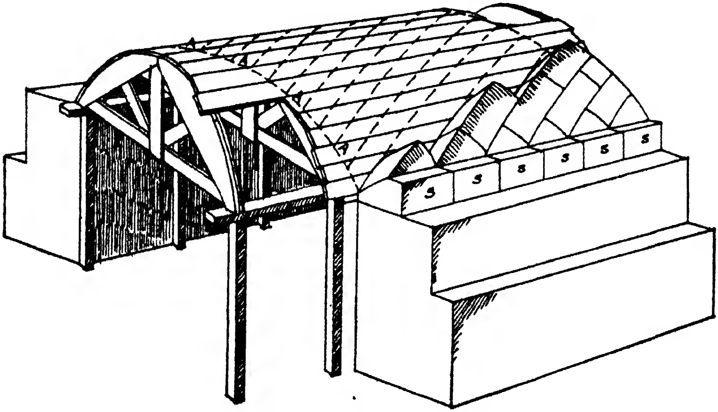

FIG. 65.—Arrangement of courses in skew arch.
(AAA) Face line of arch. (SSS) Springers, cut to form skewbacks.

Where girder bridges are constructed on the skew, the cross girders are still run at right angles to the main girders, with the result that some of the cross girders near the ends are shortened, each resting at one end on the abutment and at the other on the main girder. This means that the loading on each main girder is not quite symmetrical. The flooring system of overbridges for roads is somewhat different from that for bridges carrying railroad track, and will be dealt with in the section devoted to roads.

TUNNELS

Tunnels are necessary in railroad construction when the cost of open cutting becomes too great, or where open cuttings are forbidden, as in a large town, on account of their permanent interference with the roads and traffic. In the latter case, they may often be economically constructed in **cut and cover**, that is, an open cutting is made in which the tunnel is constructed, the side walls being built and the top covered in either with an arch or with girders and concrete. The earth is then filled back over the tunnel and the surface made good. Ordinary tunnels, however, have to be driven as described in Chapter VI, either from the ends or from intermediate shafts. Their shape varies, being often straight-sided in rock with roof arch ; nearly elliptical with the long axis vertical in ordinary soil ; and circular in wet clay (Fig. 18). They are usually lined with brickwork, and at intervals recesses are constructed in the walls as refuges for the platelayers. The intermediate shafts are also lined with brickwork, a small round house being erected at the top to act as a ventilator and for protection of the public.

Railways are sometimes constructed for lighter rolling stock, and are often laid on ordinary highways. These are known as **light railways**, and they are usually of narrower gauge than the standard. They are not common in Great Britain. **Mountain railways** are also constructed to ascend slopes so steep that the frictional adhesion of the wheels to the rails is insufficient to prevent slipping. The grip is augmented either by having a pair of central wheels gripping tightly both sides of a central rail—the "Fell" system—or by having a toothed rack in the centre into which a pinion under the body of the engine gears.

II. ROADS

When a road has to be constructed over virgin country, its centre line is first pegged out as for a railway, paying due regard to limiting gradients and curves. For ordinary horse-wheeled traffic the gradient should not ordinarily be more than 1 in 10. In this case, however, curves may be of almost any radius. For motor traffic flat curves and gradients are required, but there are as yet no generally accepted figures for these in common use, although standardized practice will no doubt be evolved by the Ministry of Transport. The width of the road—the **carriageway**—is generally made some multiple of 9 ft., that being the width required for one line of ordinary wheeled traffic, and in towns the footways are each made about a quarter of the width of the carriageway.

The first work to be put in hand is the culverting of the streams crossing the line of the road, and the erection of small bridges. Where the road crosses level or low-lying land, parallel ditches are dug along the sides, commencing at some watercourse at the lowest point so that the ditches may drain themselves. The excavated material is thrown on to the road, thus raising its level, and the surface is rolled to a slight **camber**. A foundation is then laid of large stones—where these are available—or of any other hard material which can be obtained, such as clinker, coarse gravel, hard bricks, or even burnt clay, to a depth varying with the nature of the traffic to be expected from 6 in. to 12 in., and this is also rolled to an even surface. On the foundation is laid the wearing coat of broken stone, flints or gravel, 4 in. to 6 in. thick, which is also rolled, a quantity of clayey sand being spread and watered at the same time as " binding " material to aid in the consolidation of the wearing coat. This surface is known as **waterbound macadam** (Fig. 66). It has become evident of recent years that waterbound macadam—even when made of the best material, viz. broken granite, and well rolled with a steam roller—will not withstand the sucking action of rubber motor tyres, and it is now being gradually replaced by the better but more expensive material, **tar macadam.** In this form of construction, the wearing coat is composed of broken stone—granite, limestone or blast furnace slag—mixed with gas tar before being laid to form a kind of concrete, or laid dry, the tar being poured over it, another layer of stone being applied and the whole rolled solid.

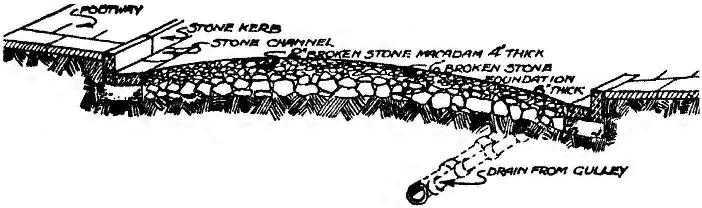

FIG. 66.—Section of macadamised town road with paved footways.

The tar referred to is the ordinary black coal tar obtained from gas works, or oil tar from the refining of crude petroleum, sometimes mixed hot with melted coal tar pitch to thicken it. There are also on the market forms of natural **bitumen** or mineral pitch mined in a natural state, and used for thickening the tar in the same way as pitch. They are much better than coal tar pitch for this purpose, but are also more costly. The tar is usually made up to comply with requirements of the British Road Board Specification —now the Ministry of Transport Specification—as regards viscosity and composition. Many country roads are now constructed of ordinary waterbound macadam, which is allowed to consolidate for a while and is then sprayed with prepared tar. This forms a thin coating, which is dusted with granite chips, sand, or road sweepings in order to prevent it from adhering to the wheels of vehicles.

Town roads are usually paved, either with granite setts for very heavy traffic, or with local stone, wood blocks or asphalte for lighter traffic. In each case a concrete foundation is laid over the whole road bed, curved to the required camber, of a thickness ranging from 6 in. to 12 in, according to the severity of the traffic. On this **granite setts**—roughly squared blocks of hard granite about 9 in. × 6 in. × 3 in. are laid on edge on a bed of about an inch of sand or sifted ashes in regular courses across the road, and the spaces between the setts are run with melted pitch to form a joint. **Wood blocks**—which may be of hard wood, usually Australian karri or jarrah, or of creosoted deal, 9 in. × 5 in. × 3 in.—are laid in the same way, the grain of the wood being vertical and showing its end on the road surface. As wood expands and contracts according to the weather, an open joint of about an inch is left against the kerbstone, and filled in with clay. **Asphalte** is a natural rock mined in Switzerland, France and Germany. It is a limestone impregnated with bitumen, and when crushed and heated it can be laid as a powder about 2 in. thick direct on a concrete foundation, and rolled and rammed with heated tools. This causes it to consolidate and form a resilient covering, which is without joints and therefore very sanitary.

Footways, yards, and concrete roofs which are not exposed to wheeled traffic are also covered with asphalte to which extra mineral bitumen has been added. When heated, this "mastic" asphalte, as it is called, becomes soft and can be spread without ramming. It is usually made gritty by the addition of a quantity of sharp sand where much traffic is expected. Other materials for the paving of footways are natural stone **flags** bedded on mortar, fine gravel laid and rolled as for roads, fine tar macadam——sometimes but erroneously called asphalte—artificial flags made of concrete, and occasionally specially hard paving bricks.

In America both concrete and bricks are used as wearing surfaces for carriageways, but they have yet to be tried on an extensive scale in this country.

Roads which are divided into footway and carriageway usually have a **kerbstone** fixed at the edge of the footway, which raises its level above the adjoining carriageway, and against the kerbstone on the carriageway side is laid the **channelling**—of stone setts, concrete slabs or brick blocks—which prevents the wash of rain water from undermining the kerb. At intervals gullies are inserted in the channel which connect by means of drain pipes either with the sewer or with the roadside ditches in order to get rid of the rain water. The gullies may be of cast iron—patterns may be seen in the catalogues of ironfounders—or in the form of brick chambers.

ROAD BRIDGES

Road bridges may vary in size from a simple culvert over a brook to enormous suspension bridges, such as the Brooklyn Bridge at New York. The smaller ones are generally built in the form of brick arches, and the rules for thickness, etc., already given for railway overbridges may be applied. Reinforced concrete, however, will probably eventually supersede brick arches in this connection. Larger spans may be constructed of steel plate web or open web girders as for railway bridges (Fig. 67).

Road bridges are usually designed to carry either an overall load due to a dense crowd—about 100 lb./sq. ft. of surface covered—or one or two heavy traction engines with specified axle loads, placed in such positions that they cause the most severe stresses on the members of the bridge. It is important to remember that when dealing with an evenly distributed load, such as that due to a crowd, the stresses on the webs of the main girders near the centre of the span are most severe when the crowd does not extend over the whole span of the bridge. Since the live load on a road bridge may be in almost any position on the bridge and is not confined to tracks, the flooring system is rather different from that designed for supporting railroad tracks. It usually consists of some form of **steel troughing**—different forms are made by the large steel firms—covered in with cement concrete, which fills the troughs and provides a foundation for the paving. In narrow bridges the troughing may span between the main girders, the corrugations running across the bridge. In wider ones cross girders are used, the troughing running longitudinally. Allowance is made as in the case of railway bridges for " impact " effect but to a reduced extent. Stresses due to wind are also allowed for in the same manner.

An old form of flooring which is still used for railway overbridges carrying roads, is that consisting of cross girders spaced in the usual way, with smaller longitudinal girders between them about 2 ft. 6 in. apart, between which are built long barrel arches of brick, termed **jack arches** (Fig. 68). These are covered over with concrete, which forms the

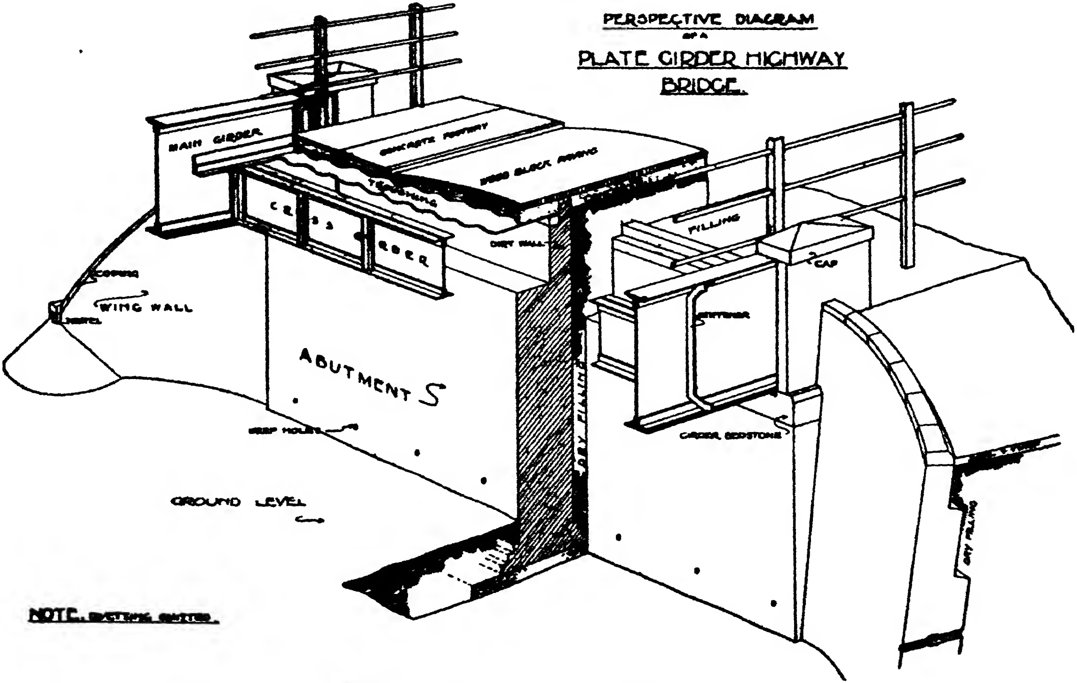

Fig. 67.—Dissected diagram of highway bridge.

foundation for the paving. It is probable that slabs of reinforced concrete will eventually supersede some of the other systems of flooring for road bridges.

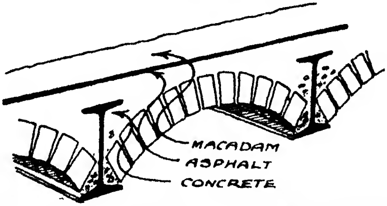

FIG. 68.—Jack arch construction for highway bridge flooring.

TRAMWAYS

Tramways are laid in Great Britain so that the upper surface of the rails is flush with the paving of the roads. This has necessitated a special shape of rail formed with a groove in its upper surface, in which the flange of the wheel runs. The rails are flat bottomed and laid on a substantial bed of concrete, their distance apart being fixed by tie bars with screwed ends. The cross sections and weights of the rails are standardized by the British Engineering Standards Association. The steel for the rails is similar to that for

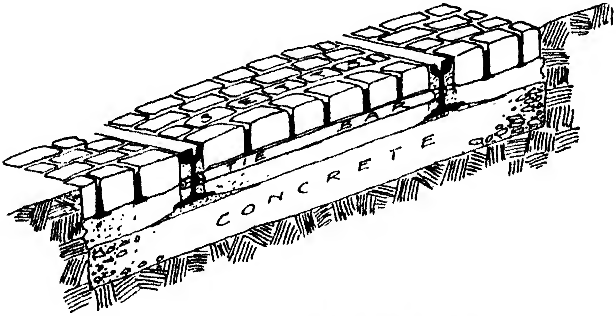

FIG. 69.—Section of tramway track and paving.

railway metals, and points and crossings where hard wear may be expected are now made of a specially hard steel containing manganese. Their manufacture is a speciality of certain steel firms. Tramway companies are by law compelled to pave the road between the tracks and for a distance of 18 in. on each side, and the Board of Trade, before a system of tramways is inspected and passed, requires certain regulations as to insulation and support of trolley wire—in the case of overhead electric systems—maximum speed, etc., to be complied with.

Most tramways in Great Britain are operated by electric power, generated at a central station and taken along the route in underground cables. At certain points these cables are connected to the **trolley wire.** The wire consists of a solid copper rod about $\frac{3}{8}$ in. diameter, suspended about 18 ft. above the track sometimes from bracket arms projecting from upright steel tubular poles firmly fixed in concrete either at the sides of the road or in the centre between two tracks, and sometimes from stout steel wire cables stretched between two such poles across the roadway, or, in some cases, between points of attachment fixed to buildings. Where the line passes around a curve it is constrained to follow the curve by having attached to it special "pull off" wires taken to straining poles. There must be no direct metallic communication between the trolley wire and the earth, and so all connections are insulated. The trolley wire requires points at junctions just as the track does. These are operated by a cord, and are called **frogs.**

The electric current is collected from the trolley wire by the pulley at the end of the trolley arm on the car travelling along it, passes along a cable in the centre of the arm to the motors, then through the car wheels to the rails and so back to the generators, to which the rails are electrically connected. It is important that the rails should be electrically continuous, and at the joints short lengths of thick copper strip, stranded cable, or rod are used for this purpose, called **rail bonds.** At intervals also the rails are similarly bonded across the track.

On many systems the rails are connected together by fishplates and bolts similar to those in use on railways. On others the rails are welded together solidly, either by the use of a high temperature electric arc, or by casting a mass of molten iron around the joint by the patented "Thermit" process. No provision is thus made for the expansion and contraction of the rails due to changes in the temperature, but it is found that the stresses so induced are not too severe for the metal to withstand, although trouble may be caused by the rails lifting from their bed.

The general arrangement of points and crossings is similar to that adopted for railways, with the exception that in many cases, *e.g.* at the entrance to a passing place, or short length of double track in a single track route, the points are required to throw always to the left when acting as "facing" points, and are set automatically in that position by a spring. This spring allows the switch to be forced open by the wheels when the same points act as "trailing" points to a car running in the opposite direction, and again close it in the correct position when the car has passed.

III. MARINE WORKS

Facilities are required on a coast for three main purposes: (1) for protecting ships in stormy weather, (2) for taking on board and discharging cargo and passengers, (3) for examining and repairing vessels. For the first purpose, natural roadsteads and harbours are made use of so far as possible. A **natural roadstead** is not a harbour in that it is either exposed to the full force of the waves or only partially protected by an island, its recommendation being that it possesses good holding ground for anchors. **Harbours**, on the other hand, are more or less landlocked, the water inside them being comparatively calm. Where natural harbours have to be improved or created, protection from the sea may be increased by the formation of a **breakwater**, either detached, almost covering the entrance to the harbour, or projecting from one side like an encircling arm.

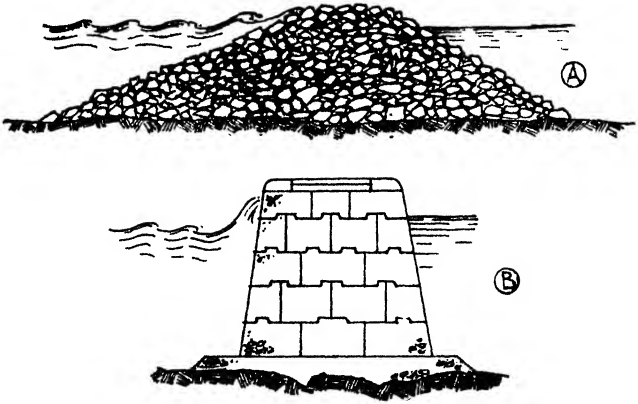

Fig. 70.—Breakwaters.
(A) Random blocks. (B) Joggled concrete blocks.

The commonest form of breakwater is the long mound of large rocks or blocks of concrete deposited by scows or lighters at random along the proposed line (Fig. 70A). These random blocks are allowed to lie pell-mell in a heap with sloping sides, the size of the blocks being too great to allow them to be moved by the waves, the disturbing effect of which may reach to 30 ft. below water level. The breakwater is finished at such a level that it only just shows at low spring tides, and is usually covered by water.

The **tides** around our coast rise and fall twice every twenty-four hours, the difference between the levels of high and low water being called the **range.** This range is constantly changing, being greatest at the time of spring tides which occur every fortnight, and least at the time of neap tides, which also occur every fortnight midway between the spring tides. For engineering purposes it is usually important to know the highest and lowest levels which may be expected, apart from the exceptional tides which may be caused by heavy gales, and these are marked on the drawings as H.W.O.S.T. or L.W.O.S.T. (high water or low water ordinary spring tides).

The engineer has also often to carry out works for the protection of a foreshore which is suffering rapid denudation from the sea. This may be effected either by the construction of a **sea wall**—similar to a small quay wall, except that the face need not be so nearly vertical—or by means of **groynes,** which are low obstructions of planks or sheet piling running at intervals across the shore from high to low water mark. These arrest the slow lateral drift of sand and shingle which is usually taking place on an exposed shore, and cause it to heap up and act as a protection to the land farther inland. The correct placing of groynes requires an intimate knowledge of the prevailing winds and currents.

The designing of **lighthouses,** whether on the mainland or on isolated rocks, or of **beacons,** which are small lighthouses not arranged as residences but attended to from the shore, is a specialized business which is not likely to fall to the lot of the ordinary civil engineer and will not be dealt with here.

QUAYS, WHARVES, PIERS, JETTIES

When a breakwater runs out from the shore it is often economical to use it as a quay for the loading and unloading of vessels. In such a case it may be built in a similar manner to a breakwater, but finished well above high water with a solid wall of concrete or masonry, or it may be built from the foundation with vertical or slightly battered faces. Such walls contain less material than ordinary breakwaters, but have to resist very heavy wave pressures, the amount of these depending to some extent on the "fetch" of the sea on their seaward faces, *i.e.* the extent of open water. The blocks are usually deposited by a Titan crane (Figs. 71-72).

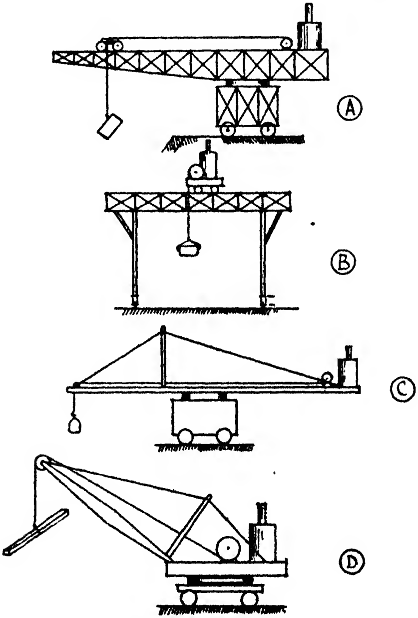

FIG. 71.—Types of cranes for heavy work.
(A) Titan. (B) Goliath. (C) Hercules. (D) Jib crane.

Where harbours of the preceding types are created, a demand usually develops for loading and unloading facilities, which means in the first place the construction of wharves, quays, piers or jetties. **Wharves** are essentially platforms running along the shores of the harbour, against which ships can lie, being moored by cables stem and stern to stout uprights or bollards. They are usually constructed of skeleton framing in timber, reinforced concrete, or steel (Fig. 73). Piers and jetties are similar, except that they project at right angles to the shore, and thus give more space alongside which vessels can berth. Quays are similar to wharves, but are formed of solid walls of masonry or concrete (Fig. 74). In the case of shallow harbours provided with only small wharves, quays or jetties,

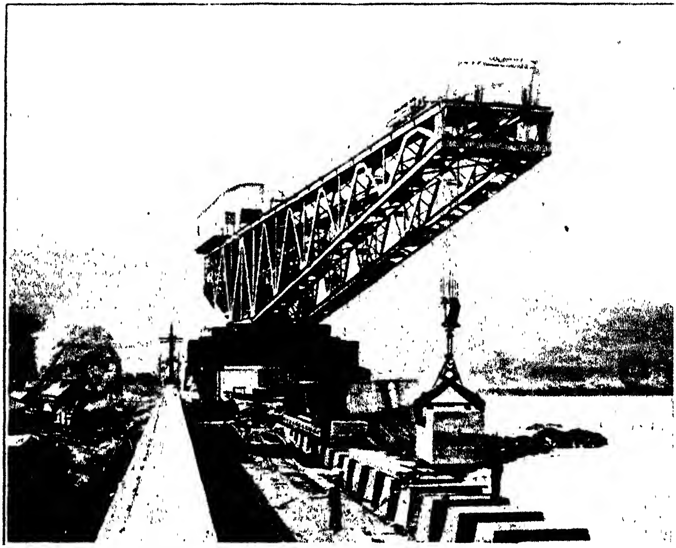

FIG. 72.—Titan crane setting concrete blocks slung in nippers.
[*By courtesy of Messrs. Stothert & Pitt, Ltd.*

large vessels must lie off in deep water and transfer their goods to lighters, which then unload at the quay side.

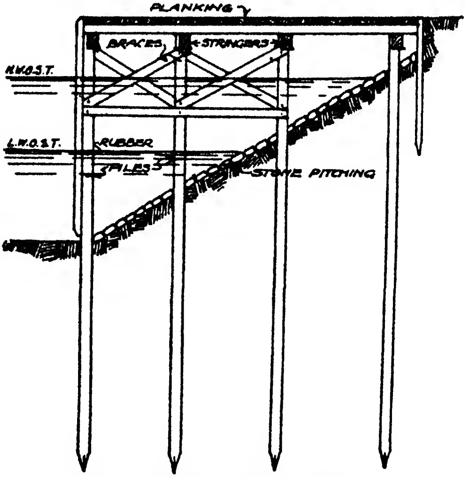

Fig. 73.—Section of timber wharf.

Quays are often arranged around a small subsidiary artificial harbour with a very narrow entrance, which is then termed a basin, or **tidal basin.**

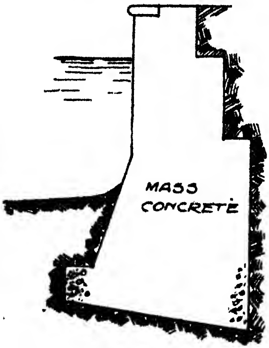

Fig. 74.
Section of concrete quay wall.

Piers and **jetties** in exposed situations are often planned with T-shaped heads to provide a lee berth for vessels with any wind. They are usually of some form of skeleton construction on piles, either timber, reinforced concrete, or cast-iron or steel screw piles, braced together with steel tie rods. **Wharves** are of somewhat similar construction, the simplest form being a single row of king piles driven along the foreshore, with horizontal walings bolted to them, behind which are driven runners of 9 in. × 3 in. planking. This is often called " camp shedding " or " camp sheeting " (Fig. 75). The tops of the king piles are tied back by long steel rods to masses of concrete 30 or 40 feet back embedded in the ground, or to short piles firmly driven. Earth is then filled up against the planking, and a vertical or almost vertical face is thus formed, against which vessels can lie for unloading. Stronger forms of wharf consist of double or triple rows of king piles connected at the top by decking which is used as a loading platform.

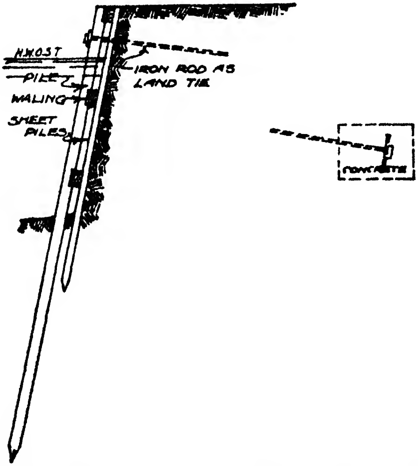

FIG. 75.—Section of wharf constructed of " camp sheeting."

Quay walls are of massive concrete construction designed to resist the thrust of the earth behind them, which is often waterlogged (Fig. 74). They are often faced with granite and finished with a heavy granite coping. Their construction is usually a difficult problem owing to the depth to which the foundations must be carried and the presence of large volumes of water in the soil.

Docks

It is found that the fluctuation of the tides and consequent rise and fall of the vessels interferes with the operations of loading and unloading, and therefore basins are often constructed with a narrow entrance which can be closed by heavy watertight gates. This is called a **wet or floating dock**—not to be confused with the " floating dry dock " to be described later. At high water vessels enter the dock, and the gates—which open inwards—are shut. This keeps the water level constant in the dock while the tide falls outside. The gates are so constructed that the pressure of water against them keeps them tight. They can only be opened when the tide outside rises again.

In order to allow vessels to enter or leave between times of high water, a **lock** is often constructed at the entrance to the dock. This consists of a chamber with gates at each end, one pair opening into the dock, the other pair into the open harbour. When a vessel is to enter the dock at low water, the outer gates are opened, the level of water in the lock being the same as that in the harbour outside. The vessel is towed into the lock and the gates are closed. The lock is then gradually filled with water by opening sluices communicating with the dock inside, until the level in the lock is the same as that in the dock, the vessel, of course, rising at the same time with the water. The inner gates of the lock are now opened so that she can proceed into the dock. Another vessel can now be towed from the dock into the lock, the inner gates closed, and the water in the lock allowed to escape through sluices into the harbour outside, the level gradually dropping until the outer gates can be opened and the vessel towed out. Obviously a certain amount of water is abstracted from the dock each time, but this does not lower the level unduly.

Facilities for examining and repairing the hulls of vessels are provided in various ways. For small vessels a timber framework or **grid** is occasionally constructed on the foreshore at low water. This is submerged at high water, and a vessel can be floated over it and allowed to settle as the tide falls, leaving her dry at low water. Another method for small vessels is to construct a long sloping platform called a **slipway**, running from above high water across the foreshore to about low water mark. On this is fixed a light railway track fitted with a specially shaped cradle on wheels. At high water the vessel is floated over the cradle and allowed to settle on it. As the water drops and the cradle bears the full weight of the vessel, it is hauled slowly up the slipway by a rope fixed to a winch at the top until it rises above high water mark.

Larger vessels are examined and repaired in what are known as **dry** or **graving docks.** Such a dock is simply an enormous lock with only one entrance, usually opening out of a wet dock. Water is allowed to enter the dry dock until its level is equal to that in the wet dock. The gates are then opened and the vessel is towed or pushed inside. The gates are again closed, and powerful pumps are set to work to empty the dry dock. As the water level falls the vessel sinks until her keel rests on a row of special keel blocks down the centre of the dock. As the water falls still further, she is kept upright by long timber struts against the side of the dock, until the dock is quite empty, and the hull can be examined at leisure. After the vessel is repaired water is admitted to the dock until she floats, the struts are taken away and the dock gates opened.

Another form of dry dock, called the **floating dry dock,** is composed of a large chamber formed of two skins of steel plating in the form of a rectangular box, which can be floated under a vessel. Water is then pumped out from the space between the two skins, which are of watertight construction. The box rises, bringing the vessel with it, until the floor is above the water level and the vessel is exposed to view. The construction of such docks is rather the work of the naval architect than the civil engineer.

Dry dock walls are of similar form to quay walls, except that they are constructed with stepped faces. These steps are known as **altars**, and hold the ends of the shores or struts which keep the vessel upright. The gates, which are in two halves or leaves, if of timber are usually constructed in greenheart, and each leaf consists of massive vertical heel and meeting posts with horizontal beams framed between and close caulked sheetings of planks. Steel gates are formed of two skins of plating with a stiffening of girders. Gates may also be formed of steel plate cellular caissons, which are rolled or floated into position at the entrance when required and sunk into grooves cut in the stone, where they make a watertight joint. The construction of the stonework around the gates which takes the thrust of the water needs to be carried out with great care.

IV. WATERWORKS

The engineer has to deal with the collection, storage, conveyance and distribution of water for domestic purposes, for fire prevention and for power purposes. The water is obtained in various ways. For small supplies it may come from a **shallow well**. The water in this case is variable in quantity according to the season, and is often unsafe for drinking purposes owing to the possibility of sewage soaking into the well. **Deep wells** are better in both respects, deep wells in the technical sense being those which, although sunk from the surface, have to pass an impervious stratum or to a considerable depth before the water is reached. Deep wells are used for town supplies in many cases, particularly in chalk. The supply from these wells is pure but the water is hard, that is, soap does not readily form a lather with it. For small supplies the deep well may be a simple borehole, say 6 in. or 9 in. in diameter, lined with thin steel piping until the water-bearing stratum is reached. Larger supplies are obtained from wells dug and lined with brickwork or concrete in the usual way. Water obtained in this way must be pumped.

PUMPS

In the case of boreholes, special **borehole pumps** are used consisting of a small bucket and plunger fitted with a non-return " clack " valve. This is lowered down the borehole until it is immersed, the delivery pipe being screwed on length by length as it is lowered. The plunger is worked by vertical rods of steel or wood, which extend from the ground level—where they are worked by a rocking lever driven by an engine—to the plunger below. In the case of large wells the commonest type is the three-throw pump fixed to a framework of girders at the water level, with three plungers working at intervals, delivering a steady stream. Air vessels are required on the delivery mains—usually called rising mains—and sometimes on the suctions, in order to equalize the discharge, which with pumps of this type is intermittent, and to prevent bursting due to shock. Reflux valves, which are simply flap valves opening forwards, are also useful to prevent the water from running back to the pump if a leak should develop.

In some cases the **air lift pump** is employed, in which a large pipe is let down the well, containing another rather smaller, both being well immersed in the water. Down the central pipe is pumped compressed air, which bubbles out at the bottom and rises in the annular space between the two pipes, lifting a certain quantity of water with it, which discharges at the top. Although not very efficient, the air lift has the advantage that there are no moving parts down the well, and that it can deal with water containing silt.

For large quantities and low lifts the **centrifugal pump** is employed, as well as **direct acting pumps** of the Worthington type; while for high lifts **turbines** may be employed. Although the selection of the type of pump and the testing of its capacity and steam consumption often devolve upon the civil engineer, the actual design is done by the manufacturer, who usually gives guarantees in his contract with regard to efficiency and duty.

RESERVOIRS AND DAMS

Water is also obtained in large quantities by impounding a **catchment area.** This usually means throwing a dam across a valley and so forming a lake, the water being obtained from all the streams which drain into the valley above the dam. The amount of water available depends on the area which drains into the lake, and this is ascertained by careful survey with levels. If the annual rainfall be known, the total amount of water may be calculated. From this must be deducted an allowance for water which soaks into the soil and is never recovered, and also for that lost by evaporation from the catchment area and the lake, the two together often accounting for 50 per cent. of the original amount. Moreover, the water which is impounded in the lake or reservoir is not all available for supply. A certain amount—it may be one-third of the total—must still be allowed to follow its old course down the valley as compensation water for the benefit of landowners and occupiers of the banks of the old stream. The actual amount is, of course, settled when the Act of Parliament authorizing the construction of the works is obtained.

The amount of water required is usually arrived at by taking a known or estimated figure for the consumption per head per day—often 25 gallons—and allowing for an estimated increase in population during the "economic life" of the works. Such a **reservoir,** as the artificial lake is called, is usually high up in a mountainous or thinly populated country, and the water will flow by gravity to the town requiring it. The capital cost of construction is high, but the running expenses may be low owing to there being no need for constant pumping. The impounding reservoir is usually made large enough to hold about three to six months' supply, the actual quantity depending on the amount, and particularly on the regularity of the rainfall, which must be carefully studied.

The throwing of the dam across the valley is obviously a large and costly undertaking. In England it usually consists of an **earthen embankment** with a core of concrete or clay carried well down into the solid ground to prevent infiltration under the embankment (Fig. 76A). The bank is very wide at the foot in order to obtain stability, the slopes being often 3 horizontal to 1 vertical and 2 horizontal to 1 vertical on the inside and outside respectively. The inside is faced with a pitching of stone to prevent any erosion by the waves of the lake. The compensation water is led round the end of the embankment into a stone channel, which reaches the stream below by a series of steps, in order to prevent too great a rush, as the gradient of this channel is usually steep. A valve tower of masonry is built at the deepest part of the reservoir, with an arrangement of inlet pipes at different levels, so that water may be drawn off at the proper level, neither from the bottom nor the top layers.

It is strained through fine wire mesh and enters the main, which passes through the embankment near its end on its way to the town.

Dams are also built of solid **masonry** or **concrete** where such can be obtained cheaply and where the foundation is of solid rock (Figs. 76B and 77). They are designed so that the pressure on the masonry does not exceed a safe amount, usually about ten tons per sq. ft., after taking into account the dead weight of the dam and the overturning pressure of the water when the reservoir is full. The compensation water from such dams and the overflow water generally may be allowed to flow directly over the crest, instead of being diverted down a byepass. Where the valley to be drained is deep and the side hills of solid rock, such a dam is often constructed curved in plan, with the convex side

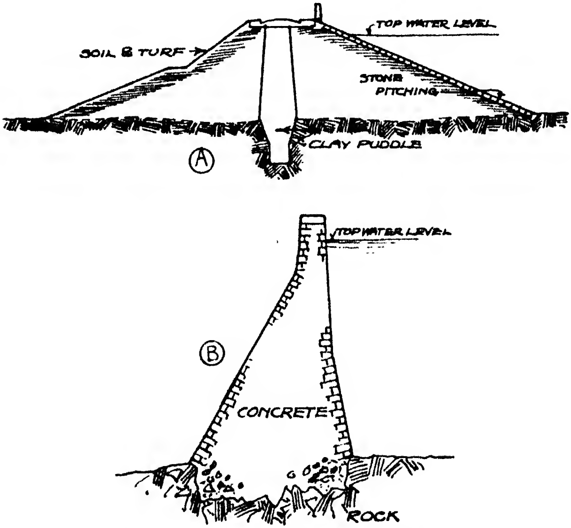

Fig. 76.—Dams for impounding water.
(A) Earth dam with core. (B) Masonry.

upstream, thus acting as a horizontal arch, and being made proportionately thinner than the straight dam, which resists the water pressure by weight alone, and has to be of what is called a "gravity" section. The outlet main is arranged similarly to that for an earthen embankment, or it is sometimes taken through the dam.

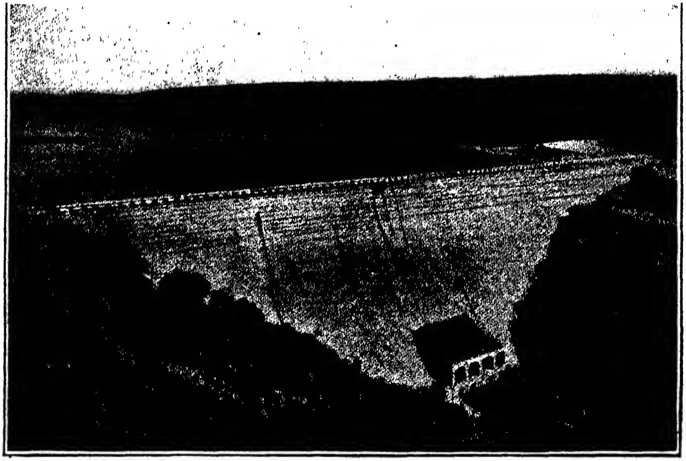

FIG. 77.—Masonry Dam, New South Wales.
[*Engineering*, 24th April, 1908.

PIPE LINES, AQUEDUCTS, AND FILTERS.

The conveyance of the water from the reservoir to the town may be effected either by means of **pipes** or by an open **aqueduct.** In the first case a direct route can be chosen, the pipes being laid to climb the hills and descend into the valleys as required, with the exceptions that they should not rise above what is known as the **hydraulic gradient**; that is, a line representing the pressure of water in the pipe by its height above the pipe at any point. In the case of a pipe of uniform cross section, discharging freely, the hydraulic gradient is practically a straight line joining the surface of the water in the inlet reservoir and the outlet of the pipe. Where the pipes rise above this line, air is liable to collect and so restrict the flow. Moreover, they should not descend very far below the hydraulic gradient, as the pressure at such points is very heavy and might burst the pipes. Such a pipe line may be many miles in length, and may be divided into sections by means of large sluice valves, which will isolate any given section when required for repairs.

In addition to these there will be **washout valves** at the bottoms of the valleys, which may be opened when required to empty any given section of pipes; **air valves** at the crests of hills, which may also be opened to let out air which may have accumulated there—derived from air dissolved in the water; and **reflux valves** of a non-return type, which will prevent the water which is ascending a rising gradient from flowing back if a burst should occur at the bottom. Valves of a somewhat similar kind are also fixed at intervals on falling gradients, which only come into operation when the pressure on the far side of the valves is much reduced by a burst. This prevents the reservoir from being drained entirely through the burst before the section valves can be closed by hand.

The mains are often laid as two separate pipes for convenience in repairs. The pipes themselves may be of cast iron or steel, laid either on the surface of the ground or in shallow trenches. In some cases tunnels are necessary through the crests of hills to keep below the hydraulic gradient, and these may be lined with concrete or brickwork, made as smooth as possible in order not to impede the flow of the water. The mains may be carried across deep valleys or aqueducts on a series of small bridges, or where the increased pressure is not too great they may dip down into the river beds below the water level and rise again on the other side.

The second method of carrying the supply is by means of open channels. These must be carefully levelled, so that they do not rise above or fall below the hydraulic gradient. They are often cheaper per yard run than pipes, but they obviously cannot follow a straight line except at enormous expense for cuttings and aqueducts, and they usually wind about the hillsides, gradually dropping as they go.

The aqueduct, whether of open channel or closed pipe form, and whether from a reservoir or pumping station, discharges near the town into one or more small **service reservoirs**, which contain about two days' supply. These service reservoirs are constructed either of concrete or brick, and are usually roofed over to prevent the growth of mosses, etc., in the water. They act as storage tanks in the case of a stoppage on the main from the pumping station or impounding reservoir, and from them are taken the **distributing mains** to the town, usually large cast-iron pipes with lead joints. These mains have branches taken off at various points, and are arranged where possible without " dead " ends, so that there is a constant circulation in the pipes. They may decrease in size down to 3 in. and even 2 in. diameter. From them the house services are taken. At various points also branches are taken to **hydrants** fixed in the road. These are simply valves of a special form with screwed ends, to which a vertical stand pipe can be fixed. The end of this pipe is also screwed to take a standard fire hose thread, and by merely turning the hydrant valve with a special key a stream of water under pressure is obtained direct from the main.

Water is sometimes obtained from large **rivers**. In this and in other cases where its purity is not above suspicion, it must be filtered. This is done by constructing **filter beds** of clean sand resting on clean gravel, contained in large brick or concrete tanks. The thickness of the sand bed may be 3 or 4 ft., and the water, which is flooded over the top, percolates through and is collected at the bottom into the outlet pipe, whence it proceeds to the distributing main. At intervals the top layer of sand is scraped off, washed by agitating in water, and returned.

Much of the routine work of a waterworks engineer consists in detecting and stopping leaks. This is generally done by fixing a waste-water meter on the main and noting the flow at midnight, when there should be very little water passing. The main is divided into sections by valves, and it is possible in that way to localize the leak to some extent.

V. SEWERAGE WORKS

Where a town is without a copious water supply or where the dwellings are very much scattered, it is not usual for a sewerage system to be installed. In such a case the **conservancy** system is adopted. Earth or pail closets are used, or even middens, which are either emptied and the contents dug into the land by the occupiers or by the local authority, which, of course, then charges the cost on the rates. The liquid refuse from the house, such as bath and sink slops, is either run over the garden or into a cesspool, which is emptied from time to time by the occupier or by the local authority on the same conditions as the middens.

When a proper **sewerage system** is installed, the owners of property within a certain distance are compelled to connect into it, and it then takes the sewage from water closets, sinks, lavatory basins and baths, and various forms of trade waste from manufacturers as well. In addition, rain water from roofs and roads must be dealt with. This may all be turned into the sewer as well, under what is known as the combined system, or it may run into separate sewers under the separate system; or a partially separate system may be adopted, in which the rain water from the roads only is taken away by special storm-water drains. The foul-water sewers then do not need to be so large, for they are not so likely to be flooded. This is especially important in flat and low-lying towns where, as will be seen later, the sewage has to be pumped before it can be got rid of, the cost of pumping, of course, varying with the quantity.

House drains are formed of glazed stoneware or fireclay pipes, and they discharge into the small sewers vested in the local authority, which is responsible for their upkeep. These sewers are also usually glazed pipes 9 in., 12 in. or 15 in. diameter, according to the quantity which they have to take. It is usual to allow about 25 gallons per head per day—the water supply figure—plus an allowance of ½ in. of rainfall in one hour on the area which actually discharges into the sewers through gullies. The sizes of the sewers are calculated to take that amount, or alternatively six times the dry weather flow (d.w.f.) of 25 gallons per head per day, whichever may be the larger, if the combined system is adopted. Hydraulic calculations are made to determine these sizes, which are also dependent on the fall or slope of the sewers.

The minimum slope in any case must be enough to give a velocity of at least 2½ feet per second, this being sufficient to move solid matter and thus keep the sewers cleansed. In a flat district, in order to obtain this fall, the sewers become gradually deeper, until at the outlet they are below the level of the purification works. This necessitates pumping. As the sewers increase in size beyond the limit for glazed pipes—say 18 in. diameter—they are built in brickwork, egg shaped in cross section, so that the narrow portion at the bottom may be kept clear of solids by always having a fairly deep stream running through it even during dry weather. Larger sewers are constructed of brickwork, circular in section, often up to 8 or 9 ft. diameter.

At intervals along the sewers **manholes** are built of brickwork, which enable stoppages to be localized. The sewers are usually ventilated by connecting glazed pipes to them at the top, and running these pipes to cast-iron upcast shafts fixed at the side of the footway, the sewer gas being discharged at the top into the open air. In some cases the manhole covers are also formed of open gratings, discharging at the road surface. Where a sewer is calculated to take more than six times the d.w.f., any excess over this amount which may come down the sewer during heavy rain is diverted by means of a "storm overflow" weir down a branch pipe to the nearest watercourse.

When the sewers reach the low-lying portion of the town, it is often more economical to pump at various points, lifting the sewage into shallower sewers, and so conducting it to the outfall, than to run a long length of sewer at a great and constantly increasing depth, leaving the whole of the pumping to be carried out at the end. The former method of pumping is usually performed either by electrically driven turbines started and stopped automatically as required by a float, or by compressed air "ejectors" worked in the same way, the air being supplied through pipes from a central compressing station. Pumps at the main outfall may be of the same kind, but as very large quantities have to be dealt with, direct acting steam-driven pumps or centrifugal pumps are usually employed. The Humphry gas pump—which has no piston—is also useful for sewage, for the latter often contains a large amount of grit in suspension.

Treatment of Sewage

The sewage when it arrives at the outfall must, in most cases, be **purified** before it is discharged finally into a stream or river. Towns on the open sea coast are allowed to discharge their sewage into the sea, carrying the outfall sewer well out beyond low water mark. A spot is chosen where careful observations of the prevailing currents by means of floats show that the sewage and the accompanying solid matter will be conducted away from the coast and town. It is usual to discharge only on the ebb tide, and this means that for about six hours out of every twelve the flow of sewage must be stopped by a **penstock** or large screw-down sluice valve, operated by hand in a manhole or penstock chamber. The sewage then heads up in the outfall above the penstock, which must be made large enough to contain and store at least six hours' supply without heading back into the town. The penstock is opened as the tide falls.

Towns situated on tidal estuaries usually purify the sewage partially by allowing it to settle for a time in large tanks of concrete or brickwork. The liquid is then allowed to run off, and the sludge which settles to the bottom is pumped into hopper barges which take it well out to sea, where it is dumped.

In the case of inland towns where the sewage must be thoroughly purified, it is pumped first into a small tank, called a detritus chamber, where heavy silt falls to the bottom. It then flows over a weir into a larger tank holding about a day's supply, through which it flows very slowly. Here it undergoes septic (or putrefying) decomposition, with the result that many of the solid matters are liquefied and it becomes highly offensive. From this **septic tank**—which is sometimes roofed over—the effluent passes to the filters, which may be either **contact beds** or **percolating filters.** In the first case the filter, which is in the form of a large concrete or brick tank filled with clinker, gravel, coke or broken stone to a depth of about 4 ft., is filled with sewage and allowed to remain full for about three hours. The sewage is then allowed to drain through an outlet at the bottom and the filter stands empty three hours. It is again filled, and the process is repeated, each cycle occupying eight hours. The effluent from the contact bed is considerably purified, and if necessary it is run through another similar bed in the same way, being finally discharged into the stream.

Percolating filters are of similar construction, but usually of greater depth, and the sewage is distributed over them by some form of sprinkler which causes it to fall in drops. The action is continuous, and two beds, a coarse and a fine one, are generally required before the sewage is finally purified. The purification effected in both these types is not merely due to mechanical filtration, but also to the action of bacteria which are developed in the pores of the coke, etc., from which the beds are often called bacteria beds. The amount of sewage treated in this way is generally three times the d.w.f., the rest being purified over " storm-water " beds of somewhat similar form, through which the now dilute sewage is allowed to flow at a much greater rate. The purification works are designed like the sewers for about 25 gallons per head per day d.w.f., an allowance being made for an estimated increase in population during their " economic " life.

Where sufficient land is available, the effluent from the septic tank may be turned on to a large surface which has been carefully levelled, and allowed to soak through it, being drained away as ordinary subsoil water down the natural watercourses. This method is known as **broad irrigation.** Where the land is drained artificially by ordinary earthenware pipes—unglazed and laid without collars—more sewage may be dealt with, and the system is then called **intermittent filtration.** Older methods of sewage purification depended on the use of chemicals, such as lime or alum, but these are being gradually superseded by the bacterial system. With any system, however, a certain amount of sludge accumulates at the bottom of the tanks. This is pumped out, and either run upon the land, dried and dug in, or pressed to form a solid cake which is used as fertilizer, or, where facilities exist,.is barged away.

Solid refuse from dwellings, or **dust,** is collected in carts and either burnt in a refuse destructor, or tipped on to waste land ; in the case of seaport towns it may be barged out to sea. Its heating value when burnt is very small. In some cases it is pulverized and sold as fertilizer. The clinker from the burnt refuse is often utilized as aggregate for concrete paving slabs.

VI. WATERWAYS AND IRRIGATION

Waterways may be of two kinds, natural or artificial. In the case of **natural waterways** the work of the engineer usually resolves itself into improving the channel of a river, deepening it and removing obstructions. Isolated rocks may be blasted away. The obstructions to navigation are usually due either to the silting up of the bed of a slow-moving stream, with the formation of sand or mud banks, or to the shallow current of a rapid river. In the first case, the mud banks may be removed and the channel deepened by constant dredging, or **training walls** parallel to the banks but nearer the centre of the stream may be built, generally of earth but sometimes of masonry. The space behind these banks may eventually be filled in and the land reclaimed. The banks confine the river to a narrower channel, increase its velocity, and cause it to scour its way through.

Most rivers, where they discharge into the sea, have a lowered velocity due to the sudden widening of the mouth. The silt carried down by the river is deposited there and forms a **bar**. This is often kept clear by building two jetties at the mouth of the river which act as training walls, and so confine the current and increase its velocity, the resulting scour keeping the channel clear.

Rivers which have too great a velocity are rendered navigable by erecting dams or weirs across them at intervals, thus forming a succession of long pools of comparatively calm water but at different levels. Where the weirs occur a side channel is cut round the end of the weir, in which is constructed a lock, similar in principle to that at the entrance to a wet dock. Vessels are thus enabled to pass from one level to another.

If the river has a very variable flow, the effect of the weirs may be in some cases to cause flooding during heavy rain or when the snows melt. In such cases the weirs must be of such a form that when necessary they can be lowered to let the flood water pass without heading back. Such weirs may be formed of timber framework in which are fixed sluice gates, which may be opened or shut by hand when required, or they may be formed of "needles," that is, a series of vertical balks of timber resting against the framework, which may be pulled out one by one and allowed to float, being prevented from drifting away by chains.

In hot climates such a system of damming up rivers is often adopted, not for the sake of obtaining navigable waterways, but in order to cause the river to overflow and irrigate the country on either side. Such a scheme has been carried out in the Nile at Assuan, where the weir, however, is a massive masonry dam fitted with sluices, the object being to impound a large quantity of water, and let it out as required for the country below. In India irrigation works consist usually of schemes for impounding water, either by means of large masonry dams thrown across deep valleys, or by long embankments forming large shallow reservoirs called "tanks," which store rain water in time of flood where the ground is naturally low-lying, afterwards distributing it by means of artificial canals with sluices to allow the water to run over the fields through which the canals pass.

Artificial waterways consist of canals cut in the surface of the earth, either for ordinary barges or for large ships. They have necessarily to be level, and so wind about a good deal following a level contour of the ground. Where valleys or hills must be crossed, locks are used, either singly or in series. Where horse haulage is provided, one of the banks of the canal is made about 12 ft. wide at the top, and is formed into a tow path. If the soil in which the canal is constructed is porous, it is necessary to construct a clay puddle core to the embankment. The water supply for a canal is usually obtained from a reservoir at its summit fed by a stream. Where the canal crosses over a stream or river, it is carried by an aqueduct, usually of stone or brick arches, the channel being lined with clay puddle, and at such places provision is often made by which the canal can be drained into the stream when repairs are necessary to the banks.

Ship canals work on the same principle, but are very much larger, and tax all the resources of the engineer in their construction. The most notable example in Great Britain is the Manchester Ship Canal.

APPENDICES

APPENDIX I

THE following is an abridged list of **standard specifications** dealing with Civil Engineering, published by the British Standards Institution, 28 Victoria Street, Westminster, S.W. 1 :—

Publication No.		Price net.
1.	**Rolled Sections for Structural Purposes, Lists of**	2s.
12.	**Portland Cement,** Specification for	2s.
15.	**Steel for Bridges, etc., and General Building Construction,** Specification for Structural	2s.
29.	**Steel Forgings for Marine Purposes** (may be used for steel forgings such as bearings for bridges), Specification for Ingot	2s.
30.	**Steel Castings for Marine Purposes,** Specification for	2s.
63.	**Broken Stone and Chippings,** Specification for, Sizes of	2s.
65.	**Salt-Glazed Ware Pipes,** Specification for	2s.
76.	**Tars, Pitches, Bitumens, and Asphalts** when used for Road Purposes. Report on **Nomenclature** of, and Specifications for, **Tar and Pitch** for Road Purposes	2s.
78.	**Cast Iron Pipes and Special Castings** for Water, Gas and Sewage, Specification for	2s.
104.	**Light Flat Bottom Railway Rails and Fishplates,** Sections of	2s.
105.	**Light and Heavy Bridge Type Railway Rails,** Sections of	2s.

Publication No.		Price, net.
144.	**Creosote for the Preservation of Timber,** Specification for	2s.
153.	**Girder Bridges.** 1. Materials; 2. Workmanship; 3. Loading and Stresses; 4. Details of Construction; 5. Erection	2s.
308.	**Drawing Office Practice**	2s.
449.	**Steel Buildings**	2s.
538.	**Metal Arc Welding**	2s.

There are also many specifications dealing with workmanship and materials for the building trades.

REFERENCE BOOKS

The following list gives the names of reference books which will be found useful for further study. It is by no means exhaustive, and the student is recommended to consult the up-to-date book lists issued by the various publishing firms, and obtainable from them or from a local bookseller.

Rankine's *Civil Engineering* (Griffin) deals more particularly with the theoretical principles underlying design.

Vernon Harcourt's *Civil Engineering as applied in Construction* (Longmans), gives a good descriptive account of the most important works recently carried out.

Matheson's *Aid Book to Engineering Enterprise* (Spon) deals principally with the commercial side of engineering.

Smiles' *Lives of the Engineers* (Murray, five volumes) gives interesting general information about early works.

For specification writing a useful book is *Specification*, published annually by the Architectural Press, Ltd. Leaning's *Building Specifications* (Batsford) may also be consulted.

Arrol's *Bridge and Structural Engineer's Handbook* (Spon) contains, in addition to useful data for design, a set of excellent structural specifications for bridges, roofs, etc.

Evans' *Building Contracts* (Chapman and Hall) contains useful information on direct labour.

For the subject of quantities any standard text-book, such as Leaning's *Quantity Surveying* (Spon), may be referred to, although much of the book is taken up with intricate details of architectural work.

General construction in masonry, brickwork, timber, concrete and steel is dealt with in the standard text-books on building construction, such as Rivington's *Building Construction* (4 vols., Longmans) or Mitchell's *Building Construction* (2 vols., Batsford).

Steelwork is treated in a practical manner in Farnsworth's *Constructional Steelwork* (Griffin).

For special construction the following books may be consulted:

Mills' *Railway Construction* (Longmans).
Cunningham's *Dock Engineering* (Griffin.)
Cunningham's *Harbour Engineering* (Griffin).
Aitken's *Road Construction and Maintenance* (Griffin).
Moore's *Sanitary Engineering* (Batsford).
Burton's *Water Supply of Towns* (Crosby Lockwood).
Wilson's *Irrigation Engineering* (Chapman and Hall).
Jeans' *Waterways and Water Transport* (Spon).

APPENDIX II

Working stresses for use in designing are shown below. For **buildings** the regulations of the London County Council are quoted and the figures are marked thus (L.C.C.). For **bridges** the stresses used on the Indian Government Railways, mentioned in the *Proceedings of the Institution of Civil Engineers*, vol. cc., are given, and are marked thus (I.G.R.). Other stresses are based on the author's experience. Reference is made to numbered notes, which should be consulted carefully, as they modify the allowable stresses in many cases.

Material.	Nature of Stress.	Value of Working Stress.	Structure and Remarks.
Structural Steel.	Tension.	7·5 tons/sq. in. (L.C.C.).	Buildings and roofs, dead and live loads.
„	„	8·0 tons/sq. in. (I.G.R.).	Bridges, dead load.
„	„	8·0 tons/sq. in. (I.G.R.). (1), (4)	Bridges, live load.
„	„	16,000 lbs./sq. in. (L.C.C.).	Reinforced concrete. Dead and live loads.
„	Compression.	7·5 tons/sq. in. (L.C.C.). (3)	Buildings and roofs, dead and live loads.
„	„	8·0 tons/sq. in. (I.G.R.). (2)	Bridges, dead load.
„	„	8·0 tons/sq. in. (I.G.R.). (1), (2), (4)	Bridges, live load.
„	„	16,000 lbs./sq. in. (L.C.C.). (9)	Reinforced concrete, dead and live loads.
„	Shear.	5·5 tons/sq. in. (L.C.C.). (10)	Rivets in buildings and roofs, dead and live loads.
„	„	5·0 tons/sq. in. (I.G.R.). (10), (4)	Rivets in bridges, dead and live loads.
„	„	3·0 tons/sq. in.	Webs of plate girders only, dead and live loads.
„	„	12,000 lbs./sq. in. (L.C.C.).	Shear, members of reinforced concrete, dead and live loads.
„	Bearing.	11·0 tons/sq. in. (L.C.C.). (10)	Rivets in buildings and roofs, dead and live loads.
„	„	11·0 tons/sq. in. (I.G.R.). (10), (4)	Rivets in bridges, dead and live loads.

Material.	Nature of Stress.	Value of Working Stress.	Structure and Remarks.
Wrought Iron.	Tension.	5·0 tons/sq. in. (L.C.C.).	Buildings and roofs, dead and live loads.
"	"	6·0 tons/sq. in. (I.G.R.).	Bridges, dead loads.
"	"	6·0 tons/sq. in. (I.G.R.). (1), (4)	Bridges, live load.
"	Compression.	5·0 tons/sq. in. (L.C.C.). (11)	Buildings and roofs, dead and live loads.
"	"	6·0 tons/sq. in. (I.G.R.). (2)	Bridges, dead loads.
"	"	6·0 tons/sq. in. (I.G.R.). (1), (2), (4)	Bridges, live loads.
"	Shear.	4·0 tons/sq. in. (L.C.C.).	Rivets in buildings and roofs, dead and live loads.
"	"	4·0 tons/sq. in. (I.G.R.). (4)	Rivets in bridges, dead and live loads.
"	"	2·0 tons/sq. in.	Webs of plate girders, dead and live loads.
Cast Iron.	Tension.	1·5 tons/sq. in. (L.C.C.).	Buildings and roofs, dead and live loads.
"	"	1·5 tons/sq. in.	Girders, dead load.
"	Compression.	8·0 tons/sq. in. (L.C.C.). (5)	Buildings and roofs, dead and live loads.
"	"	8·0 tons/sq. in.	Girders, dead load.
"	Shear.	1·5 tons/sq. in. (L.C.C.).	Buildings and roofs, dead and live loads.
"	"	1·5 tons/sq. in.	Girders, dead load.
"	Bearing.	10·0 tons/sq. in. (L.C.C.).	Buildings and roofs, dead and live loads.
"	"	10·0 tons/sq. in.	Girders, dead and live loads.
Portland Cement Concrete.	Compression.	12·0 tons/sq. ft. (L.C.C.).	8 to 1 concrete in foundations, etc.
"	"	600·0 lbs./sq. in. (L.C.C.). (6)	4 to 2 to 1 reinforced concrete.

Material.	Nature of Stress.	Value of Working Stress.	Structure and Remarks.
Portland Cement Concrete.	Shear.	60·0 lbs./sq. in. (L.C.C.).	4 to 2 to 1 reinforced concrete.
Timber.	Tension.	0·6 tons/sq. in.	Fir, dead and live loads.
,,	,,	0·8 tons/sq. in.	Oak, dead and live loads.
,,	Compression.	0·5 tons/sq. in. (8)	Fir, dead and live loads.
,,	,,	0·65 tons/sq. in. (8)	Oak, dead and live loads.
,,	Shear.	0·065 tons/sq. in.	Fir, along the grain, dead and live loads.
,,	,,	0·1 tons/sq. in.	Oak, along the grain, dead and live loads.
,,	Bearing.	0·6 tons/sq. in.	Fir, end grain, dead and live loads.
,,	,,	1·0 tons/sq. in.	Oak, end grain, dead and live loads.
Brickwork.	Compression.	12·0 tons/sq. ft. (L.C.C.). (7)	Blue brick in cement.
,,	,,	8·0 tons/sq. ft. (L.C.C.). (7)	"Hard" brick in cement.
,,	,,	5·0 tons/sq. ft. (L.C.C.). (7)	"Soft" brick in cement.
,,	,,	3·0 tons/sq. ft. (7)	"Soft" brick in lime.
Stone.	Compression.	25·0 tons/sq. ft. (7)	Granite, single blocks.
,,	,,	15·0 tons/sq. ft. (7)	York stone, single blocks.
,,	,,	8·0 tons/sq. ft. (7)	Rubble masonry in cement.

NOTES TO APPENDIX II

(1) The live load must be increased before the stresses are determined by the Pencoyd impact formula $\frac{300}{300+L}$ for railway bridges, and $\frac{150}{300+L}$ for highway bridges. L is the distance the load has to travel in feet from the position at which it first causes a stress in the member under consideration to the position at which it causes the maximum stress in

that member. In the case of both web and flanges of plate girders L = span. For cross girders it is taken arbitrarily as twice the spacing of the cross girders.

(2) Reduce these stresses to allow for the slenderness ratio,

$$S = \frac{\text{length}}{\text{least radius of gyration}},$$

by the following formula, where f is the safe stress given in the table (which applies to a short specimen only) after impact has been allowed for if necessary. In any case S must not be more than 100 for main members and 120 for subsidiary ones.

$f(0{\cdot}95 - 0{\cdot}003S)$ for riveted ends.

$f(0{\cdot}95 - 0{\cdot}0045S)$ for pin-jointed ends.

(3) If S is the slenderness ratio—see note (2)—the safe stress on a compression member, per sq. in., is given by the following pairs of formulae, taking in each case that formula of any pair which gives the lesser value.*

$\left(4{\cdot}5 - \frac{S}{40}\right)$ or $\left(7 - \frac{S}{20}\right)$, if both ends are hinged.

$\left(5{\cdot}5 - \frac{S}{40}\right)$ or $\left(9 - \frac{S}{20}\right)$, if one end is fixed and one hinged.

$\left(6{\cdot}5 - \frac{S}{40}\right)$ or $\left(10{\cdot}5 - \frac{S}{20}\right)$, if both ends are fixed.

(4) Where the wind load alone causes a stress of 25 per cent. or less of that given in the table as allowable for dead and live loads, plus impact allowance, it may be neglected. If it causes a stress more than 25 per cent. of that otherwise allowable, the excess over 25 per cent. must be allowed for by increasing the sectional area of the metal to bring the stress per sq. in. back to the safe amount, viz. the tabulated figure plus 25 per cent.

(5) If S is the slenderness rato—see note (2)—the safe stress per sq. in. on a compression member is given by the following formula: *

$\left(4{\cdot}5 - \frac{S}{20}\right)$, if both ends are hinged.

$\left(5{\cdot}0 - \frac{S}{20}\right)$, if one end is hinged and one end fixed.

$\left(5{\cdot}5 - \frac{S}{20}\right)$, if both ends are fixed.

(6) Restrict to columns less than 20 diameters high.

(7) Where the pressure is uneven over the cross section, the maximum and not the average stress must not exceed this figure.

(8) Reduce this stress (f) in the case of struts of slenderness ratio S —see Note 2—by a strut formula such as Rankine's, *e.g.* $\frac{f}{1 + \frac{1}{2500}S^2}$.

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* These stresses may be exceeded for eccentric loads by 25 per cent. if such excess is due to wind pressure alone.

(9) In columns the stress must not exceed 15 times safe stress on concrete in compression, *i.e.* 9000 lbs./sq. in.

(10) It is usual to allow only 80 per cent. of those stresses for field rivets and bolts, and to take area in double shear as being on 1¾ area in single shear.

(11) Stresses to be allowed as in note (3), multiplied by 0·75.

APPENDIX III

THE units in which quantities of the commoner materials are usually billed should be known. Details of these are given in the *Report of the Institution of Civil Engineers on Engineering Quantities* (2s.), and, for building works, in the *Standard Method* published by the Surveyors' Institution. A few prices are here given so that the student may form a *rough* idea of the cost of different works at the date of publication. They are between two and three times as much as those ruling before the War of 1914–18 and are, of course, liable to fluctuation. Lists are given weekly in the building papers. The prices given below include labour, material, and overhead charges for supervision and office work, but should not be used in practice for pricing as they may be seriously in error owing to the circumstances and locality of any particular work.

Excavation in trenches, at per yard cube, 4/- to 6/-, including keeping the trenches dry and carting away the spoil, up to 6 ft. deep.

Concrete in mass, at per yard cube, £1 10/- to £2, according to its richness.

Excavation less than 12 in. thick, at per yard super, about 1/6.

Concrete less than 6 in. thick, at per yard super, about 5/-.

Strutting and planking to sides of excavations if the item dealing with excavation is not described as including this, at per yard super, about 2/6.

Brickwork in mortar, at per yard cube, or, alternatively, at per rod reduced*, about £3 per yard, or £33 per rod.

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* See page 30.

Brickwork in cement as brickwork in mortar, or, alternatively, as an extra only over brickwork in mortar, in which case its quantity must have been previously measured in and billed with the brickwork in mortar. The extra cost will be about £1 per rod.

Facings extra only over brickwork, at per yard super, about 3/6. This includes the *extra* cost of the facing bricks over the ordinary bricks, plus the extra labour required in building the face more carefully and in striking or pointing the joints as may be described.

Cutting brickwork, over arches or up sloping gables, at per foot run (the width of the cutting being stated in the description), or at per foot super, about /6.

Slating or tiling, at per square of 100 sq. feet, including the battens, nails, etc., about £4 or £5. It is usual not to include in this the labour in making cuttings against walls, chimneys, etc., but to take these at per foot run separately.

Stone walling, if thin, at per yard super, describing the thickness, or, if thick, at per yard cube, about £6.

Stone dressings and ashlar generally, at per foot cube, 16/- to 25/-, according to the amount of work done on it.

4 in. glazed stoneware pipes, including also excavation and filling, at per foot run, 3/- to 4/-.

Timber in framing, joists, beams, piles, etc., at per foot cube, including fixing and filling, 5/- to 6/- if of deal.

Iron straps, pile shoes, etc., but not including the labour of fixing these, in tons, cwts. and qrs., about £20 per ton.

Driving piles, by foot run or by foot cube, 5/- ft. run.

Pitching piles, labour in fixing shoes and rings, by the number, £3 to £5 each.

Doors, by the foot super, 2/- to 2/6 if of deal.

Window sashes, and including also the frames if they are hollow cased sliding sashes, by the foot super, 3/- to 3/6.

Solid window and door frames, by the foot run, 1/- to 1/3.

Plastering, by the yard super. If on laths, it includes the laths also, 3/- to 3/6.

Constructional steelwork, by weight, including all labour and rivets. About £20 per ton.[1]

Lead in roofs, etc., by weight, about 50/- per cwt.

Paintwork, by the yard super, describing the number of coats, 2/- to 2/6 for three coats.

Small isolated articles, such as door and window catches, cramps, etc., by number, with a detailed description of each.

APPENDIX IV

A SHORT set of quantities for the purpose of estimating the probable cost of one bay of a panelled retaining wall built in brick (Fig. 78) is here given, with the drawing from which the quantities were taken, and the taking off, abstracting and billing in reduced facsimile (*v.* page 279 and on).

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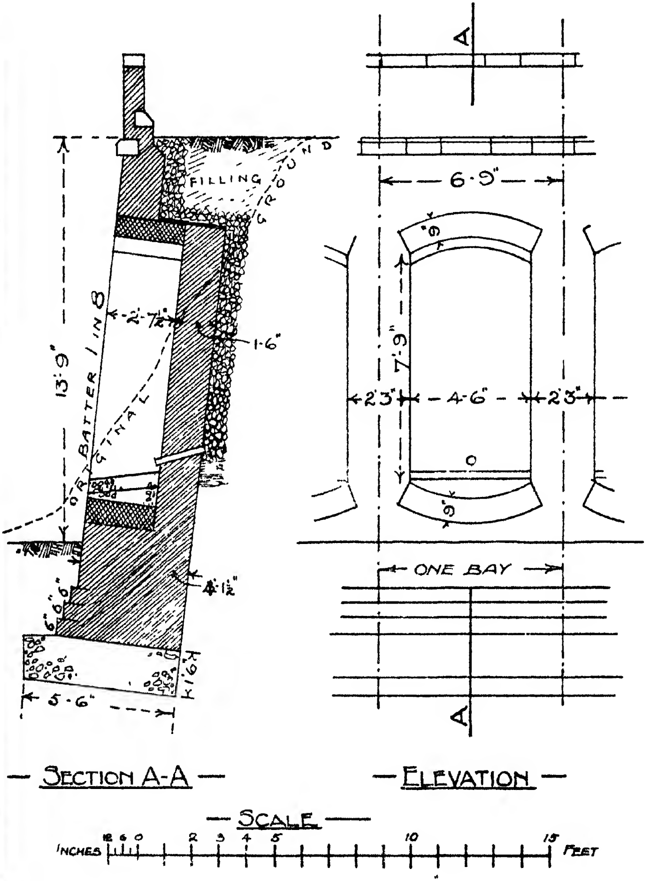
[1] Two other methods are also used for steelwork:

(1) Bill the actual weights of the steel members, keeping joists, angles, tees, etc., in separate categories. Bill separately in addition the number of holes, giving diameter and thickness of plates in which they are drilled. Number the rivets, stating their size, and also any special smith's work, such as curving or joggling.

(2) Give a separate dimensioned sketch of each member, and state on the sketch how many of each are required (usually by the label "No. 10 off" if 10 are required).

— PANELLED RETAINING WALL —



WALL OF HARD BRICKS IN LIAS LIME MORTAR. FOUNDATION OF CEMENT CONCRETE ARCHES OF BLUE BRICKS IN CEMENT MORTAR. COPING AND PLINTHS OF YORK STONE. ASPHALT RENDERING OVER ARCH. RUBBLE BACKING

FIG. 78.

Panelled Retaining Wall One bay 6'-9" wide.

6-9 4-0 11-0	297-0	Excavate to form^{n} level, shore, & cart away
6-9 6-0 5-0	202-6	Excavate in trench part fill in & ram part cart away.
6-9 5-9 1-6	58-3	P.C. Concrete 8 & 1 in foundation
6-9 17-8 6	59-8	Bkwk. in lime mortar footings 4-1½ 4-3¾ 4-6 4-8¼ 17-7½
6-9 4-1½ 13-0	362-0	Add in wall to top of arch
4-6 2-7½ 8-6	100-6	Ddt in recess
6-9 1-6 2-6	25-4	Add in wall
6-9 1-1½ 1-3	9-6	Add plinth
6-9 9 1-6	7-7	Add parapet wall
-9 2-7½	7-10½	Cutting & forming skewbacks
5-6 2-7½	14-6	Circular cutting (bed for invert)
4-9 2-7½	12-6½	Use & waste centering to top arch.
5-6 1-6	8-3	Circular cutting over top arch
5-6 1-6	8-3	Ditto back of wall
5-6 2-6	13-9	Rendering in asphalt

2/	5-0 2-9½	19-7	E.O. bkwk for arches in blue bk in ct.
	4-6 2-8 9	9-0	4 & 1 P.C. concrete apron in recess
	4-6 2-8	12-0	Rendering ditto 1" thick
	6-9 19-3	130-0	E.O. bkwk & blue bk for facing. 16-6 2-9 19-3
	4-9 2-7½	12-5½	Add soffite of arch
2/	2-7½ 8-0	42-0	Add sides of recess
	No.	1	Weep pipe, including cutting bkwk & making good
	6-9 9 6	2-7	York stone in front plinth
	6-9 -9 -6	2-7	Ditto in rear plinth
	6-9 -9 -6	2-7	Ditto in coping.
	No	3	Cramps to coping & fixing
	6-9 -9 13-6	68-9	Rubble backing filled in. 2-6 2-6 8-6 13-6
	6-9 3-0 2-6	50-8	Selected filling over back of wall

Panelled Retaining Wall   One bay 6'-9" wide

Excavation p.f.&r. & cart away	Bkwk in lime mortar	Circular Cutting	Centering use & waste	York Stone	Filling Selected
yds. cube 297-0 202-6 27)499·6 18-13-6 ✓	yds. cube 59-8 362-0 25·4 9-6 7-7 464-1 100-6 27)363·7 13-12-7 ✓	ft. sup 14-6 8-3 8-3 31-0 ✓	ft. sup 12-7 ✓	ft. cube 2-7 2-7 2-7 7-9 ✓	yd cube 27)50-8 1-23-8 ✓
Concrete in foundation yds cube 27)58-3 2-4-3	Ddt. 100-6				
Facing bkwk yds. sup 130-0 12-6 42-0 9)184-6 20-4-6 ✓	Blue brick in arches E.O. yds. cube 27)19·7 0-19-7 ✓	Skew cutting ft. sup 7-10½ ✓	Rendering asphalte ft. sup. 13-9 ✓	Rubble backing yd cube 27)68-9 2-14-9 ✓	Concrete in apron. yds cube 27)9-0 0-9-0 ✓
			Weep pipe No 1 ✓	Cramps No 3 ✓	Cement rendering yds sup 9)12-0 1-3-0 ✓

Estimate for Panelled Retaining Wall. One bay 6'9" wide.

yds	ft	in				£	s	d
18	13	6	cub.	Excavate, part fill + ram, part cart away				
				including shoring + strutting	10/-	9	5	-
2	4	3	cub.	8 to 1 P.C. concrete in founds	2/1	4	6	4
–	9	-	cub.	4 to 1 ditto in apron	2/10		16	8
1	23	8	cub.	Selected filling, well rammed	8/-		15	-
2	14	9	cub.	Rubble backing	1/15/-	4	14	7
13	12	7	cub.	Brickwork in lime mortar	3/1/-	40	7	11
–	19	7	cub.	E.O. for blue bricks in arches	2/1/-	1	9	1
	7	9	cub.	York stone in copings etc tooled.	14/-	5	8	6
20	4	6	sup.	E.O. brickwork for facing in selected bricks	3/6	3	11	9
				raking out + pointing in cement.				
–	12	7	sup.	Centring, use + waste only	7/6		3	6
1	3	-	sup.	Cement rendering to concrete apron	7/-		9	4
–	13	9	sup.	Asphalt rendering over arch	9/-		4	7
	31	-	sup.	Circular cutting to brickwork	1/-	1	11	-
	7	11	sup.	Skew cutting to ditto	-/9		6	-
		No.	3	Copper cramps + fixing	5/-		15	-
		No.	1	Weep pipe including cutting + making	1/1/-	1	-	-
				good.				
					£	75	4	3
				Add for contingencies say about 10%		7	15	9
				Total	£	83	-	-

NOTE – The above prices include a due proportion of establishment charges & profit in addition to the actual cost of materials & labour. The descriptions would be in more detail however for a Bill of Quantities to be used for tendering.

APPENDIX V

Drawings of a small cottage are here given (Figs. 79 and 80) to show the amount of detail usually required upon plans drawn to the usual scale of 8 feet to an inch (the scale of the originals of these). Also a short outline specification, giving sizes in common use for the cheapest class of construction only. The technical terms used in the specification are defined in any standard text-book on Building Construction (*v.* Appendix I).

Design for a four-room cottage. Outline of specification requirements :

Excavator to remove surface soil, dig trenches, fill and ram. Concrete to be 6 to 1, clean gravel and Portland cement. Drainage to be of glazed socketted pipes to even falls and straight lines, jointed in Portland cement and sand. Brickwork in stretcher bond, hollow walls outside, 2 in. cavity. Mortar to be 2 sand to 1 lime.

Chimneys above roof to be built in 3 to 1 cement mortar. Galvanized wall ties every 3 ft. apart horizontally, 1 ft. 6 in. vertically. Facings of picked bricks. Joints raked out and pointed in cement. Air bricks under floors. 1 in. cement paving on 4 in. concrete outside. Tiled hearth in living room, rest cement rendered only. Stone heads to windows and external doors 9 in. deep, 4½ in. wide, with 6 in. bearing at each end. Red deal timber throughout. Eaves 9 in. overhang. 1 in. wrought and chamfered fascia and 4 in. × 3 in. ogee eaves gutter screwed to it. 9 in. × 1½ in. wrought and chamfered barge board. Floors 1 in. tongued and grooved. 2 in. × 1½ in. herringbone strutting to floors over 8 ft. span. Skirting 6 in. × 1 in. torus moulded.

Front and external door, 2 in. framed, ledged and braced, upper part glazed in beads. Back door and W.C. door, 2 in. framed, ledged, and braced of 1 in. boarding and 1 in. ledges. Door to coals, ledged and braced only. Internal doors, $1\frac{3}{4}$ in. four panelled, moulded both sides. All doors, except coals, larder, and W.C., to be 2 ft. 8 in. × 6 ft. 8 in. External door frames, 4 in. × 3 in., rebated, chamfered, and beaded. Internal door linings, 1 in. board with $\frac{1}{2}$ in. stop planted on. Architraves, 4 in. × $1\frac{1}{4}$ in. moulded.

Casement windows, side hung below transom, top hung above, 4 in. × 3 in., rebated and beaded frames, 6 in. × $3\frac{1}{2}$ in. sills to project, throated, all grooved for linings. Sashes 2 in. thick. Stairs, $1\frac{1}{2}$ in. wall string, 2 in. outer string, $1\frac{1}{4}$ in. treads, 1 in. risers, 4 in. × 3 in. carriages, 3 in. × 3 in. newels, 3 in. × 2 in. moulded handrail, 2 in. turned balusters, 2 to each step.

Walls to be rendered floated and set, ceilings to be lathed plastered, floated and set, and living room to have plaster cornice 15 in. girth. Countess slates, centre nailed to 2 in. × $\frac{3}{4}$ in. battens, fixed to rafters, 3 in. lap, double eaves course. Ridge and hips to be plain V tiles bedded in cement. Valleys to be of 5 lb. sheet lead, chimney flashings of 5 lb., and 4 lb. soakers to be built into brickwork over beads of frames. Water supply to be of $\frac{1}{2}$ in. heavy lead pipe taken direct to sink and fitted with bib tap.

Windows to have 16 oz. clear sheet glass. Glazed door 21 oz. All woodwork to be knotted, primed, and stopped, and to have 2 coats in addition. All ironwork to have 2 coats before fixing and 1 coat after.

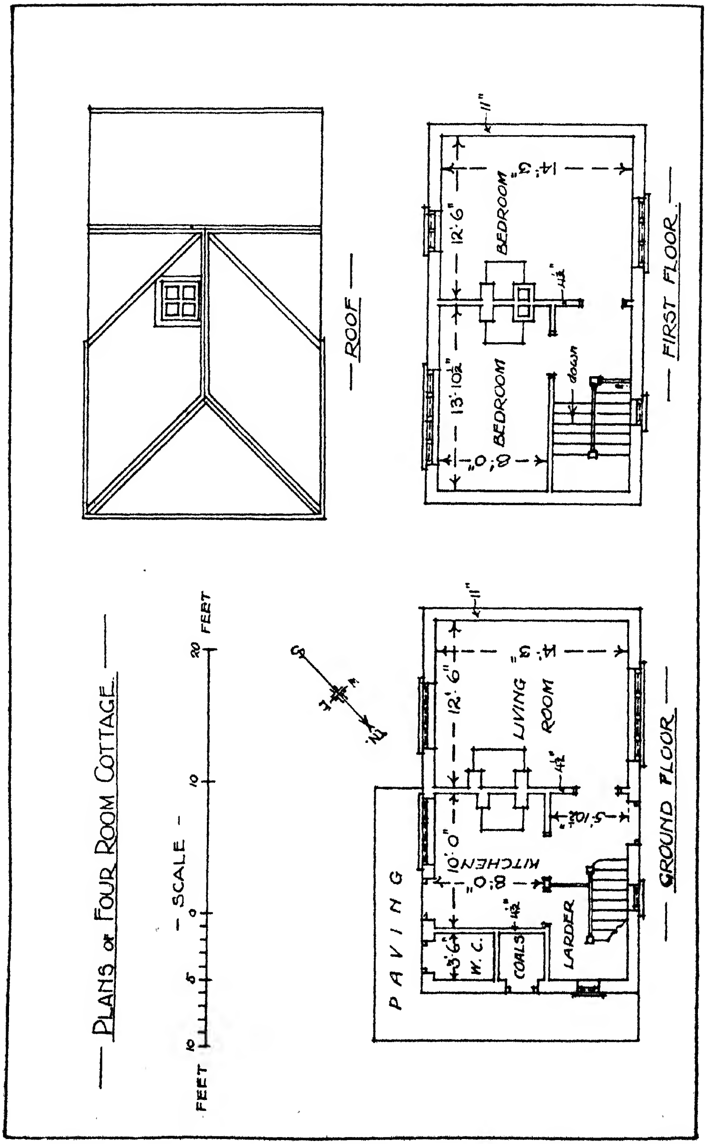

PLANS OF FOUR ROOM COTTAGE
— SCALE —
FEET
10
5
0
10
20
FEET
ROOF
FIRST FLOOR
BEDROOM
12' 6"
14' 3"
11"
4½"
BEDROOM
13' 10½"
8' 0"
down
GROUND FLOOR
LIVING ROOM
12' 6"
14' 3"
11"
4½"
5' 10½"
KITCHEN
10' 0"
8' 0"
W. C.
3' 6"
COALS
4½"
LARDER
PAVING
N
S
E
W

FIG. 79.

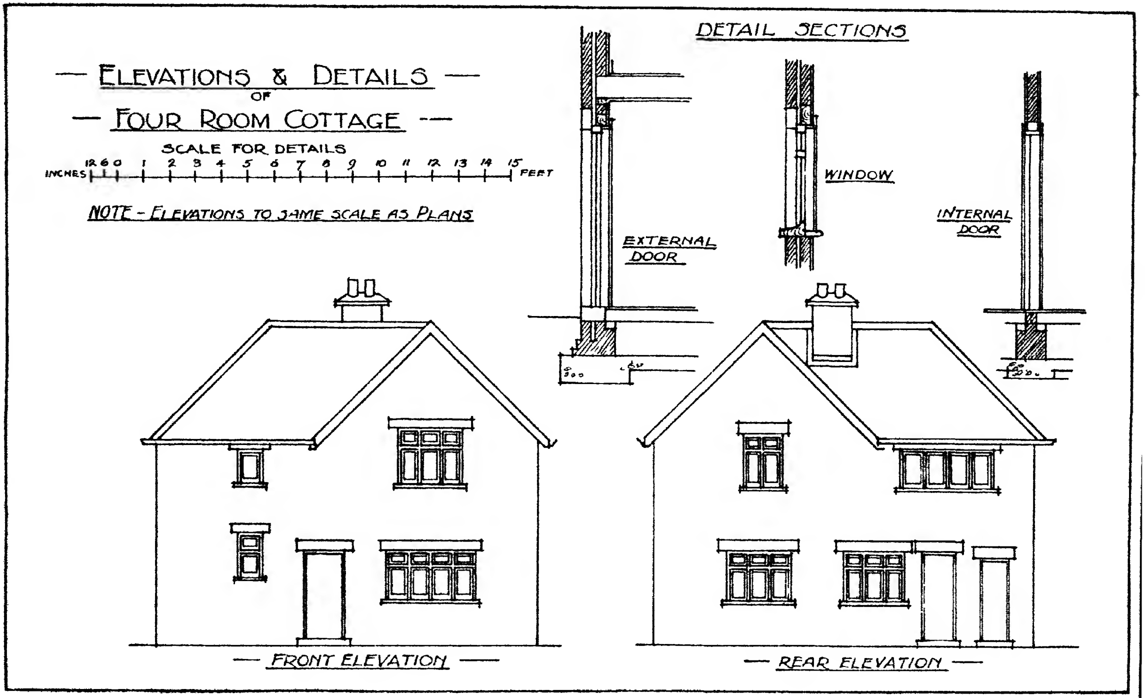

— ELEVATIONS & DETAILS —
OF
— FOUR ROOM COTTAGE —
SCALE FOR DETAILS
INCHES 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 FEET
NOTE - ELEVATIONS TO SAME SCALE AS PLANS
DETAIL SECTIONS
EXTERNAL DOOR
WINDOW
INTERNAL DOOR
— FRONT ELEVATION —
— REAR ELEVATION —

FIG. 80.

APPENDIX VI

THE **Standing Orders of the House of Commons,** which can be obtained through a bookseller, are divided into two parts—the first relating to **public** business and the second to **private** business. It is with the second that we are concerned. Private Bills are also divided into two classes, the second class only dealing with constructional works, such as railways, waterworks, tramways, roads, etc. The Standing Orders prescribe the times and places of deposit of documents, the form of the estimate, and deal more particularly in Section 4 of Part II. with the plans, books of reference, sections and cross sections, which are prepared by the engineer. A short summary of these provisions is as follows:

Plans to be drawn to a scale not less than 4 in. to a mile, and buildings 1 in. to 400 ft. For **railways,** distances must be marked from one end along the track, radii of curves must be shown, and tunnelling must be indicated. Diversions or widenings of roads and junction with existing lines must be shown. For **tramways,** the plan must show clearly the portion of the track in the road, and indicate where less than 9 ft. 6 in. intervenes between rail and kerb. **Tidal waters** must be coloured blue. Sections must be drawn to the same scale as the plan, and to a vertical scale not less than 1 in. to 100 ft., giving existing and proposed levels, heights of **embankments,** depths of **cuttings,** datum line, and height above ordnance datum. Rail level must be given at the beginning and end of each track and at changes in gradient, level crossings shown, bridges giving levels of roads under or over the railways, and the height and span of every bridge must also be given. **Tunnelling** must be clearly indicated on the section. In the case of bills for improving the navigation of a river, the heights of both banks must be given.

APPENDIX VII

THE following questions are intended to direct attention to the more important points dealt with in the text and to afford a means of testing the student's grasp of essential principles. Those numbered 76 to 83 inclusive, have been set at recent examinations for Associate Membership of the Institution of Civil Engineers (Section C.).

1. Give a list of the classes of publications which are required for reference by civil engineers in addition to text-books.

2. What consideration has the engineer to bear in mind in deciding upon a safe working stress for a material, the properties of which he can ascertain in a testing machine ?

3. What working stress would you allow in a tension member of a railway bridge for a dead load ? The material is steel conforming to the British Standard Specification, No. 15.

4. State in general terms how you would modify the stress given as an answer to question 3, (*a*) for a live load such as a railway train, (*b*) for an extra stress caused by wind pressure, (*c*) for a compression member subject to dead load only.

5. What working stresses would you allow for (*a*) granite bedstone, (*b*) Yorkstone bedstone, (*c*) blue brickwork in cement mortar, (*d*) a short stout post of oak—all in compression ?

6. Compare the safe working stresses on (*a*) Portland cement concrete 6 to 1 as used in foundations, (*b*) the same 4 to 2 to 1 as used in reinforced concrete.

7. Give a list of what you consider to be suitable colours for representing the materials in general use by civil engineers.

8. Describe the use of the Amsler planimeter for measuring areas on a drawing.

9. Print the words Great Southern Railway in (*a*) block capitals $\frac{3}{4}$ in. high, (*b*) single line capitals 1 in. high.

10. What are the data required by a contractor before he can estimate accurately the cost of any work which he proposes to carry out according to drawings, specifications and quantities supplied to him ?

11. What are the commoner structural materials required by a contractor for the erection of a steel bridge and masonry piers, and in what units would he obtain them ?

12. In what units are the following usually given in a bill of quantities prepared by a consulting engineer, (*a*) brickwork, (*b*) facing, (*c*) cement concrete, (*d*) rubble masonry, (*e*) timber in heavy framing, (*f*) steelwork in girders ?

13. Give a list of what you consider as reasonable prices for the work mentioned in question 12, carried out in your own locality at the present time.

14. Describe in general terms how you would prepare and bill the quantities for a bridge abutment.

15. Take off, abstract and bill the quantities for an isolated brick pier to stand 6 ft. above the ground, 1 ft. 6 in. square in plan, resting on two courses of footings and a block of concrete 4 ft. square, 1 ft. deep, the upper surface of the concrete being 15 in. below the ground level. The top of the pier is to be covered with a stone cap 6 in. thick and 18 in. square, its thickness being included in the 6 ft. above mentioned. Make a dimensioned sketch of the pier before commencing the quantities. Rule your own paper.

16. The directors of a railway company intend to deepen a cutting on their line in order to flatten the gradient and so reduce running expenses. The cost of deepening the cutting is estimated at £25,000 inclusive of all works of drainage, etc. The directors consider that the deepening will be of advantage for 50 years at least. Included in the scheme is the construction of a bridge, estimated to cost £10,000. The life of the new bridge will probably be 30 years, and the annual cost of painting and repairs is estimated at £100. What annual saving must be effected on running expenses in order to justify the carrying out of the scheme ? The rate of interest at which money can be borrowed by the company is 5 per cent., and at which it can be invested safely by them is 4 per cent.

17. Give an outline of the requirements of the Houses of Parliament with respect to the engineering particulars to be shown on deposited plans in connection with a Private Bill.

18. Give an outline of the work devolving upon an engineer if he decides to carry out a certain work, (*a*) by direct labour, (*b*) by contract.

19. What are the main points to be borne in mind in devising a simple system of accounting for stores to be obtained and used upon a large contract ?

20. What are the documents required to form a complete contract and what is the purpose of each ?

21. Give a list of six of the more important general conditions of a contract, with the purpose of each.

22. Explain what are meant by (*a*) provisional sums, (*b*) prime cost sums, in a contract; how are they dealt with during the progress and on completion of the work ?

23. Give outline clauses in the general conditions of contract dealing with (*a*) payment to the contractor, (*b*) daywork, (*c*) arbitration.

24. Write out a typical form of advertisement inviting tenders for a contract for the construction of sewerage works for a borough.

25. What data would you require in order to certify payment of money due to a contractor while a contract is being carried out, and in what form would you make out the certificate ?

26. Give a list of the tools, hand and machine, used in excavating in earth.

27. Describe how you would set out for (*a*) a deep cutting, (*b*) a deep embankment, on a line of railway over undulating ground, omitting the calculations necessary. In the absence of precise instructions, what side slopes would you allow ?

28. Describe the method of setting out a trench to a fall by means of sight rails and boning rods.

29. Give a sketch showing the timbering of a trench 18 ft. deep by means of runners in bad ground. The width of the trench at the bottom is to be 2 ft. 6 in.

30. How would you sink a shallow trench in dry running sand from the surface ?

31. Give a sketch plan of the timbering of a shaft 9 ft. square by means of runners.

32. Describe two methods of sinking brick wells without timbering the excavation.

33. Describe how a circular cast iron cylinder bridge pier 8 ft. in diameter may be sunk in a gravel river bed to a depth of 40 ft. below river bed level.

34. What are the essential points of difference between (*a*) a cylinder, (*b*) a caisson, (*c*) a stranded caisson ?

35. Give a sketch cross section of a puddled cofferdam 15 ft. high on a sloping foreshore, to keep out 10 ft. head of water.

36. Give outline specification clauses dealing with creosoted deal piling for the foundation of a bridge abutment.

37. Describe the method of timbering a heading in fairly soft ground.

38. Describe in general terms the construction of a large brick-lined tunnel with a top heading.

39. What precautions have to be adopted in the construction of a large embankment and what preliminary works are necessary ?

40. Give a sketch and description of an ordinary pile frame. What precautions are necessary in driving concrete piles ?

41. Name six kinds of stone in common use in your locality and state for what purposes they are used.

42. Give sketches showing how the bedding planes should be arranged in (*a*) a wall, (*b*) an arch, (*c*) an overhung label course.

43. Sketch and describe two devices in common use for enabling stones to be lifted without the necessity of passing slings around them.

44. Sketch an elevation of a small portion of wall in (*a*) uncoursed rubble, (*b*) snecked rubble, (*c*) block-in course.

45. Sketch (*a*) a copper cramp in position for joining two coping stones, (*b*) a cement joggle for a similar purpose.

46. Give outline specification clauses for the masonry of (*a*) a snecked rubble bridge abutment, (*b*) a block-in course retaining wall.

47. Give an outline of the process of making bricks by hand, and burning in a clamp.

48. Give a list of six well-known *special* kinds of brick and the uses to which they are generally put.

49. What are the precautions to be observed in building good engineering brickwork apart from the details of bond ?

50. Give a description and sketch of English bond and the rules to be observed in carrying it out correctly.

51. Sketch a cross section of a solid brick retaining wall in ordinary earth on a concrete foundation. Unsupported height of wall 9 ft.

52. Give outline specification clauses dealing with (*a*) brickwork in thick walls, (*b*) brick arches, (*c*) mortar.

53. Give a list of six kinds of timber in common use, specifying the purposes for which each is used.

54. What are the common causes of deterioration in timber structures, and what are the usual methods of guarding against them?

55. What is the distinction between lapped, fished and scarfed joints ? Give a sketch of one of each kind.

56. Describe in outline the manufacture of a rolled steel joist from the ore by the open hearth process.

57. What are the present requirements of the British Standard Specification for (*a*) structural steel, (*b*) rivet steel, as regards physical tests ?

58. What are the usual sections in which structural steel can be obtained ? What extras are usually charged by manufacturers on the " basis " price ?

59. What precautions should be observed in designing a riveted joint apart from strength calculations ?

60. What requirements would you specify as regards the quality of cast iron for a structural column ?

61. In what forms are cast-iron tanks usually constructed ? How are they jointed and supported ?

62. Give sketches of two forms of joint in common use for cast-iron pipes.

63. What are the requirements of the British Standard Specification as regards the physical tests for Portland cement? How is the testing carried out?

64. What are the precautions to be observed in mixing and depositing concrete for reinforced concrete work?

65. Give an outline specification clause to cover the mixing and depositing of concrete for a massive retaining wall (not reinforced).

66. Give in list form the main operations to be performed in building a small one-storeyed engine house, in their correct order, omitting drainage and water supply.

67. Sketch a typical cross section of a single track railway on embankment, according to ordinary British practice.

68. What are the main considerations affecting the choice of the type of bridge to be used for crossing a tidal river with shipping traffic.

69. Give a sketch cross section of a typical town road 50 ft. wide with footways paved with concrete flags, the carriageway finished with tar macadam.

70. What are the essential differences between road and railway bridges affecting their general design?

71. What are the purposes of a wet or floating dock, and in what way does it differ from a tidal basin?

72. What are the precautions to be adopted in running a large pipe line from a reservoir to a town, say, 30 miles distant over hilly country?

73. What data are required for the design of large sewers in the "combined" system, and in what way would they be modified if the "separate" system were adopted?

74. What are the usual methods of sewage purification at the present day?

75. How may natural waterways be improved by the engineer?

76. Draw a brief specification, with description and sketch, for one of the following: (*a*) a length of cast-iron pipes 36 in. in diameter, including jointing, (*b*) a tramway track, including foundation and paving. (A.M.I.C.E.)

77. Take out and schedule quantities for (*a*) a road bridge (drawing supplied with question.) (A.M.I.C.E.)

78. Draw up general contract clauses dealing with any two of the following, (*a*) labour, (*b*) contractor's plant, (*c*) maintenance. (A.M.I.C.E.)

79. Give the general clauses in the British Standard Specification for (*a*) mild steel railway rails. (A.M.I.C.E.)

80. To what points would you give attention in inspecting any of the following, (*a*) mild steel bars for reinforced concrete, (*b*) wood block paving. (A.M.I.C.E.)

81. Make a rough dimensioned sketch of (*a*) a reinforced concrete wharf to carry a track for a 30 ton crane along the front, and 10 cwt. per sq. ft. on the remainder. Range of tide 20 ft., depth of water at low water 30 ft., river bed of boulder clay. (A.M.I.C.E.)

82. Draw up a special contract clause dealing with running sand in an excavation. (A.M.I.C.E.)

83. Draw up a brief report on the following, giving reasons for failure, accompanied if necessary by sketches, (*a*) leakage of sewer. (A.M.I.C.E.)

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