BRIDGE OVER THE TRENT, AT NOTTINGHAM, MR. M. O. TARBOTTON, M.INST.C.E., ENGINEER.
MADE AND ERECTED 1869-70, BY ANDW. HANDYSIDE AND CO., DERBY AND LONDON.

See page 158.

WORKS IN IRON.

BRIDGE AND ROOF STRUCTURES.

BY EWING MATHESON,
M.Inst.C.E.

WITH EXAMPLES OF STRUCTURES

MADE AND ERECTED BY

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PREFACE.

ALTHOUGH published under an old title—adopted four years ago for a book on the same subject—the present Work is entirely new. Not professing to deal with the pure science of engineering practice, it treats of practical considerations which affect the choice of design in regard to iron structures. The qualities of material, the classification of different systems, the incidents of transport, and the methods of erection, are stated from a manufacturer's point of view, with a special reference to comparative cost.

The "Examples" given on pages 135 to 190, and 239 to 289, are all selected from Works constructed by ANDREW HANDYSIDE & Co., at Derby, and of which the author is personally cognisant.

The need often felt by engineers for a dictionary of foreign technical words suggested the Vocabulary given in the Appendix.

The author is glad here to acknowledge the assistance rendered him by Mr. A. BUCHANAN, of Derby (under whose direction all the Examples of Structures referred to above were carried out), and by Mr. MAX AM ENDE, of London.

LONDON,
January, 1873.

PREFACE TO SECOND EDITION.

IN the revision necessary to a new Edition, the fluctuations in prices on page 4 have been continued to March, 1876; the remarks on the qualities of iron and steel have been modified; and some new "Examples" (Nos. 8^{A}, 10^{A}, 30^{A}, 55^{A}, 61) of structures have been added.

LONDON,
December, 1876.

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WORKS IN IRON.

PART I.—BRIDGES

CHAPTER I.

THE QUALITIES AND PRICES OF CAST IRON, WROUGHT IRON, MALLEABLE CAST IRON, STEEL. THE WEIGHT OF IRON AND STEEL.

CAST IRON.

THERE are very wide differences of quality in the various kinds of cast iron which are made in Great Britain; and although the experiments of the last thirty years have done much to make these differences better known, they are not so generally appreciated as are those in wrought iron.

The introduction of the hot blast in ore-smelting furnaces, forty years ago, had the immediate effect of increasing the quantity of pig iron produced from every ton of ore; but, at the same time, the quality somewhat deteriorated. Now, however, by improved systems of working and applying the hot blast, the difference in quality between iron so made and cold blast iron is greatly lessened, and is for most purposes practically of no effect. The small quantity of cold blast iron which is now made is for special purposes.

Cast iron is used to a large extent for articles (gas-pipes, short columns, &c.) whose dimensions are determined, not so much by an investigation into the forces they may have to resist, as by purely practical considerations, such as architectural outline, intended long duration under unfavourable conditions, the impossibility of casting large pieces with a small thickness of iron, &c., most of which favour a consumption of metal often greatly in excess of what would be needed if only the capability (which is very great in cast iron) of resting compressive strains were considered. For such purposes the most rudimentary criticism of the quality of cast iron will be sufficient, *i.e.* that it is stronger than stone or clay, that it can assume almost every imaginable shape, and that it lasts very long under a coat of oil paint. These qualities are not wanting in any substance which is sold under the name of cast iron. But there are many articles or structures made of cast iron which have to support great loads, and to resist very considerable forces, under circumstances where no excess or waste of metal is required. Such are columns of great height in proportion to their diameter (almost all columns are here comprised) where the quiescent central pressure produces a transverse strain besides the compression; such, also, are girders where the transverse strains are direct; and such, again, are articles subjected to powerful vibrations and concussions which altogether evade calculations of an ordinary kind. In these cases the intensity of molecular cohesion and the elasticity possessed by good cast iron become of the greatest importance.

Considerable experience and skill are needed to judge of the quality of cast iron from inspection even of a fracture, but there is little or nothing in the outward appearance of a casting to denote quality.

The same smelting furnace, with the same description of material, may be made to produce several descriptions or qualities of iron, according to the proportion of fuel employed in the operation of smelting: thus, when the fuel used is in large proportion to the burden, soft, tough, grey iron will be produced, but when the quantity of fuel is diminished to its lowest point, hard and brittle white iron is the result.

There are six varieties of pig iron, known by the following numbers or names, viz.:—

NO. 1. Is the production of the furnace when charged with a large quantity of fuel in proportion to the quantity of ironstone. This iron is the most slowly made of all the descriptions of pig iron, and contains a larger proportion of carbon, in chemical combination or mechanical admixture, than any other quality. It is the most fusible pig iron, and most fluid when melted, and is used for small and delicate castings. The fracture of this quality of pig shows a dark grey colour, with high metallic lustre; the crystals are large, many of them shining like particles of freshly-cut lead. However thin this metal may be cast, if of good quality, it retains its dark grey colour. This iron is the best description and the highest in price. The amount of carbon it contains is as much as from 3 to 5 per cent.

NO. 2. Is intermediate in quality and appearance between Nos. 1 and 3.

NO. 3. Contains much less carbon than No. 1. The crystals shown in a fracture of this iron are smaller and closer than in No. 1, but are larger and brighter in the centre than nearer the edges of the fracture. This is a strong iron when of good quality, and is sufficiently fluid for use in the foundry for large castings. A mixture of this with a proportion of No. 2 forms excellent foundry metal. The colour is a lighter grey than No. 1, with less lustre.

NO. 4, or BRIGHT. This iron has a light grey fracture and but little lustre, with very minute crystals of even size over the whole fracture. It is the "leanest," or contains less carbon, of any of the grey irons. It is not fusible enough for foundry purposes, but is used in the manufacture of wrought iron. It is the cheapest of the grey irons. When inferior in quality, and nearly passing into the variety of pig iron called "mottled," there is usually a thin coat or "list" of white iron round the exterior edges of the fracture.

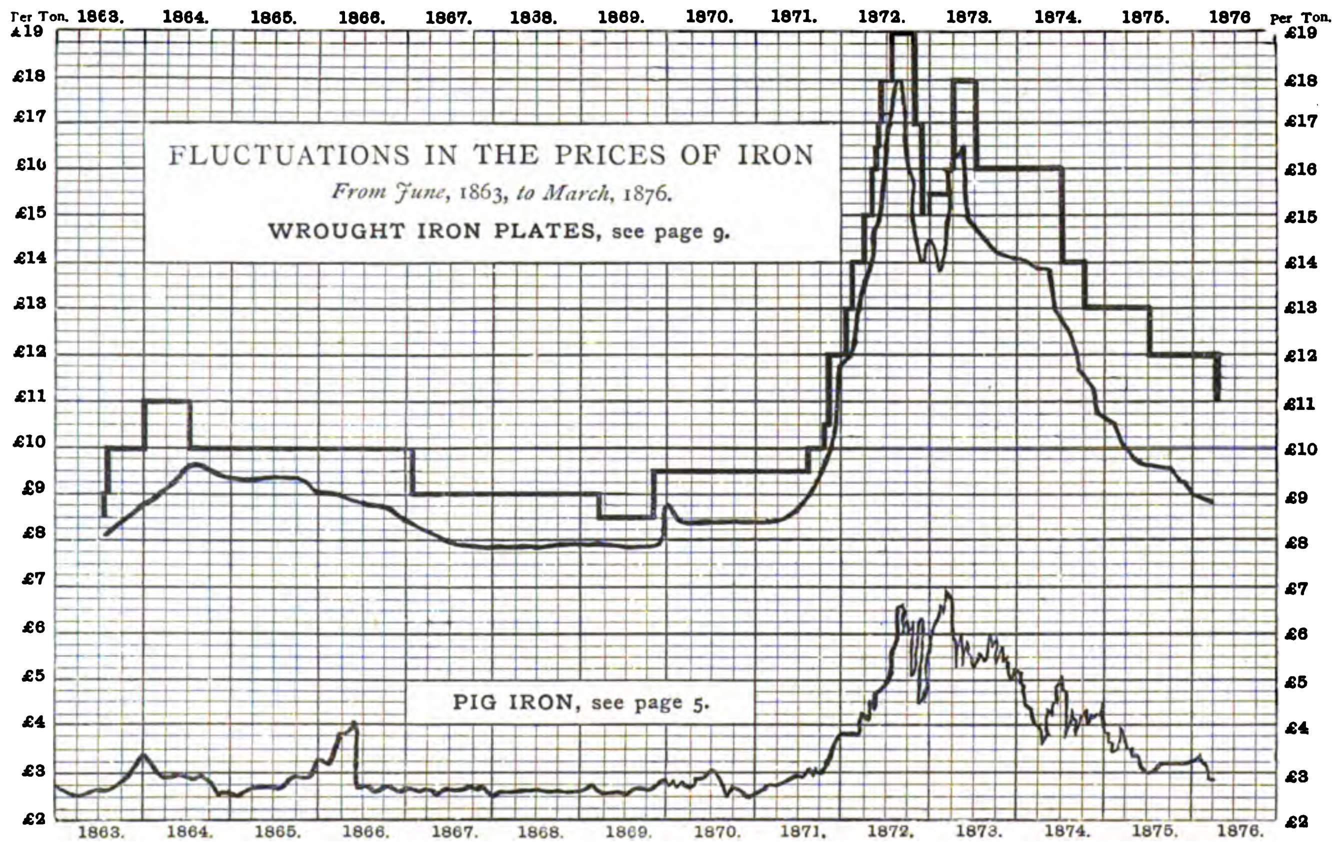
MOTTLED. Is intermediate between No. 4 and White; the fracture being dull dirty-white, with pale greyish specks, and with a white "list" at the edges.

WHITE. This is the worst and most crude, hard, and brittle of the pig irons; the fracture being metallic white, with but little lustre, not granulated, but having a radiating crystalline appearance. This iron is largely used in the manufacture of inferior bar iron. It is sometimes produced by the furnace working badly, or is made by using a minimum of fuel with the ore and flux.*

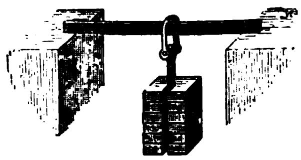
It is the art or business of an iron-founder to know what is the best mixture of iron for any special purpose.

Where specially severe service is required from cast iron, special tests are generally demanded, as in the case of railway chairs, where the test of a weight falling on the casting resembles in some measure the heavy and sudden shocks which have to be endured in actual service during the passing of trains. But for ordinary purposes, what may be termed the "beam test" is that now generally adopted by engineers, and by it the transverse strength and elasticity of the iron can be

* The above classification is quoted from "The Manufacture of Iron in Great Britain," by George Wilkie. London: Fullarton & Co. 1857.


FLUCTUATIONS IN THE PRICES OF IRON
From June, 1863, to March, 1876.
WROUGHT IRON PLATES, see page 9.
PIG IRON, see page 5.
Per Ton.
1863. 1864. 1865. 1866. 1867. 1868. 1869. 1870. 1871. 1872. 1873. 1874. 1875. 1876.
£19 £18 £17 £16 £15 £14 £13 £12 £11 £10 £9 £8 £7 £6 £5 £4 £3 £2

measured. As affording a convenient unit for comparison, a standard size of test bar, 3 ft. 6 in. long, 2 in. deep, and 1 in.



broad is generally used; and this is placed on bearings 3 ft. apart, and loaded in the middle till broken.

The weight sustained by this bar or beam before fracture indicates the strength of the metal; but, as considerable power of cohesion may be attained in alliance with extreme hardness and brittleness, it is necessary also to measure the amount of bending and deflection which occurs, and thus to ascertain the elasticity and ductility of the iron. If a bar made of twice melted iron (*i.e.* iron first made into pigs from the ore and then remelted) be subjected to the test just described, it will be found that the weight necessary to break the bar will vary (if the bar be made of one kind of iron), according to the locality from which the ore is obtained, from 2,300 lbs. to 3,500 lbs., and, if made from mixed irons, from 2,700 lbs. to 4,300 lbs.; and that the ultimate deflection before fracture will vary from $\frac{2}{10}$ths to $\frac{5}{10}$ths of an inch. These are wide limits, indicating very great differences in the value of the iron; and it is therefore not surprising to find a corresponding difference also in the prices. There are constant variations in the market prices of pig iron, as will be seen from the diagram on page 4, which gives the prices of ordinary Scotch iron according to the current daily rates at Glasgow for the thirteen years ending 1876. Special brands of superior Scotch iron, and some of the best Derbyshire and Yorkshire irons, are generally sold at higher rates than the kind which is given on the diagram; while inferior sorts may be purchased at prices ranging from 10 to 20 per cent. below the diagram.* The enormous quantity of iron which is produced in the Middlesborough district includes different qualities, some of them of a very inferior kind; and although, by judicious mix-

* The *relative* prices of different kinds of iron are subject to variation under certain circumstances. During the exceptional period of 1872, as indicated on the diagram, Scotch pig iron, though high in price, was not so high in proportion to other kind as usual.

ture of the local ore with other and better sorts, a good standard may be reached, the inferior iron is available for those who wish to purchase at a low price. The hematite iron found in different parts of Cumberland and Lancashire costs from 30s. to 40s. per ton more than the rate shown on the diagram; and this iron is of a peculiarly tough nature, which renders it very valuable for mixing with other kinds.

Only the lower tests given on page 5 can be sustained by cheap iron; but, as all kinds of pig iron are much improved by mixing with other sorts, the quality of the metal used in castings would be kept nearer to an average standard if mixing were adopted to a sufficient extent. But in those cases where the cost per ton is the only consideration of the purchaser, the lowest price for castings will of necessity be obtained from those founders who use the cheapest iron, and who do not incur the expense of buying and carrying to their premises more expensive kinds for mixing with it. The cheapest castings are in some cases not made from pig iron at all, but directly from the ore-smelting furnaces, and thus contain the dross or refuse which would be abstracted by a second melting. A large proportion of the iron castings supplied for building purposes in this country are made without any reference whatever to the quality of the iron. It is often the case that an increase in the dimensions is supposed to compensate for inferiority of quality; but it is well known to engineers that certain shapes should be avoided, and that beyond a moderate thickness cast iron becomes spongy or open. A hollow column 1 in. thick would not be doubled in strength if made 2 in. thick.

It will be seen from the figures given on the preceding page that the price of different sorts of iron varies considerably; but the cost of labour and of transport are, of course, the same for all, and pig iron of a lesser cost and proportionately lower quality will, when made into a casting, show an inferiority more than proportionate to its low price: thus a saving of 25 per cent. in the cost of the raw material will be reduced to 10 per cent., or even less, in the finished casting, which still preserves its inferiority in quality of 25 per cent. As inferior iron must be cast into heavier forms than would be necessary with better material, the cost of carriage is also increased in proportion; and for foreign countries, where the original price of the castings in England bears but a small proportion to the total cost after the expense of sea freight and land carriage has been defrayed, it is but the pretence of economy to use cheap iron. Moreover, inferior metal is generally brittle, and its use involves more than an average risk of breakage during transport and transhipment. It would be an advantage, therefore, if specifications of iron work were given with greater distinctness and more often enforced. A strength capable of enduring 25 cwt. on the test bar without fracture should be the minimum quality allowed even for short and heavy columns; but for other purposes a load of from 28 to 30 cwt. and a deflection of $\frac{3}{10}$ in. should be demanded. The deflection will vary from ·3 in. to ·5 in. There is no difficulty in getting such iron, and higher qualities can be given if necessary, breaking strains of 30 to 35 cwt. being obtainable with judicious mixtures of the best kinds of iron; and in testing such iron it will generally be found that some of the bars will endure as much as 38 cwt.

In the minds of those who are not aware of the great differences of quality that have been here referred to, the numerous accidents and risks that often attend the use of cheap metal have created a prejudice against the use of cast iron altogether; and many people, considering it to be without elasticity, avoid it wherever wrought iron can by any means be used instead. This is the more to be regretted, because cast iron allows infinite variety of shapes, more nearly approaching the exact forms and sizes required by design or strength, than is possible with wrought iron; and for many situations cast iron is even stronger and more enduring.

The various prices of cast iron given in later chapters are all based on an assumed rate of £4 per ton for pig iron.

Refined and homogeneous iron can be made by mixing proper kinds of pig iron together, casting them again into pigs, and remelting them for castings. Steam and hydraulic cylinders are with advantage cast from superior iron of this sort.

In 1870, the production of pig iron in Great Britain amounted to 6 millions of tons.*

* "Mineral Statistics of the United Kingdom," by Robert Hunt, F.R.S. London: Longmans & Co.

WROUGHT IRON.

In describing the strength of wrought iron, it is usual to adopt the common unit of one square inch of section as a standard of comparison; and such terms as—a strain of 5 tons per square inch, or 10 tons per square inch, allow the total on a given area to be easily calculated.

The quality of wrought iron, although depending in the first instance on the kind of raw material (pig iron) from which it is made, is affected to a great degree by the amount of working to which it is subjected during the process of manufacture. The recent introduction of machine puddling is likely to render more equable the treatment of the iron during this stage of the manufacture, and probably at a less cost than the general method of manipulation by puddlers. Bars that by their shape or small section demand more than the average amount of working and rolling, are generally of better quality than the larger and simpler sections produced from the same material but by less labour. If a round bar 3 in. diameter, of a strength equal to a breaking strain of 20 tons per square inch, were rolled down to 1 inch diameter, the iron at the reduced size might probably endure a strain of 25 tons per square inch. Wire can be subjected to very much higher strains without fracture. Sometimes, however, the method of rolling iron into peculiar sections causes lamination in some of the parts, which renders the iron not everywhere equally strong or elastic. From this it arises that from certain sections, where the iron is afterwards heated in the fire or worked on the anvil, it is difficult to produce the shapes that may be desired without burning or cracking the iron.

It was till lately the custom of most engineers to specify the kind of iron they required, as "Best," "Best, Best," "Best Staffordshire;" and, so far as these words distinctly implied a certain quality, they were sufficient; but as the B. of one district was equal perhaps to the B.B. of another, and the terms thus conveyed a conventional and rather uncertain meaning, at last it became necessary to indicate the really best iron in the market as "Best, Best, Best." It is now thought expedient to avoid such phrases, and to state distinctly the strains and tests to which the iron shall be equal. Certain of the best brands or trade-marks of old-established manufacturers still sustain their reputation; and, because of the guarantee which the brands are supposed to afford, such iron always commands the highest market price. As, however, there are many other good rolling mills in various parts of the country, it is more economical to specify clearly the *quality* that is desired, and to leave open the locality where the iron is to be made.

The prices of iron fluctuate very considerably, and on some occasions during the last ten years with an unprecedented rapidity, so that any bare statement of the present prices might probably mislead. But the *relative* prices of different kinds of iron do not generally vary much;* and the differences between pig iron, plates, bar, and L iron, &c. that always prevail, may be gathered with a very fair degree of accuracy from the prices given on the next three pages, and from the diagrams on page 4. As the various iron structures quoted as examples (see Bridges, Piers, Roofs, &c.) have appended to each of them the approximate costs, an arbitrary value of iron must, amongst various other considerations, be assumed as a basis for calculation. That value has been taken from the prices given in this section, and not from the actual costs at the date of the present publication. The diagrams on page 4, which refer to the past, may be of some assistance in judging of the probabilities of the future.

The upper diagram indicates the fluctuations from 1863 to 1876 of the "list" price at Birmingham for good Staffordshire plates of a quality fully equal to that described on page 10, as suitable for structural purposes. But while plates bearing well-known brands of old-established reputation can always command the full price, plates of good quality by other makers can generally be purchased at from 5 to 15 per cent. less, the second diagram showing the fluctuations in the price of such iron. Inferior qualities, such as have been made in Wales and elsewhere, may be purchased at from 10 to 20 per cent. less than the diagram standard. But the rapid growth of the rail

* A sudden or great demand for one sort of iron of course tends to raise its price. The price of plates in June, 1872, was higher than usual as compared with bars.

trade in South Wales had the effect of diverting attention from other branches of iron making, and during the ten years ending 1875 bars and plates did not form such a large staple of trade as formerly. How far the substitution of steel rails for iron rails will set free again the Welsh iron rolling mills for plates and bars, remains to be seen.

The reaction downwards from the high prices of 1872 was one that was generally anticipated, but it is hardly probable that the low prices of 1869, even if reached at all, will ever long prevail. The constantly diminishing purchasing value of gold is apparent in the iron trade as elsewhere; and as not only the prices of fuel and the rates of wages have risen, but the hours of labour have been reduced, there are many elements at work to keep up prices. Against these must, of course, be placed the economies that have been and may be obtained by improvements in machinery, new methods of working, the competition of an increased number of iron-works, and fluctuations in the home and foreign demand.

Taking £12 as the price of plates at a given time, then if notoriously cheap and inferior sorts be omitted, wrought iron of other sections may be obtained in the open market at the rates per ton quoted on page 13 to sustain the following strains; and respectable manufacturers of bridges, roofs, and other iron structures, may be expected to use such iron without express stipulation. Square, round, flat, and L bars will endure a tensile strain of from 20 to 24 tons per square inch before breaking, and 20 tons should be considered the minimum. T bars have about the same strength; but, owing to the manner in which they are rolled (see description of joist I iron in Chapter V.), it is in some other respects inferior to L and simple bars. Plates, as a rule, are not capable of sustaining such a high degree of tension as bars made from the same quality of pig iron; and from 18 to 22 tons may be taken as their breaking strain. As the breaking strain of a number of bars purchased together will vary, a specified minimum breaking strain implies an *average* strength of a higher figure; and, for iron of fair quality, this average may be taken as about 22 tons for bars, and 20 tons for plates.

Iron begins to elongate directly it is strained, and stretches $\frac{1}{10000}$th of its length for every ton strain per square inch, up to the limit of elasticity.* With a strain of 10 or 11 tons, an elongation of $\frac{1}{100}$th part will be reached; and, if the force be withdrawn, the iron should be of such quality as to return to its original length. If the iron is stretched beyond this point, the rate of elongation increases, and the *permanent set*† commences, *i.e.* the bar will not entirely recover itself after the strain has been withdrawn. The limit of elasticity, rather than the ultimate or breaking strength possessed by a piece of iron, determines its value for structural purposes; and, although the quality of wrought iron depends also on the breaking strain, and is often so specified, this by itself is of little significance. For determining the quality of wrought iron apart from the mere breaking strength, the decrease of area at the point of fracture—showing thus how much the iron has stretched—will give the amount of elasticity. A diminution of area of 10 per cent. in plates, 15 per cent. in T and L iron, and 20 per cent in bars, affords a proof of sufficient elasticity, and if combined with the breaking strains given on the preceding page such iron is of a quality admirably suited for railway bridges. If it is attempted to obtain with such tests for elasticity higher breaking strains than these, the difficulties of manufacture are so much increased as to render necessary an increase of price out of proportion to the extra quality of iron so produced. The fact that the iron can be bent cold to a certain angle without damage will show its toughness.

* The maximum amount of strain which any piece of iron will endure without losing its capacity of returning to its original condition when the force is withdrawn, is called its "*limit of elasticity;*" and in wrought iron under a tensile or compressive strain, this limit, or commencement of permanent set, occurs at about half the breaking strain, the exact point varying with the quality of the iron, and the kind of treatment to which it has been subjected during manufacture.

† *Permanent set.* Although, after enduring a tensile force equal to half the breaking strain, wrought iron will practically return to its original length when the force is removed, and *permanent set* may be said to commence only after this strain has been exceeded, the statement is perhaps not absolutely correct. It is asserted by some engineers that even after 2 and 3 tons there is—however infinitesimal it may be—an amount of permanent set that can be measured. For all practical purposes, however, this may be ignored; although, probably, if the iron were subjected to a *long succession* of heavy strains, its elasticity might be diminished, and the permanent set commence earlier and be more apparent.

For instance, a plate ½in. thick, bent to an angle of 35° without damage, will, if it possesses sufficient breaking strength, afford, for ordinary purposes, a satisfactory proof of its elasticity. Of course, the thicker the plate the more acute should be the angle by which it is tried. Some kinds of wrought iron will bend to a much greater angle than 35°; Lowmoor iron will bend nearly double without breaking. An iron bar which under the hammer will bend 180° without rupture, the space between the two ends being equal to the thickness of the iron, is good for almost any purpose.

Although the quality of plate and bars just described is that generally used, higher qualities may be obtained. Bars rolled entirely of scrap iron and of a strength equal to 25 tons per inch breaking strain can be procured; but, unless the sections are small, it is difficult to obtain an absolute guarantee of such a strength, without paying a more than proportionate price. Iron equal to breaking strains of from 24 to 28 tons is occasionally made for special purposes, but is seldom used for girder work. In demanding a very high tensile test without other stipulations, there is the risk that it may be obtained at the expense of other necessary qualities; and the iron which can withstand a force of 24 tons per sq. in., may possess a very small capability of stretching, which is to a great degree essential to the safety of a wrought iron structure.

It is the general practice of engineers, in designing bridges, roofs, and other structures, to give such dimensions and thickness of iron as shall involve only a maximum working strain of from 4 to 7 tons per sq. in. Within these limits, the strain varies with the nature of the service. In railway bridges and other structures, where sudden and oft-repeated strains have to be endured, 5 tons is the utmost tension allowed under a test load. In road bridges, roofs, and other structures, where the service involves less severe percussive strains, 6 and even 7 tons are sometimes allowed, but this depends on various circumstances.* The iron from which *rivets* are made should be of a better quality than ordinary bars, and its ductility should be such that it will bend double when cold without cracking.

Referring to the remarks on page 9, and the diagram on

* See "Loads and Strains on Bridges and Roofs."

page 4, as describing the fluctuations in the price of iron, the following may be taken as the relative prices of the different sorts: Assuming that the price for plates is £12 per ton, ordinary flat and round bars may be purchased at £10 to £10 10s., L irons at £10 10s. to £11, and T irons at £11 to £12 per ton. But for L and T irons of a section whose total dimensions exceed 8 in. (that is exceeding 4 in. by 4 in., or 5 in. by 3 in.), and for bars over 6 in. wide, extra prices have generally to be paid. Joist I iron and channel ⊔ iron of small sections up to about 7 in. in depth may be obtained at the same price as T iron; but, with the larger and wider sections, the price rapidly advances, so that with a depth of 12 or 14 in., a price of £15 is reached. Bars of all kinds may be obtained in lengths of 20, 30, and even 40 ft., according to their section; but, when a weight of 4 cwt. is exceeded, extra prices are charged. As seen from the foregoing figures, plates are generally dearer than ordinary bars and L irons. Plates can be obtained of any size up to an area of 24 ft., if not exceeding 4 cwt., without extra price; but the increase in price is not very great up to 8 cwt. Thin plates of large area cannot be rolled. From many manufacturers, plates 12 in. wide can be purchased rolled as bars, that is to say, with edges true and square enough to obviate the necessity of planing.

A superior kind of iron is rolled by several manufacturers, of whose brands those of Lowmoor, Bowling, and others in the same district, are well known. Special care is used in the choice of material for this iron, but its superiority is obtained chiefly by the extra labour bestowed upon the rolling. It has a greater strength than ordinary iron, and has a high limit of elasticity; but, when compared to ordinary iron, these qualities are not high enough in proportion to its high price (£18 to £28 per ton); and although for exceptional cases it might be desirable to use it for structural purposes, in most instances where great strength is wanted steel would be better. These irons are principally made for using in the furnaces of boilers, and in other situations where they are exposed to great heat, the elaborate process by which they are rolled rendering them homogeneous, and peculiarly free from liability to blister.

As a general rule in all structures, economy is obtained by using bars and plates of ordinary sizes and sections, and by avoiding an unnecessary variety of sizes. The strains upon a bridge or roof often require in theory different sizes of iron varying by fine gradations at different points; but even if a slightly less total weight would be thereby obtained, it will generally be found cheaper to have few and simple, although larger sections. As no one iron-maker has rolls for all sizes of iron, the greater the variety of sections required the greater is the inconvenience in obtaining them.

MALLEABLE CAST IRON.

Articles of cast iron, if subjected to an after-process of annealing, may be softened, and will acquire some of the toughness of wrought iron. The castings are made from pig iron, and by preference from a special kind, and being packed in boxes with suitable ingredients,* are kept in an annealing oven at an equable heat for a time varying according to the form and size of the castings. By this process, and the decarbonising which takes place, the metal is so changed as to become malleable; and, though without the peculiar fibre that rolled or hammered iron possesses, it will exhibit many of the properties of wrought iron and steel. The malleable castings, as they are called, may be bent, hammered, and twisted without fracture, and can without risk be exposed to concussion, torsion, or other sudden strains which could not be endured by ordinary cast iron. The fact that they can be run, when fluid, into small and intricate moulds renders these annealed castings valuable for many situations where forged wrought iron would either be very expensive or altogether impossible to deal with. In a steam-engine or other machine there are many small parts which are subjected to such sudden shocks and torsion that cast iron must be of extreme thickness to endure them, while at the same time these parts do not require all the ductility and elasticity of wrought iron. It is in these cases that malleable castings are valuable; and if, owing to a repetition of the same machine, a

* Hematite iron ore is generally employed, and sometimes also the iron scale or black oxide detached from wrought iron in the process of forging or rolling. These and some other ingredients give out, when heated, a considerable amount of oxygen, which, when imparted to the castings, removes from them the carbon in the form of carbonic acid gas.

large number of similar castings have to be made, the economical advantages afforded are obvious.

The attention of engineers has been much directed to the use of cast steel for machinery and structural purposes; but, as stated on page 18, it is found difficult to get sound, strong castings except in simple shapes that can afterwards be rolled or hammered. In many such cases malleable cast iron will, to a very considerable extent, supply the place of steel. For the shoes and connecting pieces in roof structures, ordinary cast iron is sometimes used where the malleable castings would be much better suited to the service required.

The cost of the annealed castings depends mainly upon the size of the articles and the quantity made at the same time; because, if the quantity be large, special arrangements can be contrived to economise labour. The prices vary from 3d. to 6d. per lb., or 28s. to 56s. per cwt.

STEEL.

A chemical combination of iron with a certain quantity of carbon is called steel; and, with regard to this quantity of carbon, steel stands between cast iron and wrought iron. Cast iron contains about 1 per cent. of pure carbon and 2½ per cent. of carbon mixed with graphite, while the quantity contained by wrought iron is so small as to be inappreciable. Steel is in all cases made from iron, and the different methods of production may be broadly divided into crucible and Bessemer; the first being a process of carbonising wrought iron, which, as just stated, contains very little carbon, while the latter is the reverse process of decarbonising cast iron which contains too much. Crucible steel is made by melting pieces of blistered* steel in fire-clay pots, or crucibles, and pouring it into ingots or moulds of a desired shape. The steel thus produced is subjected to after-treatment by hammering, rolling, &c.; but as it is seldom used for girders and the other similar purposes described in this book, it is needless to refer further to it here. The novelty and economy of the process by which Bessemer steel is made,

* *Blistered* is the name given to steel when first converted from iron, and in this country it is generally made from malleable iron by a process called *cementation*. Shear steel, for making certain kinds of tools, is made from blistered steel by heating and working pieces of it under heavy hammers.

consists in its being a direct conversion of cast iron, a portion of the combined carbon, and the whole of the mixed carbon being removed during combustion. The Bessemer steel ingots contain about 0·4 per cent. of combined carbon, a minute amount of mixed carbon and a certain quantity of silicon, sulphur, phosphorus, and other impurities, the amount of which in any piece of steel to a great extent determines its quality. Part of these impurities are got rid of by hammering or rolling the ingot into the shapes required, or by first remelting it in crucibles and then giving shape to the material thus refined, by hammering or rolling. By the former and simpler of the two processes, most of the steel plates, rails, L, T, and other shaped bars are obtained.

The strength of rolled steel bars and plates for resisting tension varies very widely, and depends on the quality of the cast steel and the amount of working afterwards bestowed upon it. Breaking strains of from 30 to 60 tons per square inch indicate the extreme points of difference; and the *limit of elasticity*, or the point where *permanent set* commences, depends on various causes, and compares even more irregularly than in iron to the breaking strain. A tensile and compressional strength equal to a breaking strain of 30 to 40 tons, with a limit of elasticity of 15 to 20 tons, may be stated as the quality of the plates, L and T sections, which are now made for constructional purposes. Up to the year 1875 steel of this kind could be purchased in England from £20 to £24 per ton, if iron were selling at the prices stated on page 13, and at lower rates when iron was cheaper. As stated below, the trade in steel appears (1876) to be changing. Up to the present time steel has not been rolled into so many different sections as iron; and, as the same rolls are not suitable for the two metals, the choice of sections is limited, unless the quantity of a new kind which is required is sufficient to induce the manufacturer to make a set of rolls costing from £40 to £100. Both L and T sections of all sizes up to 4 in. by 4 in. are now made, but beyond this limit the sections for which rolls exist are few in number, and, as is the case with iron, cost more per ton than the smaller sizes. Steel equal to a tensile breaking strain of from 40 to 55 tons is made for special purposes, such as chain links for suspension bridges; and properly-shaped bars cost from £35 to

£50 per ton. With steel of this kind it is most important to know the limit of elasticity, and without this knowledge its real value per ton cannot be ascertained. The quality of the steel in this respect depends entirely on the methods by which it is prepared; and bars of steel, which in the earlier stages of manufacture are the same, may, according to the skill which is bestowed upon them, differ very widely in their figure of elasticity.*

The prices of steel, as compared with those of wrought iron, have hitherto hardly afforded a correct criterion of the relative cost of production. The manufacture of iron has been carried on to so large an extent and by so many people, that prices have been brought down to the lowest remunerative point; while, on the other hand, the manufacture of steel bars and plates has been in few hands, special skill, not widely found, is needed for the manufacture, and the amount produced is so small (when compared to iron), that regular market prices cannot always be obtained. The very large quantity of steel rails that is made forms an exception to this statement, but helps to prove its general correctness. Steel rails, which when first introduced cost £17 per ton, were afterwards reduced to £11, and can now (1876) be bought for £9; and there is no doubt that, if a large demand arose for L, T, and other sections, they would soon be supplied at much lower prices than those quoted above.

As a summary of what has been said on the previous page with regard to the strength of steel, it may be stated generally that it is in most respects twice as strong as wrought iron, and that the price for ordinary bars and plates has been in about the same ratio. There would appear, therefore, to have been no economy in using steel in cases where strength is the only consideration, and it must depend on the importance which attaches to other qualities whether the application of steel is preferable to that of wrought iron. Such qualities are, the greater resistance against wear and tear (as in rails and boiler plates) possessed by steel, and the reduction in weight which its use allows. Though this reduction may be possible, it is only

* The strength and other qualities of steel, as ascertained by elaborate experiments, are described in "Etude sur l'Emploi de l'Acier dans les Constructions." Baudry: Paris. Most of the contents of this book are given, with illustrations, in *Engineering*, August to December, 1875.

in large self-supporting structures such as bridges and roofs of great span that lightness of the metallic parts is of importance, because it is only in such structures that the weight of the metal forms a prominent item in the strains. In small structures the weight of the material bears so slight a proportion to the total load to be provided for, that any reduction in the weight of the parts would have but little influence in reducing the strains, while on the other hand, the tendency to vibration under moving loads, which in light structures always more or less exists, would be increased.

To describe fully the many kinds of steel known in commerce would be to discuss in detail all the various modes of manufacture which each brand represents. Such a task cannot be undertaken here, but some further points may be referred to, which, up till the present time, have had no small effect in restricting the use of steel. These considerations are three in number, the first being that the quality of a bar or piece is only to be relied on so far as an equal amount of labour has been bestowed on all its parts; the second, that there is a risk of injuring the homogeneous texture of the metal by heating it beyond a certain degree. Thus the welding of steel is a somewhat precarious operation, and even the smithing of it a matter of risk, great care being required to avoid heating the pieces beyond a certain point. The liability to overheating is of consequence in the case of rivets, but if, to escape such a risk, iron rivets should be used for steel girders, the alteration thus effected in the connections greatly reduces any saving that might be obtained by using steel at all. The third point is, that steel made into irregular shapes—unless it can be effected by casting under a great pressure, or by pressing it into moulds, or by hammering—always offers a strength much inferior to that of simple-shaped rolled bars. Molten steel flows more sluggishly than iron, and the process of casting is not so easy. Whitworth's process of compressing by hydraulic power the steel while it is in a molten or semi-molten condition, has the effect of producing steel of great strength and tenacity. Up to the present time (1876), although steel castings have been made by Whitworth in this way for torpedoes, hydraulic cylinders, and other special purposes, the process has not yet been generally extended to articles of utility.

From the foregoing statement, the conclusion may be drawn that steel can successfully replace wrought iron only in parts of the most simple shape, and that even then its application is expedient only in very large structures. As, however, there is a growing disposition in this and in other countries to construct bridges and roofs of very large span, it cannot be doubted that the real capabilities of steel will be tested in actual structures on a greater scale than has hitherto been attempted. The importance of the subject is fully appreciated, and during the last few years engineers and steel manufacturers have conducted a series of experiments with a view of obtaining such reliable information as will show how steel may be best applied in the many situations where iron has hitherto been the only material available. The marked progress that has been made since 1870 in the processes of steel-making, renders it extremely probable that the remarks made here as to the present position which steel occupies may be rendered obsolete if, as is hoped, and as appears probable, some of the objections to its adoption are removed and its use extended. The improvements that have been made in the manufacture of steel by Siemens and others since the Bessemer process was first introduced, and the large number of new Steel Works that have been established in England and on the Continent, have together had the effect of reducing the prices of steel, and at the same time of lessening the uncertainty that attended all attempts at uniformity of quality. Even at the present time, however, steel has been employed with advantage for the tension members of girders, for the chain links in suspension bridges, and in other structures which are mainly of iron; and as steel is rolled into the forms that are usual in iron, it is not unlikely that solid piles or columns for sustaining bridge girders may be made of steel. For small bridges, however, where iron piles of small diameter would be used, it would be impossible still further to reduce the diameter, so as to effect any saving by using steel. For bolts and pins where very severe strains have to be resisted, steel is most judiciously used. It is, however, not quite so easily worked as iron, and to the cost of material, therefore, must be added a larger price for the workmanship. And if in the process of manufacture steel has to be cut, the waste of material increases considerably the cost of the finished structure, because the waste pieces cut off are only worth as scrap about one-fourth of the original price. At the present time the cost per ton of steel girders is about double the price of iron girders, but if a regular demand arose, the price of them would soon approximate more nearly to that of iron girders.

Where bridges have to be conveyed in pieces over new or difficult country, or where for military and other reasons portability becomes of great importance, the arguments for and against steel would have a different value; and as structures can be designed to meet these special cases, they would, when so contrived, be considered from an entirely different point of view to those ordinary bridges where solidity and permanency are the only conditions which prevail.

WEIGHT OF IRON AND STEEL.

A square foot of Cast Iron, 1 in. thick, weighs 37½ lbs.
A square foot of Wrought Iron, 1 in. thick, weighs 40 lbs.
A square foot of Steel, 1 in. thick, weighs 40½ lbs.

In calculating the weight of iron-work these standards are generally used. Where an approximate weight only is required, it will be found easier to adopt the even figures of 40 lbs. per square foot for both cast and wrought iron; and 10 lbs. per foot for ¼in. thick, 20 lbs. for ½in., and 30 lbs. for ¾in., are figures also easily remembered. The assumption of 40 lbs. per foot for cast iron about compensates for the small fillets and angle pieces, which can be omitted in the calculation. The task of measuring the weight of iron-work, or "taking out the quantities," is facilitated by published books of tables,* which give in a convenient form the weights of round and square iron, plates, pipes, &c. of different sizes. As it is impossible to make iron absolutely to the sizes specified, and as there are often complicated shapes where the weight cannot be exactly calculated from the drawings, manufacturers are generally allowed a limit of 2 to 5 per cent. above and below the calculated weights, within which limits the iron-work is made as nearly as possible what is desired.

* "Tables of Weights," by Samuel Penn. London : Fox, Paternoster Row
"Weight of L and T Iron," by C. H. Jordan. Spon : London.
"Guide to the Iron Trade," by J. Hogg. Britten : West Bromwich.

CHAPTER II.

BRIDGES. INFORMATION NECESSARY FOR DESIGN.

THERE is probably no kind of structure in which more ingenuity of design and fertility of resource have been exercised than in the construction of bridges; but, notwithstanding the numerous examples that exist, and the immense amount of experience that is constantly accumulating on the subject, almost every new situation requires a special design, and in each case a bridge must be constructed specifically fitted for the service required.

In deciding upon the form of structure which shall best combine efficiency with economy, many points, depending more or less upon each other, have to be considered. The *piers* and the *superstructure* are the two main divisions into which the design may be separated, and the nature of the site and the circumstances of each case determine their relative importance. The cost of the superstructure increases with the length of the spans, and, therefore, if cheapness of the superstructure were the only consideration, it would always be best to have short spans. But as that would imply multiplication of piers, it has to be considered at what point the best combination can be arrived at. Where the height is small, the river not navigable, and the piers easy to build, very short spans may be adopted, and, in some cases, it is cheapest to have a series of brick or stone arches, and to avoid iron-work altogether. But in many places it is difficult and expensive to build piers in the water, and this is especially so in bad foundations, in deep and rapid rivers, or in those subject to heavy floods. Also in navigable rivers it is important that the water-way should be obstructed as little as possible. It is desirable very often, for these reasons, to have few or no piers in the stream, and, even at considerable cost, to construct the bridge in one or more long spans.

Thus it is most important—particularly when bridges have to be designed and manufactured in England for erection in foreign countries—that very full and accurate information of the conditions of the case shall be sent from the site, as the want of this information renders the task of designing a bridge difficult, and may lead to much disappointment. The following is given as a list of the points upon which information is most needed.

1. *The length* of the proposed bridge, as shown by a *cross-section* of the site. If the bridge is for a river, the section should show also the depth of water at various periods of tide or flood, the height of the river banks, and the clear headway that is required for the passage of vessels, or floating trees, &c. This headway is the vertical distance from the water-level to the undermost line of the superstructure. In an arched bridge, this distance should be measured to the soffit of the arch at the crown. The level of the approaches or of any existing roads to which the roadway of the bridge must correspond, should be given, and also the greatest admissible gradient on the bridge and the approaches. If an arch or suspension bridge is proposed, it is particularly necessary to know the slope of the river banks, and the fitness of the soil there for abutments and foundations.

2. *The nature of the river bed.* On this point the importance of complete information is often far too little appreciated by those who have to supply it. A misconception of the nature of the strata in the river bed, as well as in the banks, will not only prevent the designer from properly considering whether the advantage will lie in the use of a number of piers and short bridge spans, or in using fewer piers and longer spans; but it may sometimes even lead to the selection of an entirely inapplicable system of construction. If the existence of a quite reliable and solid foundation, such as rock, hard gravel (not liable to be underwashed by the river or by springs), stiff clay, &c. at a certain depth, has not been well ascertained, it is necessary to make trial borings, and to describe, not only the composition of the excavated soil, but also to state what power has been needed to penetrate through the different strata. It is also useful for ascertaining the depth of solid ground, to drive iron-shod piles, until they cannot be driven any further, by a ram of stated weight and fall; then to extract them if possible, and to examine the condition of their points. The actual or probable presence of boulders, trees, and other obstacles in the

soil of the river-bed, should be well examined before a decision can be properly formed with regard to the kind of foundation and piers required.

3. *The service required.* There are railway bridges, roadway bridges, and footway bridges. In each case, the width of the bridge is almost the first thing to be decided on. For a railway, it should be stated whether there is a single or double line of rails, and the width of the rail gauge. It is, of course, necessary also to know the weight of the heaviest load likely to pass over the bridge; but this is a matter of somewhat deeper investigation, and is referred to further on.* For roadway bridges, it is generally assumed that the entire bridge may be covered with people, and reference is made on another page* to differences of opinion amongst engineers as to the maximum weight to which, in that event, the bridge is liable. The kinds of vehicles and their loads which will pass over the bridge should be described, so that the pressure upon each wheel, as well as the distance between the wheels, may be determined. This is of some importance, even in those cases where the vehicle and all its appendages would weigh less than the standard crowd which it displaces, because, from the unequal distribution of the weight, it may bring excessive strains upon parts of the structure—such as the cross girders—when subjected to the loads concentrated on the wheels; but if such loads pass infrequently, it is considered admissible to disregard a slight extra strain. If any special road surface material is required—metalling, stone, timber, &c.—these should be stated, so that the dead weight may be allowed for in the design.

It is obvious that complete information on this point (3) *should be supplied when a design and an estimate of cost are required, because it is a usual and proper condition that no portion of the bridge under consideration shall be strained above a certain limit.* In determining the value of a bridge in regard to the strength it possesses for the service required, or in estimating the comparative values of alternative designs, two things must be considered together, viz. the load which the bridge is intended to bear, and the strain on the iron which that load involves. For instance, a designer may state that his bridge will safely carry

* See "Loads and Strains on Bridges."

100 lbs. per square foot, while, in regard to a competing design, only 90 lbs. may be stated as the proper load; but it would be premature to consider the first as the stronger bridge until the additional information is given as to the strain which the specified loads will, in each case, induce upon the iron. If with the 100 lbs. load, six tons per square inch has to be endured by this iron, such a bridge is not so strong as a bridge which will carry 90 lbs. per square foot with only five tons strain on the iron. For a further elucidation of this, see "Loads and Strains on Bridges."

4. *Local facilities.* If there are difficulties in the way of transporting materials to the site, they should be stated, so that, if necessary, the bridge may be made in pieces of moderate size and weight. It is useful to know whether skilled workmen can be obtained for erecting the bridge, so that if it is difficult to procure them, the design may be contrived with special reference to facility of erection. Information also should be afforded as to what materials, such as brick, stone, or timber, can be obtained near the site, and, if possible, at what prices.

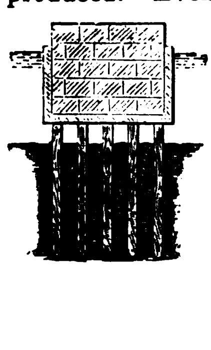
The engineer who is furnished with the information described under the preceding heads, will be enabled to select that, among all known systems of bridges, which is best suited to the circumstances and necessities of the case. Whatever system be adopted for a bridge, it may be divided, as before mentioned, into the PIERS and the SUPERSTRUCTURE, and in the following pages some of the usual kinds of each are described.

CHAPTER III.

BRIDGE PIERS. SCREW PILES. CYLINDERS AND CAISSOONS. PNEUMATIC METHOD OF BUILDING PIERS. DIVERS. HYDRAULIC EXCAVATION. BRICK PIERS ON IRON CURBS. COFFERDAMS. ABUTMENTS AND WING WALLS.

BRIDGE PIERS.

WHERE bridges are built over water, the construction of the piers generally involves a large proportion of the total cost, although the expense and risk have been greatly reduced by modern engineering skill. Not many years ago piers always were made either of stone, brickwork, or timber, alone or in combination. Bridges, even in important situations, were built entirely of timber, and, while the piles embedded in the soil would often last for a long time, the upper portions, exposed to the atmosphere, and to constant changes from a wet to a dry state, needed periodical repair and renovation, and were exposed to destruction by fire. Although stone or brickwork was used in structures which were intended for long endurance, timber was always an indispensable material for cofferdams, or for making the bases of the stone piers in those cases where a solid foundation could not be reached by excavation inside the cofferdam. Where this occurred, a number of piles were driven into the ground, their tops were connected by horizontal beams, and the masonry was built upon the platform thus produced. Even now this plan is frequently found the most



practicable in countries or districts where timber is not expensive and where iron is available only at great expense (see Bridge Example No. 16). A combination of the cofferdam with this plan has been successfully adopted for brick or masonry piers. A group of piles having been driven into the river bed, a wooden box or chamber is lowered down on to the piles, as shown in the engraving, and a permanent pier of masonry is built within. The spaces between the piles below the masonry may be filled with concrete or ballast.

The use of iron for foundations is comparatively of a recent date, and was first introduced by Mitchell in the year 1834 by his invention of the screw pile. But very soon afterwards iron in other forms began, first in England and then abroad, to replace timber to a great extent as a material for the foundations of bridges. If it is justly considered that a new era in bridge-building commenced with the first introduction of iron in the superstructure, because of the great increase in bridge-spans which was thus rendered possible, it can almost be stated with equal justice, that a new era commenced when iron columns, cylinders, or caissoons,* were first sunk into the bed of a river; for, by the use of iron in some shape or other instead of timber piles, engineers succeeded not only in reducing the cost of the foundations, but they were able to build bridges in situations where the difficulties were almost insurmountable before.

A classification of the services which iron is called upon to perform may be attempted in the following manner:—

1. As piles or columns entirely of iron with an enlarged base. (Screw piles.)

2. As hollow columns open at the bottom and wholly or partly filled with concrete; the superstructure resting on the iron casing, and through it on the ground below, or on a concrete base formed within the lower part of the column.

3. As hollow columns or cylinders entirely filled with concrete, brickwork, or masonry, the pressure of the bridge superstructure being applied directly to the masonry, while the iron column serves to protect and stiffen the pier.

4. As caissoons,* *i.e.* as water-tight cases sunk into the river bed to shut out the water while the masonry is built as in a chamber, the caissoons standing only slightly higher than the ordinary water level, and to be removed after the completion of the pier if possible. They differ from Class 3 in being not entirely filled with masonry.

* French, *caisson;* coffer, compartment, chest.

5. As an edged curb at the bottom of a hollow masonry pier, the curb cutting its way into the ground, assisted by the constantly-increasing weight of the masonry built above, and by the excavation of the soil through the hollow centre.

6. As cofferdams.

The methods of constructing iron piers are the following, according to the class of pier:—

(*a*) Screwing freely or under pressure.

(*b*) Sinking by the weight of the iron itself or by extra weight placed above.

(*c*) Sinking by the pneumatic system.

(*d*) By the falling weight of a pile engine.

(*e*) By the aid of divers.

These methods are again referred to in the following description of the six classes enumerated on page 26.

SCREW PILES.

The facility with which screw piles may be fixed has led to their frequent adoption, and among their different varieties will chiefly be found the iron piers in Class 1, *i.e.*—

1. *Piles or columns entirely of iron, with an enlarged base.*

There are many different forms of screw piles, and no fixed rule can be made for general application, as much depends upon the strata they have to pierce, the strength necessary to resist the concussion of passing vessels, the load to be sustained, and other local peculiarities. Piles are made either hollow or solid.

Hollow piles are parallel tubes of from one to three feet diameter, made generally of cast iron in convenient lengths, and joined by bolted flanges, sockets, or otherwise. Solid piles are made of wrought iron from 4 to 9 inches diameter, and they can be manufactured in pieces of considerable length. Those of 4 inches diameter can without extra price be rolled in lengths of 15 feet, and larger diameters can be made in pieces not exceeding 5 cwt. each. Longer and heavier pieces can be rolled if necessary. Welding, *when carefully effected*, is a convenient

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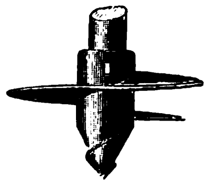

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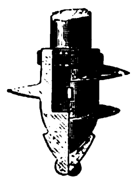

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method of forming the joint in solid piles, as the diameter is not increased by it, and the attachments necessary for bracing can afterwards be placed or adjusted at any point. Welded joints, however, often make a greater total length than is convenient for carriage (see Chap. XI.) Where the joints for cast iron piles are made with flanges, or those of wrought iron piles by means of couplings, the bearing places must be truly faced, bolt-holes drilled, and bolts turned, to resist properly the great torsion during the process of screwing in.

The screw-blades may be made of wrought iron or steel, but cast iron is cheaper and in most cases preferable. If made of good cast iron the screws will cut their way as well as if made of wrought iron, and they are not so liable to bend or to deterioration by rust. Wrought iron blades are, however, less liable to break during transport than cast iron. The diameter and pitch of the screw vary with the nature of the soil and the load to be carried.

Except in cases where the screw tapers, as in Figs. 3 and 4, the screw-blade should not have more than one complete turn round the column. Fig. 1 shows a cast iron pile of the ordinary kind—the sketch being taken from a pile 2 feet 6 inches diameter. Fig. 2 shows a special kind of pile designed by A. Handyside and Co. for cutting through chalk and other hard strata, and found to be useful also in clay. Piles of more than 3 feet diameter are seldom made, and the large majority of hollow piles are of some diameter between 12 inches and 30 inches. Fig. 3 shows a solid wrought iron pile with cast iron screw, and Fig. 4 one similar, but with blades of smaller diameter for harder strata. In this case a double gimlet point is useful. The gimlet points are not necessary in sand or soil which is very soft and yielding, and in these cases the diameter of the blade may sometimes be increased with advantage.

Screw piles are generally applicable for sand, gravel, shale, marl, clay, chalk, soft rock, calcareo-argillaceous,* and alluvial soils. They will penetrate very hard stuff, and even force their way into brickwork. It is difficult to use them in strata where many large boulders, trunks of trees, or other obstructions exist, and the use of divers may in such cases be necessary for the removal of the obstacles. Although screw piles will find a firm hold in sand or gravel, there are cases where these substances rest upon rock, and are exposed directly to the water above (are not, for instance, covered by a stratum of clay), so that a strong current may scour away the sand or gravel from the pile, and allow the latter to sink under the load. In places of this sort, cylinders or piles without screws, forced down by weight through the upper strata on to the rock, will generally prove more suitable than screw piles. Large stones placed round piles will, to a considerable extent, protect them from scouring.

For the insertion of screw piles, floating rafts or barges are sometimes used; but where it is possible a fixed staging is much to be preferred. A strong framework is needed to hold the pile in its place while it is being screwed down, and it is desirable to have more than one bearing place to guide the pile as it revolves and descends. It is usual to fix upon the top of the pile a capstan, fitting to it like a key, having all of its radial bars strongly braced together by screw couplings. A rope round the capstan is connected at each end to an ordinary crab or winch, and as equal a strain as possible is given to the two opposite forces. It is, however, somewhat difficult, with an elastic rope, to keep the two ends equally taut, and to prevent occasional jerks; while, sometimes, the winches are unable to exert sufficient power. This process is also in many cases open to the objection that it obstructs the navigation of the

* Lime and clay.

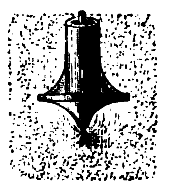
river. Having experienced these difficulties, A. Handyside and Co. have used an apparatus by which the ropes and winches are dispensed with, and worm wheels and gearing adopted instead. A machine of this sort costs from £110 to £150, according to the size of screw pile for which it is needed.

There is almost always some amount of "slip" in screwing a pile, that is to say, if the pitch of the screw be 9 inches, the pile does not descend quite 9 inches at each revolution. There is often a tendency towards the slip in clay, and the movement of the pile should be carefully watched, because, if it be turned without descending, the result will be that the soil becomes so churned up as to render further screwing difficult. The serrated pile (Fig. 2) is useful in such a stratum for facilitating the descent. In cases of this sort with a hollow pile, the inside or core should be cleared out. If the soil be soft, this can be effected by a "miser,"* or, if the soil be hard, by a boring-tool or gimlet,* or, if the pile be two feet or more in diameter, by sending a boy down to dig out the soil. Hollow piles may with advantage be filled with concrete, which not only strengthens the column but protects the iron from corrosion. To obtain this latter result the concrete should be made with lime and not with Portland cement, and should be placed in layers, with an interval of time between each deposit.

Screw piles possess enormous strength, and when properly braced form a strong pier; but the success which has attended this use of them tends perhaps to their adoption in some cases without sufficient consideration. Where the screw blade is intended not only as a means for insertion, but also as a base plate for supporting the column, it must be remembered that the screw is liable to break while the pile is being inserted, without showing any immediate sign of it, and that, even when safely fixed, the blade may deteriorate by rust or (especially the thin edges of the blade) waste away by gradual softening of the iron. The whole area of the screw should not therefore be too confidently reckoned on as a base. Where the pile is inserted so deeply into a firm stratum that it may be depended on as a column, independently of the base surface of the screw blade, the friction on the sides of the column assisting to give a

* A tool used by well-sinkers and others for excavating.

sufficient hold, greater reliance may be placed on it, and these are the cases in which screw piles are clearly of most advantage.

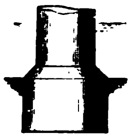


As included in the Class 1 of iron piles with an enlarged base, must be mentioned Mr. Brunlees' process of pile-fixing by a water jet, which has been successfully employed in light sand. The column is hollow and is closed at the top, except where a tube of small diameter is inserted. By means of an ordinary fire-engine, or other force pump, water of high pressure is injected, and as it rushes out at the base of the column (as shown in the sketch) it drives up the sand outside, and, keeping it in a quick or "live" condition, the pile descends. The column is guided by a frame something like that of a pile-engine, and, during the descent, a reciprocating circular movement is given which assists the downward motion. When the column has penetrated far enough, the pumps are stopped, the tube withdrawn, and the sand settling round the column, renders it perfectly firm.

CYLINDERS AND CAISSOONS.

2. *Hollow columns open at the bottom, &c.* Iron piers constructed so that the iron shall receive the load, are generally of a cylindrical form, and are applied where the superstructure is at a considerable height above the ground, where a comparatively small amount of lateral stability is required, and where a good foundation (however deep) may be relied upon with such certainty that each column may be trusted as an independent pier. Most of the rivers in England fulfil the two last conditions, because they do not convey large masses of ice, trees, or even very great floods during the rainy season, and have not deposited an excessive alluvial stratum or quicksand. Under such conditions a cast iron column open at the bottom and constructed of complete rings (or, if large, of rings made in segments) with watertight joints, is let down upon the ground, while the top of it is kept above water by constant additions to its height as it sinks. This process is carried on until the edge at the bottom reaches a stratum of sufficient firmness to serve as a foundation. The inside of the column is then

cleared out, and may be filled with concrete to stiffen the pier. These cylinders are generally made of cast iron, and their dimensions and shape depend on the firmness of the foundation ground, on the weight to be carried, and on the height above the river bed. A column, for instance, to support a load of 400 tons (including its own weight), resting on a stratum of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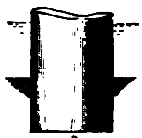
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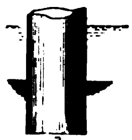
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stiff clay, and about 30 feet above the bed of the river, might have a diameter of 10 feet at the base, but would properly be contracted above the river bed, in the manner shown in Fig. 1. But if the height is much greater than 30 feet, more stability would be required in the shaft of the column, and the proper shape would be a column of 10 feet diameter (Fig. 2), without the conical reducing piece shown in the sketch. A parallel column would be suitable also if the foundation ground were superior to stiff clay, for instance, rock; an enlarged base would not in such a case be necessary (see Fig. 3, also Bridge Example No. 30). Where the superstructure rests on the iron pier, proper flanges or caps should be given to the cylinder, to afford sufficient bearing surface for the girders.

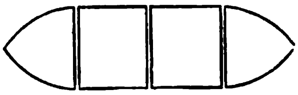
3. *Hollow columns or cylinders entirely filled with concrete, brickwork, or masonry.* The plan, as just described, of making the cast-iron columns carry the whole of the load involves more careful fitting of the joints, and generally a greater thickness of iron than is required if the load rests on the concrete or masonry core within the cylinders. For large piers of the latter kind, the iron enclosing the upper part of the column, as it serves merely as a shell to the masonry, need only be strong enough to sustain the weight necessary for sinking, as the entire vertical pressure of the superstructure is taken by the masonry. The diameter of the pier at and above its base depends on the nature of the foundation, the height, and the weight to be carried, in the same way as is described in Class 2. Bridge Examples Nos. 19 and 31 illustrate this kind

of pier. The modes of sinking cylinders are described below and on the following pages.

Piers of the construction described in Classes 2 and 3 consist of at least two columns or cylinders each, placed under the main girders of a bridge, because most bridges have at least two main girders. More than two are required if there are more than two main girders or arched ribs in a bridge, or if a greater resisting strength against the river current is required than that which can be obtained by bracing two columns together. But, under these circumstances, it is generally not found economical to sink a number of columns or cylinders very close together in a row, but to use caissons, as described in Class 4.

4. *Caissoons or water-tight cases* which enclose the base of one solid pier. These caissoons are either made in one piece, or, where the pier is very large, are composed of several caissoons, in the manner shown in the sketch, each being sunk independently. A pier having been built within a caissoon upon a base of this shape has sufficient strength in itself, and the additional stiffness which may be derived from a permanent iron shell can be dispensed with. These caissoons, therefore, are made only to serve as a cofferdam to prevent the access of water, and allow a foundation of concrete or masonry to be constructed in the interior. The material of which they are made is generally wrought iron in preference to cast iron, for several practical reasons. After the completion of the pier, all the caissoons except those which are below the ground line can be removed.

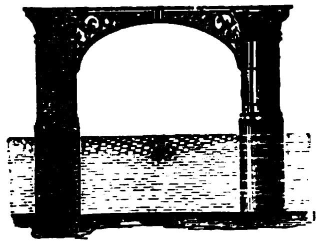
In the foregoing remarks on the use of iron for the construction of shells for masonry piers, a description of the methods of sinking them until they reach a good foundation has been omitted till now because each of the methods may be applied to any pier of the Classes 2, 3, and 4, and the superiority in any case of one method over another does not so much depend on the construction of the pier as on the nature of the river bed. The simplest of these plans is to force down the iron shell or caissoon (after its position on the river bed is properly adjusted and guided by means of a temporary timber framework) by weights on the top of it, and by dredging the soil from the inside until a stratum is reached by the bottom



CLASS 4.

edge of the shell which prevents the ingress of water to the interior of the caissoon. The water can then be pumped out, and workmen can descend and dig out the soil. When a stratum of such a kind (generally clay) is reached, it can be relied upon as a foundation, and further excavation can, if desired, be made to obtain a deeper or broader base without the labour or expense of forcing the iron shell any lower. The inside of the iron casing having been completely cleared, it can be filled with concrete and masonry. So convenient is it to have a water-tight clay stratum into which the cylinders can be forced, that, in some cases where there is no clay, it may even be advantageous to provide it artificially by throwing clay into the river before inserting the cylinders ; or after the cylinders are placed, clay can be thrown round them to prevent the ingress of water while the pumping proceeds inside. Indeed, there are so many variations of detail which may suggest themselves to the engineer in particular cases, that it is impossible here to do more than refer, as above, to some of them.

Where no clay exists among the strata, but only gravel or other permeable material which admits water, it may be possible to apply the same simple method of dredging out all the upper layers of soil, and then to prevent the ingress of water by filling the bottom of the cylinder with hydraulic concrete. This may be effected by lowering the material in boxes contrived to open when at the bottom, or by shoots which convey it to its place without contact with the water, or by divers who take it down in waterproof bags. When the cement or concrete has become hard, the leakage will have ceased, or can be overcome by pumps, and all the water cleared out. Where there is a very strong current which might wash away the loose cement, the latter may be sunk to the bottom of the cylinders in bags of ordinary calico or sacking into which the water penetrates. The bags may be rammed down so as to fill all the corners, and then left to harden and become like so many stones. In tidal rivers, or wherever there is a depth of water exercising considerable pressure, it is sometimes necessary to hold down the cement till it has hardened, so as to prevent its being forced up from below. This may be done by placing planking or other framing on the cement and loading it with stones.



The sketch on this page shows one of the mid-channel piers of a road-bridge erected by A. Handyside and Co. over the Trent at Wilford, from the designs of Mr. E. W. Hughes. The bridge is 290 feet long, in three spans, and is 32 feet wide. Each column of the pier is formed at the bottom, of cast-iron cylinders 7 feet in diameter, and above the water level is of the shape shown in the engraving. The cylinders were sunk through gravel on to rock, and the latter was cut away by a diver inside the cylinder till a level bearing was obtained. A layer of cement having been inserted, as before described, the water was pumped out, and concrete and masonry were built up within.

A proper choice of the cement best suited for use alone or in concrete, is of the greatest importance. Considerable attention has been lately directed to the processes of manufacture, and numerous experiments have been made on the strength of solidified cement. Portland cement is liable to deteriorate by damp in a hot climate, and by certain modes of mixing and applying it.* Good cement or cement concrete will "set" nearly as hard as granite in water, and will carry from 8 to 12 tons on the square foot with safety.

But if the water which penetrates at the bottom of the cylinder or caisson constantly brings in with it mud, sand, or gravel, or if strata or obstructions exist which prevent the sinking of the cylinder, and which cannot be removed by the dredger, the pneumatic or other special modes of sinking cylinders and caissoons must be adopted, or divers must be employed.

PNEUMATIC METHOD OF BUILDING PIERS.

The original manner in which the pneumatic method was introduced was by the use of the atmospheric pressure upon

* The following books give valuable information on the subject of cement and concrete: "Reid on the Manufacture of Portland Cement." Spon, London. "Concrete," by the same Author. "Strength of Portland Cement," by John Grant, M.I.C.E. Extracted from Vols. XXV. and XXXII. of the Minutes of Proceedings of the Institute of Civil Engineers.

the outside of a hollow column in which a vacuum was created by the air-pump. As the air was withdrawn from within the cylinder, the atmospheric pressure outside forced up with the water into the inside the soil upon which the cylinder rested; so that the latter sank almost with its own weight until it reached a firm stratum, or became so deeply inserted in the river bed as to offer, by the friction of its sides against the soil, sufficient resistance to the vertical load of the superstructure. This method was applied in the year 1847 for the foundations of a viaduct of the Chester and Holyhead Railway, and was also tried at Rochester* for the foundations of the piers of the bridge over the Medway. But where obstructions occur (as was the case at Rochester) which cannot be removed by the dredger, it not only offers no advantages over the more simple method of weighting the cylinders, but is also more expensive, and was therefore soon relinquished. It was abandoned at Rochester, and instead of exhausting the air from the cylinders, they were filled with compressed air; and, being closed at the top and open at the bottom, all fluid matter was driven from the interior, in the same way as from an ordinary diving-bell. By means of air-locks on the top of the cylinder, workmen were enabled to descend and remove the soil and such matter over which the dredger had had no power; by means of an air-sluice, also, the soil was passed to the outside. The air being compressed inside of the column, instead of being exhausted, the weight or pressure downwards of the column was greatly diminished, and had to be restored by artificial weight. The arrangement thus described, although many improvements have been made in its details, illustrates in general outline all the pneumatic methods now in use. The first improvement consisted in confining the compressed air to a chamber at the bottom of the cylinder, which was connected by a pipe large enough to let a man pass through it, with an air-chamber at the top. The rest of the space inside the columns communicated with the atmosphere (Saltash. Bridge; † Strasbourg-Kehl Bridge). ‡ A further improvement was to let the water into the space not

* "Cresy's Encyclopædia of Engineering." Longmans, London. Minutes of Proceedings of the Institute of Civil Engineers. May, 1851.

† "The Life of Brunel," by his Son. Longmans, London, 1871.

‡ „Zeitschrift für Bauwesen." Berlin, 1860.

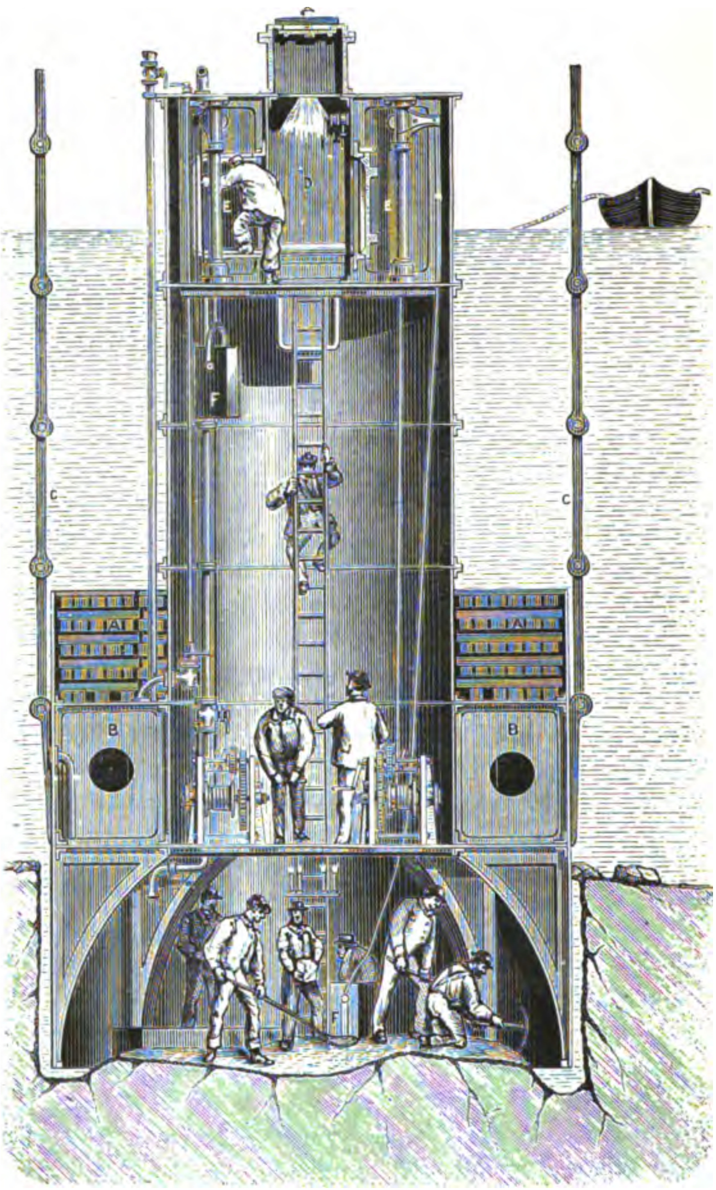
occupied, and thus to make use of its weight for forcing down the cylinder (Kovno Bridge).* The next was, at once to fill the unoccupied space with masonry which formed part of that which composed the pier when it was finished. The weight became very great as the cylinder descended, and it was hung on strong chains, in order to secure a more regular sinking (Argenteuil Bridge).† Yet another improvement consisted in suspending on chains an air-chamber with a vertical pipe for communication only, and letting it down upon and into the bed of the river; while a ring of masonry was at once commenced, and continually increased in height, so as to keep its surface above the water level, thus dispensing altogether with the tube or column of iron (Stettin Bridge).‡

The engraving on the next page shows a pneumatic cylinder or caissoon used by Messrs. Burmeister and Wain, of Copenhagen, for building the piers of an iron bridge in that city. Economy was obtained by having the cylinder of less cubic capacity than the finished pier, and in being able to take it away from each pier as it was built. When the excavation was made deep enough for a firm foundation, the building of the pier was commenced; and, as it increased in height, the cylinder was lifted accordingly until the masonry was above water-line, when the cylinder was removed to the position of the next pier, and so on until the four columns of masonry, forming two complete piers, were finished. This plan of lifting the cylinder avoided leaving the whole of the columns of the piers encased in ironwork, as in the piers of Rochester and many other bridges. The cylinder was made of wrought iron, 18 feet diameter at the lower part by 8 feet high; and from this to the air-lock above water level it was only 10 feet diameter. Just above the 18-feet diameter chamber there were two annular spaces, or chambers—one to contain iron ballast A, and the lower one water ballast B; so that in sinking, the water-chamber was filled with water for weight in addition to the iron ballast in the annular chamber above. Compressed air was supplied by an air-pump in the usual manner. The excavated material was removed by means of the buckets

* M. Cesanne, Engineer. "Zeitschrift für Bauwesen." Berlin, 1863.

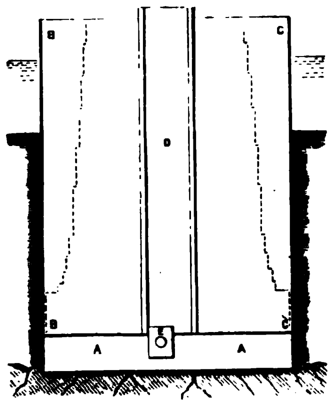
† Oppermann. "Nouvelles Annales de la Construction."

‡ "Architekten-Wochenblatt." Berlin, 1867.



PNEUMATIC METHOD OF BUILDING PIERS. *See p.* 37.

F, which were hoisted by winches with ropes passing through the columns E. When the excavation reached the solid stratum, a bed of concrete three to four feet thick was formed; and on this the remainder of the pier was built of brickwork, with granite facing. As the building of the pier proceeded, the cylinder was lifted by means of the suspension chains C, connected with staging overhead, and by pumping air into the annular air-chamber B to displace the water. The finished columns of masonry are about 18 feet diameter at their bases, and 16 feet diameter above, by 30 feet high. The whole of the work below water-line was done in the 18-ft. by 8-ft. chamber at the bottom of the cylinder. The time occupied in lowering it to the bed of the river and the completion of the first column to the water-line was only twenty-eight days, and then the apparatus was moved into position for the next column. In lowering it for the second, it unfortunately got upset, and this caused so much delay that it took thirty-six days to complete this column. The third was, however, finished in sixteen days, and the fourth in seventeen days. The air-chamber D, or lock on the top of the cylinder, was very similar to those used for sinking the piles of the Rochester Bridge.



Probably the largest scale on which the pneumatic system had up till that time been applied, was for the piers of an arched bridge over the Mississippi, at St. Louis, where a carriage road and two lines of railway cross a river 1,520 feet wide, in two spans of 502 feet, and one span of 520 feet. The piers are of masonry, built on a rock foundation, from 100 to 120 feet below the water surface, and overlaid with sand to depths of from 60 to 80 feet. In order to pierce through this sand, the engineer, at each mid-channel pier, made use of a caissoon, in which the excavation was effected in a chamber filled with compressed air. The very long spans of the bridge and their arched form rendered necessary large piers of great stability, each one at the base being about 82 feet long and 60 feet wide. The engraving on this page shows a vertical section of the caisson, which covers an area of 5,000 square feet. The outer walls BB, CC, are of plate iron, strengthened by bracing and timber inside. The air-chamber AA is 9 feet high, and is shut off from the rest of the caisson, access to the chamber being given by the shaft or passage D, through the air lock E.

The caisson having been placed in position, was increased in height as it sank. Workmen in the air-chamber excavated the sand, which was so pure and light as to be brought to the surface by sand pumps. By the injection of high-pressure water, the sand was forced up, and so effective was the process, that one pump of 3½ inches bore was capable of raising 20 cubic yards 125 feet high per hour; the water pressure required to supply the jet being about 150 lbs. per square inch.

As the caisson descended, the masonry pier, shown by the dotted lines, was built up within it upon the air-chamber. When the bottom edge of the caisson reached the rock, the air-chamber, having been entirely cleared of sand, was filled with concrete, and was left as the permanent base of the pier, while the caisson above was removed.

Although the building of the St. Louis piers, as here described, was a bold undertaking successfully completed, it is very questionable whether the best means were adopted. The depth to which the men descended was sometimes as much as 120 feet, and the pneumatic principle applied under such circumstances is attended with very great risk. The amount of risk depends on the health and temperament of the men, and the length of time they work consecutively. The maximum air pressure in this case was about 50 lbs. per square inch, or equal to more than three atmospheres, and it is hardly a matter of surprise therefore that many men were seriously affected, and no less than twelve lost their lives.* Since these piers were finished, those for the East River Bridge, between New York and Brooklyn, have been built. These are much larger than those at St. Louis, but the same pneumatic principle is adopted, the experience obtained by the Engineer of the St. Louis Bridge having been found of great value.

Eighty feet is about the limit of depth within which men

* A full description of the piers and their construction may be seen in the reports of the engineer, Captain James B. Eads, most of which reports are given in the pages of *Engineering*, Vols. X. and XI. 1870-71.

can work by the pneumatic plan under pressure with safety. In sinking cylinders according to this method, a greater pressure from the air-pump is necessary than with an ordinary diving-dress at the same depth; because sufficient air must be provided to compensate for the constant loss through the open bottom of the cylinder and during the entrance and exit of workmen and material through the air-lock.

DIVERS.

If the obstructions in a river bed are of a special or unexpected kind, divers may be employed in preference to the pneumatic system, if the nature of the soil and the depth of the foundation are such that their work will not be too much impeded.

In the ordinary diving helmet and dress—both greatly improved of late years—divers can work at depths not exceeding 80 to 150 feet, the exact depth within these limits varying with the constitution, habitude, and skill of the diver. In some rare instances the extraordinary depth of 170 feet has been reached. In England, divers are accustomed to work under water from one to five hours at a time, according to the depth of water; and their wages vary according to their skill as workmen. The helmet, dress, and complete equipment for a diver, including air-pump and tubing, varies in cost from £100 to £130.

HYDRAULIC EXCAVATION.

The difficulty of working by divers or the diving bell in very deep water renders special methods necessary in such cases. A plan of sinking cylinders and excavating within them was successfully carried out by Mr. Bradford Leslie, in the erection by him of a bridge over the Gorai river for the Eastern Bengal Railway.* In this case the cylinders for a height of 30 feet from the base were of wrought iron 14 feet diameter, and above of cast iron 10 feet diameter. The river bed was of such a

* A full account of the sinking of the cylinders and erection of the superstructure is given in a paper read by Mr. Leslie before the Institute of Civil Engineers, and printed (with illustrations) in the Minutes of Proceedings, Vol. XXXIII. Session 1871-2.

nature as to afford no good foundation until an unusually great depth was reached, the strata being alluvium, loamy earth, clay and sand, the presence of old trees adding considerably to the difficulty. For the operation of sinking the cylinders, the pneumatic process might have been used; but there were several objections to it. In piercing the river bed to a depth of 50 feet or 90 feet below low-water level, the head of water at certain periods of flood would have been 120 feet or upwards. There would therefore have been some difficulty in making the cylinders water-tight, and the high temperature which is developed when air is compressed to more than three atmospheres, would have been very trying to the workmen, who were besides not well fitted for acting as divers.

The system adopted was as follows: Two or three rings of the cylinder having been put together, a false bottom of wood was inserted and made water-tight. The cylinder, so equipped, floated; and, being kept in a proper position by suspending chains, the upper rings were added. To give sufficient weight for sinking, a ring of masonry was built up on internal flanges provided for the purposes. When the cylinder, continually increased in length by the addition of successive rings, reached the river bed, the water was admitted by means of a syphon, and the false bottom was knocked out. The excavation then commenced, and was performed by means of a rotary plough or boring head, consisting of a horizontal disc-plate of such a size and with blades so arranged as to cut a conical hole 9 feet in diameter. The vertical shaft of the boring-machine consisted of a double or annular pipe strongly framed to resist torsion, and motion was given to it by an engine above. The object of making the boring shaft in the form of a hollow pipe was for removing the excavated earth by means of a current of water continually flowing up the pipe. For this purpose a 12-inch syphon pipe was provided, the inner leg of which was immersed in the boring shaft, and the outer leg in the water of the river. The requisite current up the hollow boring shaft was obtained by pumping water into the cylinder, so as to raise its level above that of the river; and a flow of water from the cylinder through the syphon into the river was obtained proportionate to the quantity thrown into the cylinder by two centrifugal pumps.

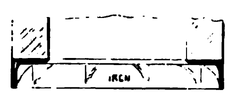
The ordinary speed of the boring bar was three revolutions in five minutes, and the depth excavated was about one foot per hour. The usual mode of working was to bore down a certain depth—two or more feet, according to the nature of the soil—lift up the boring head to prevent its being buried by earth falling in upon it, and then, after hanging a few minutes, the cylinder generally went down several feet, until the hole excavated was filled up by the sides falling in. Boring was then resumed, the loose earth which had fallen in was easily removed, and a sufficient depth of solid earth was excavated to insure another "run" of the cylinder.

When the cylinder was sunk to a sufficient depth, concrete was deposited, and allowed to set at the bottom; and, the water having been pumped out, a solid masonry pier was built within. Owing to the depth of water and other circumstances, the erection of staging would have been difficult, and the whole operations were conducted from a platform fixed on floating pontoons.

According to this system the cost of sinking does not materially increase with the depth, and the excavation can be carried on almost as well at 200 ft. as 100 ft.

BRICK PIERS ON IRON CURBS.

5. *As an edged curb of iron.* Compressed air in this case is not used in forcing down the pier, as, by means of a dredger,



the soil can be removed without the assistance of workmen descending into the tube. The only iron used in the foundation is an iron curb (which, if necessary, is hung by suspending rods) supporting a hollow column of masonry, which is gradually increased in height, and through the centre of which the dredging and pumping are carried on until by the cutting action of the curb a stratum is reached which does not allow an access of water. The inside is then cleared out and filled with concrete in the manner alluded to on a preceding page. This method of building the masonry from above has been used in England for sinking wells, and is common in India for wells and bridge piers in sandy or other places, where if an excavation were made in the ordinary manner the soil would fall in.

Probably the largest excavations ever made in this way, but on wooden curbs, were those fifty feet diameter for the shafts of the Thames Tunnel. The following account of the process on that occasion may be interesting: *—

"The mode in which Sir Isambard Brunel decided to construct the shaft was one not uncommonly adopted in the construction of wells; but to apply it to sinking a shaft fifty feet in diameter was a novel and bold undertaking. The brickwork intended to form the lining of the shaft was built on the surface of the ground, and the earth being excavated from within and underneath the structure, it sank gradually down to its final position. The brickwork was three feet thick, bound together by iron and timber ties; and there were built into it 48 perpendicular iron rods, one inch in diameter, fastened to a wooden curb at the bottom, and to another curb at the top of the wall, by nuts and screws. When the shaft or tower of brickwork was completed up to the top, 42 feet in height, the next step was to remove the blockings on which it rested, and this being done the gravel was excavated and hoisted up, and the shaft descended by its own weight. The Rotherhithe shaft, on the other side of the river, was only sunk 40 feet in this manner; the remaining 20 feet, in order to leave the opening for the tunnel, was constructed by underpinning, or underlaying, as it was then termed."

Two or more columns placed near together may serve as a basis for erecting a solid masonry pier above the level of low water. Such a plan was adopted by Mr. Strong, the engineer for a large bridge at Allahabad, India,† where the space for a pier 76 ft. long and 26 ft. wide was enclosed by ten brickwork columns, each 13 feet 6 in. diameter, on an iron curb, as described above. These columns were sunk 94 ft. below water level.

Brick cylinder foundations on a large scale were successfully used for a quay wall on the river Clyde, at Glasgow, by Mr. John Milroy, the engineer.‡

* This account is quoted from pages 9 and 10 of "The Life of Brunel," by his Son. Longmans and Co., London.

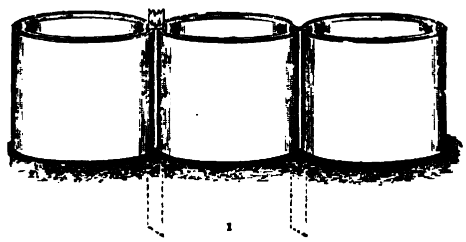
† Minutes of Proceedings of the Institute of Mechanical Engineers, 1863.

‡ See Minutes of Proceedings of the Institute of Civil Engineers, Vol. XXXV. Jan. 1873.

COFFERDAMS AND ENCLOSURES.

6. *Cofferdams.* Cofferdams are water-tight enclosures used during the building of foundations in water. The ordinary cofferdam consists of one, two, or three rows of timber piling rising above high-water mark, and bolted transversely together, the space between the rows being filled with clay. Within an enclosure so formed, excavations can be made and foundations built.

Iron has been used in direct imitation of a wooden cofferdam on the river Thames and elsewhere. Figs 1 and 2 illustrate the method introduced by Mr. Joseph Phillips, of London, who in his Patent Specification* describes the method as follows :—



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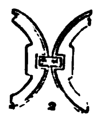
"My invention has for its object to render more or less perfectly water-tight the vertical joints, interstices, or spaces existing between metal piles or cylinders employed for structures that are wholly or partially under water, and consists in forming grooves, recesses, shoulders, or flanges, upon the contiguous sides of such piles, and then inserting into such grooves or recesses, or against such shoulders or flanges, pieces of wood or other suitable material, so formed that the pressure of the water causes them to fit tightly against one or more surfaces of the grooves, recesses, shoulders, or flanges of two contiguous piles or cylinders, and thereby to prevent the water from penetrating through the joints, interstices, or spaces between the two piles to the back of the same. I prefer to make the grooves in the piles and the pieces of wood to be inserted of a rectangular form ; and I form the lower extremity of the piece of wood with a double incline, so that, when driven into the



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* Dated January 30, 1864. No. 258.

ground in the same grooves, it is made of itself to press against the back surfaces of the two grooves and the side surface of one of them."

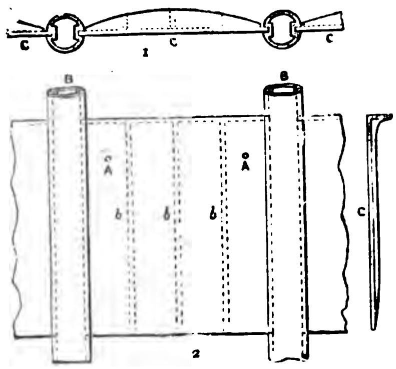
This method of keeping out the water was used in the construction of the Thames Embankment at Westminster, where it was tried for one portion of the embankment at the same time that the ordinary cofferdam (two walls of timber piles with clay between) was used for an adjoining portion. Oval tubes or caissoons of wrought iron (made of plates and L irons in the same way as iron boilers) were forced down into the river bed by dead weight, and timber piles were then driven into the spaces between, in the manner described above. Behind the wall formed by a series of the tubes, the area needed for the foundation of the embankment was excavated. At high tide there was a considerable pressure inwards of the water from the river, and the shape of the tubes enabled them to resist this when assisted by timber struts behind. The permanent granite wall of the embankment having been built, the upper portions of the wooden piles and iron tubes were removed, and were available for use for another length of wall.

In comparing this plan with the ordinary wooden cofferdam, the superiority of one over the other depends entirely on the circumstances of each particular case. If timber can be readily procured at a moderate cost, there may be no advantage in using the iron. If, however, timber is expensive, and the extent of the work permits the same set of caissoons to be used two, three, or more times, it may be found expedient to adopt them. If required, the soil within them can be cleared out and concrete placed within, so as to make a permanent wall with an iron face. Or if, as at Westminster, they are used for a cofferdam during the construction of a masonry wall, the lower portion of each tube may be filled with concrete and left in the river bed to act as an abutment or foot for the masonry. Phillips' caissoons were used for the piers of the large railway bridge over the Mersey, at Runcorn.

In water of moderate depth, the necessity for a water-tight cofferdam has been avoided by the use of cast iron plates or sheet piling round the side of an intended pier.

In the construction of the New Westminster Bridge (1855-

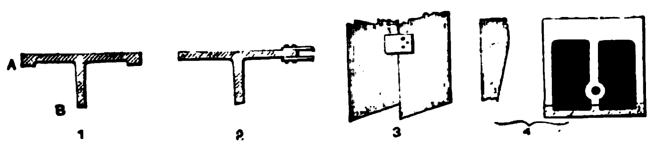
60), the engineer, Mr. Thomas Page, enclosed the spaces for the piers by a series of iron piles and plates, arranged so as to



orm a complete box or chamber. Cast-iron columns or piles B, 15 feet long and 15 inches diameter, were driven by an ordinary pile-engine into the river bed at intervals of 7 feet; and, in the spaces between the piles, cast-iron plates C, 1¼ inches thick, were driven, the plates fitting into grooves in the columns, as shown in the engraving on this page. The plates were stiffened by vertical ribs *b b b*, and on the top by a flange, as seen in Fig. 1. Above the plates the walls of the chamber were built up higher by stone; but this was a special arrangement suited to the occasion, and there is no reason why a greater depth should not be enclosed by iron alone. The chamber or caissoon thus constructed could not be called a cofferdam in the ordinary sense of the term, because it was not made water-tight, but was used only to enclose the area of the bridge pier, which was to be excavated and filled with concrete. When the piles and plates had been driven down to a sufficient depth, the mud and shingle were dredged from within, and groups of wooden piles were driven into the hard clay below. Concrete made with Portland cement was then deposited on the piles, where it hardened under water; and, when the mass of concrete reached a point rather below low-water level, the masonry piers were commenced. To provide against pressure outwards, which might be caused by the concrete swelling, tie-rods across the caissoon held the plates together.

Any novelty there might be in the use of cast-iron piles, as described above, consisted in their application for a bridge pier, sheet piling for a permanent wharf, on an almost similar system of cast-iron columns and plates, having been adopted many years previously at Deptford, Blackwall, and elsewhere on the Thames.

Cast-iron sheet piles were used by the late Sir William Cubitt, engineer, for protecting the sides of the harbour constructed by him at Lowestoft in 1832. In this case a wall more than 1,000 feet long was formed of cast-iron piles of the section shown in Fig. 1. Many experiments were made to obtain the best form of pile, and finally they were cast 30 feet long, 18 in. wide, and of a thickness greater at the centre than at the ends, a uniform thickness of 1½ in. being maintained at the edges by means of the fillets A. The rib B, of fish-bellied form, was 8 in. deep at the centre, and to counteract the tendency this form has to force the piles outward, the lower part of the rib was made in steps as shown in Fig. 5, and the cutting edge of the toe was one-sided.



1 2 3 4

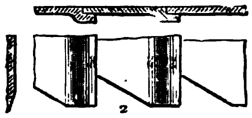
5

The piles were driven close together, edge to edge, clamps (as in Figs. 2 and 3) of wrought iron 5 in. by 4 in. by ¾ in. being riveted to the sides to act as guides. The heads of the piles were thickened out to 3 in., and were strengthened by ribs as in Fig. 4; tie-bolts being provided for tying the piles to a horizontal oak waling behind.

The piles were driven into the sea-bed by an ordinary pile engine, and it was found that by using a very heavy weight and a thin piece of elm on the pile head to receive the blow, few of the castings were cracked or broken. The piles were driven 10 or 12 feet into the sea-bed—here principally sand and shingle—with about the same depth of water above. The iron piling was found sufficient to retain the shingle of the beach behind without concrete, masonry, or any other wall. Iron was used in this case as a substitute for timber, which would have been destroyed by the teredo, and it was supposed by some engineers that the iron would become softened by the action of the water. After having been in place for forty years, it is found, however, that the iron has deteriorated only slightly at the edges of the pile, at places where the "runners" have been broken off, and where the original skin of the casting had been removed.*

Another method of applying iron sheet piling has been tried with success by Mr. S. W. Leach, the engineer of the Thames Conservancy Board, in the construction of a lock near Oxford without stopping the navigation. In this case a certain portion of the river banks had to be enclosed while the side walls of the lock were being built, and a cofferdam or any ordinary arrangement of timber would have encroached too much on a channel only 18 feet wide, the barges passing through being 17 feet wide. A cross section of the canal is shown by Fig. 1, the space to be excavated and the walls to be built being shown by the dotted lines at each side. The excavations having been performed by dredging, sheet piles of cast iron, as represented by the lines A A, B B, were driven down into the river bed; and, behind the screen thus constructed, cement concrete was deposited, and allowed to become hard in the water. As there was water on each side of the screen, there was no pressure inwards from the canal, and a few guide piles of timber and some iron ties to the shore sufficed to keep the iron piling in position. When the concrete foundation had been formed up to the water surface, a masonry wall was built upon it to the shore level.

The piling was made of cast iron plates, 12 feet long, 2 feet wide, and 1¼ inches thick, sharpened at the lower edge to ½ in. thick, the plates fitting over each other, as shown by Fig. 2. The lock therefore has its sides permanently lined up to the water level with iron, which conceals the concrete behind.



One side of the lock was finished before the other was commenced, as the guide piles mentioned above occupied 10 inches of the 12 inches (the difference between 17 feet and 18 feet) to

* The above description of the Lowestoft sea-wall has been written from particulars furnished by the late resident engineer, Mr. George Edwards, who superintended the construction of the harbour under Mr. (afterwards Sir William) Cubitt.

spare in the width of the lock. When both sides were completed, each end of the lock was temporarily shut in by a wall of timber and clay, and all the water was pumped out while the bottom was lined with concrete.

ABUTMENTS AND WING WALLS.

The different kinds of piers which have been described in the foregoing pages are used chiefly in the water channel, the shore supports or abutments being generally constructed of masonry or brickwork. But, although built in this manner on the shore, it is often as necessary during their construction to exclude the water by artificial means, as in the river piers; and, if so, a timber cofferdam, or one made according to method 4 or 6, may be used. If the water be very shallow, with a clay or rock bottom through which the water will not penetrate, the space within which the piers are to be built may be surrounded with an embankment of clay, or if in tidal waters the work may be carried on between tides. But, though in the majority of cases the shore piers or abutments are made of masonry or brickwork, it occasionally happens that iron is preferable for the same reasons that prevail for the mid-channel piers. In such cases, any of the methods that have been described for the latter may be adapted for the shore piers also.

In an arched bridge, the last or shore piers have to be constructed as abutments, to receive finally the thrust of the arches, unless the bridge is continued inshore by brick arches (as in Example No 25) or by iron girders acting as struts, through either of which the horizontal thrust may be transmitted further inshore or divided over a considerable surface in the bridge approaches. Where the approaches of a bridge are of earthwork, it is often necessary to build wing walls on each side of the abutments. These wing walls are almost invariably made of masonry or brickwork, and form part of the abutments. But where the shore piers or abutments are made of iron, and especially in countries where masonry and brickwork are expensive, the entire wing walls may be constructed of iron also. A series of iron cylinders or screw piles may be forced into the ground, and upon these can be fixed a complete shield or wall of iron plates properly stiffened and braced.

In the description that has been given of different kinds of piers, it has not been considered necessary to classify separately those of iron, which stand clear of the water on a foundation of masonry or brickwork. It sometimes happens that, on a stone base, the necessary height above water may be conveniently obtained by an iron structure. This is especially the case in very high bridges, or in viaducts crossing deep valleys, where a brick or stone pier would be heavy and expensive. In situations like these, a better support can be obtained by a framework of iron strongly braced together. Iron columns or pillars have in some cases been placed on wooden piles (Bridge Example No. 10), and the reverse plan, viz. wooden pillars on iron piles, has also been adopted.

CHAPTER IV.

CAST IRON IN BRIDGES.

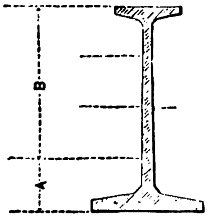
In the modern construction of girders and bridges, cast iron has, to a great extent, been superseded by wrought iron, because of the superiority which the latter possesses over the former against every kind of strain (tensile, transverse, shearing, vibrating strains, and those caused by the effects of temperature), with the exception of the quiescent compressive strain. Cast iron is much stronger than wrought iron in resistance to compression; and, owing to the existence of a natural crust or skin on its surface, it is not so liable as wrought iron to deterioration by rust, and, if kept painted with ordinary care, will prove the more enduring of the two. In the facility which it possesses of taking all possible shapes—whether required by a minute regard to the forces in a structure or for purposes of ornament—cast iron is also superior to wrought iron; while, weight for weight, it is much cheaper.

Considering the advantages and disadvantages which thus exist with regard to either material, it is obvious that any arbitrary rule against the use of cast iron in bridge construction would be injudicious; but, no doubt, the general impression of the superiority of wrought over cast iron has produced a prejudice against the use of the latter which is shared by some engineers. No inconsiderable skill is required to discriminate between the relative advantages of each material, and these depend upon the circumstances of every case which comes in question. It cannot be wondered at that failures arising from the improper application of cast iron, or the belief that all cast iron is of uniform quality, should have deterred many people from using it at all in bridge and girder construction.

It is impossible within a short space to enter into the many points which confirm the correctness of the foregoing statement; and reference can only here be made to what is said on pages 1 to 7 on the quality of iron, and to other incidental remarks in later pages with regard to different structures.

The occasional prohibition of the use of cast iron for railway bridges is based upon well-known facts, and is exemplified even by Government regulations in some countries.* To make a similar restriction in regard to road bridges would be unnecessary and unwise; because in many cases it is probable that, having a certain sum of money at his disposal, an engineer might construct a stronger and better bridge out of cast iron than wrought iron. It would be stronger and better because it would contain more material, and on this account would be of longer endurance; and, being heavier, it would with greater ease endure the strains from occasional heavy loads.

In the construction of cast iron girders, where the upper flange is in compression and the lower one in tension, it is generally considered a matter of importance to regard the greater resistance which cast iron offers against compression than against tension, and the top flanges are accordingly constructed smaller than the bottom flanges. Hodgkinson's experiments with cast iron girders, which have hitherto always been referred to on this subject, are based upon the resistance against fracture; and, according to this the bottom flange should be made six times as large as the top flange, because cast iron can endure a six times greater strain in compression than in tension. But Hodgkinson himself advises a less proportion, and names 4 to 1. Other engineers do not consider the strength of a beam to be determined by its resistance to fracture, but rather by its resistance before the limit of elasticity is reached,† and the proportionate resistance to compression and tension being in this only 3 to 1, or even 2 to 1,‡ according to the quality of the iron, they advise that flanges be designed according to these proportions. Assuming 3 to 1 as the proportion to be adopted, the section of the girder should be so arranged that its centre of gravity lies in three-fourths of its depth. That is to say, if the total depth be divided into four equal parts, the area of metal in A should be equal to the area in B.

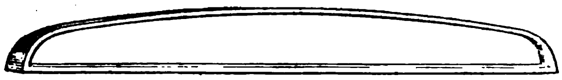


* See "Effect of Cold on Iron."

† See "Limit of Elasticity," page 10.

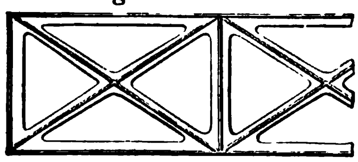
‡ This is the proportion given by Professor Reuleaux, of Zurich.

The most economical shape of a cast iron girder for an equally distributed load is the parabola either entirely or approxi-



mately. Girders with parallel flanges can be made economically by increasing the area of the flanges towards the middle and increasing the thickness of the web towards the ends; but often in practice this is not worth the trouble, and the maximum thickness is adopted throughout. As the web of a girder—especially one of considerable size—would, if made only in the proportion proper for strength, be at its junction with the flanges much thinner than the flanges, and as for convenience and safety in casting it is best to avoid such great disproportion, the web is sometimes pierced, so that the part that is left can be made thicker without wasting metal. This is also done so as to give a lighter and more ornamental appearance to the girder.

A structure in which there are cast iron trellis girders exposed to moving loads should be tested, because in casting such girders



the shrinking consequent upon cooling may produce dangerous latent strains in some parts without any visible indication of their existence. These strains are sometimes so great as to cause fracture of the affected parts before the casting has quite cooled; and it is not surprising that sometimes after castings have left the foundry in an apparently sound state, they should break under the influence of a change of season or climate. This risk can only be avoided by a judicious arrangement and proportioning of the metal in the several parts, and by the use of proper skill in the casting and cooling. (See "Effect of Cold on Iron.")

CHAPTER V.

CLASSIFICATION OF WROUGHT IRON GIRDERS. PLATE GIRDERS. ROLLED BEAMS. LATTICE GIRDERS. TRELLIS GIRDERS. WARREN GIRDERS. CONTINUOUS GIRDERS. TRUSSED GIRDERS. CURVED GIRDERS.

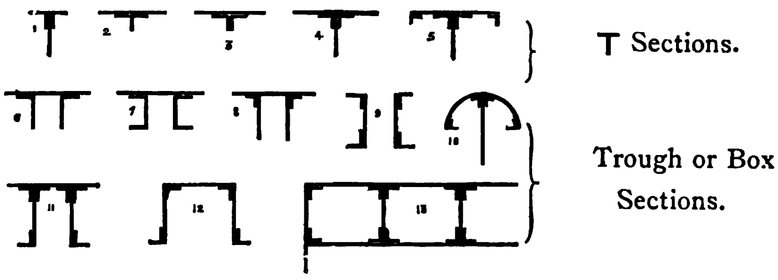
THE quality of iron suitable for wrought iron girders has been discussed at pages 10 and 11; and is of importance, not only as affecting the *strength* of a girder, but also its *workmanship*. Iron of inferior quality will not, without damage, endure the working which in many cases is necessary; and the ultimate value of any structure is determined by the quality of the material and the character of the workmanship as much as by that of the design. Reference has been made to the processes by which wrought iron is manufactured, and to the fact that the strength of any piece depends to some extent on the shape of its cross section, and on the methods by which it is produced. In bending or welding bars of T or ⊔ section, the quality of the iron is severely tried, and defects soon become apparent. In the design of a structure, even when the employment of good iron is ensured, welds and bends should be as much as possible avoided, with all sections of the kinds referred to.

Girders can be, and have been, constructed of all spans up to about 500 feet; and they preserve their characteristic rigidity within these limits to a thoroughly equal degree, if the laws which have governed the designers are sound. These laws have remained the same since bridges were first constructed, and have always been recognised by the most eminent engineers; the progress which has been made consisting only in the widespread recognition of these laws, partly upon the basis of mathematical science, and partly through experiment. Thus, forty years ago, the construction of an iron bridge was the task only of a man of genius, it is now essentially a matter of study.

The depth of a girder, in proportion to its length, varies from one-eighth to one-fifteenth for single girders, and from one-tenth to one-twentieth for continuous girders, and is determined, within these limits, as circumstances may make the application of material convenient or economical, the quantity of iron increasing as the correct proportion is departed from. In some case, where head-room is valuable, and it is impossible to use a deep girder, the necessary strength is given by heavier sections of iron; but the weight of iron required in a girder of insufficient depth is much greater than in one of equal strength, where the proper proportions are observed; and, moreover, deflection begins sooner and increases more rapidly. On the other hand, where a girder is made excessively deep, a greater weight of material is necessary in the web, or parts that connect the top and bottom members.

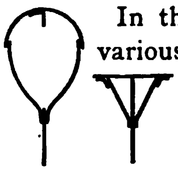
Girders, as used in bridges, may be classified in four different ways :—

1. In regard to the method of carrying the load, girders may be divided into those that carry their load on the top, and those that do not. In the former case, the cross-beams which sustain the floor unite the top flanges to the girders; in the latter case, provision must be made to retain the top flanges in position, because they have always the whole or parts of their length in compression. Where, as in continuous girders, parts of the bottom flange are also in compression, a similar provision must be made in those cases where the platform rests on the top flange. (See " Lateral Stability of Girders," page 75.)



2. Another classification of girders may be made, according to the construction of the flanges. These are either T shaped, or formed like a trough or box. The diagrams above show the most common sections.

The web of a girder of the first, or T, kind, whatever other character it may have, is single; that of the second, or box, kind is double. To make a broad distinction between the two kinds, it may be said that the first is comparatively deficient in rigidity in parts under compression, and that the forces of the web do not act centrally or symmetrically upon the section of the flange; but it is easy of construction, and therefore cheap. The second class is much superior in rigidity, but is more expensive.

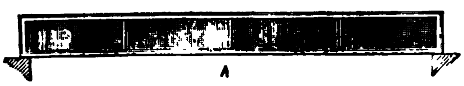


In the earlier construction of wrought iron girders, various attempts were made to obtain box or tubular-shaped flanges; and the engraving shows two sections, often used by Brunel. The improved forms which are now adopted are the result of experience thus gained, and of the greater choice of material which is afforded by the numerous sections of rolled iron which are made.

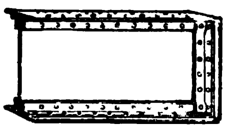
3. Another and very important classification of girders is made according to the construction of the web; the so-called systems of girders being thus accordingly named, Plate, Lattice, Trellis, Trussed, Warren, &c. Taking them in this order, they may be briefly described as follows:—

PLATE GIRDERS.

The *Plate Girder* is the most simple, and up to a certain size the most economical. It is rigid and durable, and is the most appropriate for small spans. In those of small size, the web

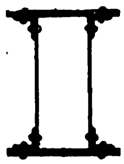


is made of a plate only; if the height of the web is great in proportion to its thickness, vertical L or T irons, or "gussets" of plate and L iron, have to be riveted upon it to prevent its buckling under accumulated compressive strains. But as in most cases the web cannot for practical reasons be made so thin as in theory would accord with the shearing strains, the surplus metal gives a stiffness which reduces the amount of additional stays which would otherwise be necessary. For the same reason, also, a plate girder cannot be counted amongst the



lightest structures. In other words, the proportion of the actual weight of a plate girder to its theoretical weight is great. Although not the lightest of structures, however, the plate girder, on account of the simplicity of its manufacture, is for small spans the cheapest.

Where great rigidity and strength are needed, two web plates are sometimes employed, thus enclosing a space and making

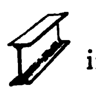


what is called a box or tubular girder. This enables wider flanges to be used, and makes a much stronger beam. It is, however, necessary that the inside of the girder shall be spacious enough to give access to the painter's brush, as, unpainted, the iron is liable to rust and consequent deterioration. For this reason, small box girders are not made so often as formerly. When the exigencies of a design render the use of small box girders necessary, special precautions should be adopted to prevent deterioration by rust. The joints may be caulked, so as to render them airtight, and where this can really be accomplished the iron will be unaffected. Wrought iron may be treated also by allowing it to rust, then scraping it and coating it with bituminous paint.* The plates should be made thick enough to allow for considerable wasting away, and as an extra precaution, the entire girder may be filled with lime concrete, which excludes the air from the iron and otherwise protects it.

The limit of size within which plate girders may be economically constructed depends on too many circumstances to allow any absolute rule to be given. There are in existence plate girder bridges of almost all possible dimensions, and some of the largest are objects of universal admiration; yet it may be broadly stated that the plate girder, if made beyond a span of 50 feet, loses those advantages which, up to that span, its simplicity affords as against the lightness of other systems.

The value of plate and box girders is from £16 to £18 per ton.†

ROLLED BEAMS.



Rolled beams are sometimes used with advantage, instead of plate girders of small depth. They are

* See "Painting Ironwork."

† For the cost of iron on which these prices are based, see page 12, and the introduction to "Examples of Bridges."

especially suitable as joists for fire-proof floors, as rafters in iron roofs, as stancheons and sometimes as longitudinal bearers in bridges. But their use must for obvious reasons be limited to such positions of secondary importance. The system of manufacture by which these beams are at present made is such as to place them in that class of rolled sections previously described as not of equal strength throughout, and unfortunately their main strength lies in the web, where it is least needed. It is, besides, difficult to make the flanges of sufficient width to receive a rivet conveniently, and—if the necessity arises—to join two beams at their ends. These rolled beams, or joists, are generally made in depths of from 4 to 14 inches, but they can be—and occasionally are—rolled of much larger dimensions. They have been made as deep as 3 feet both in England and on the Continent; but as in girders of this depth it is found economical to increase the area of the flanges towards the middle, and that of the web towards the ends, the want of these conditions in the rolled beams is a great disadvantage, as to obtain the necessary strength by riveting plates on to the beams is not an economical or good plan. It may therefore be assumed, that for a greater depth than 10 or 12 inches, a plate girder, composed of plates and L iron, is preferable to a rolled beam in every respect. Visitors to the Paris Exhibition of 1867 will remember a rolled beam of extraordinary dimensions, exhibited by Messrs. Petin, Gaudet, & Co. It measured 1 metre (39⅜ in.) in depth, 10 metres (33 ft.) in length, and weighed 2,500 kilos. (2½ tons). This beam, instead of being made in the usual way, was subjected to the pressure of four rollers, by which process the quality of the iron in the flanges was preserved, as well as of that in the web.

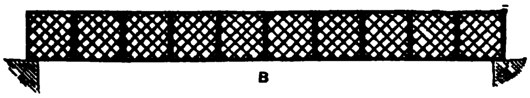
But even although rolled beams should be made in this way as cheaply as by the ordinary methods, it is difficult to see how their use should become extended beyond the present limits, so long as they cannot be manufactured with an increased area of flange and a diminished area of web towards the centre.

A considerable quantity of rolled beams is imported into this country from France and Belgium, and some of the cheaper sorts are not equal in quality to those made in England. Various kinds, other than the ordinary **I** section, are made, and are described in Chapter IX. on "Bridge Roadways."

By the ordinary process, joists are made from 4 inches to 18 inches in depth, and cost from £12 to £16 per ton (at a time when plates cost £12); the smallest and narrowest sections being the cheapest. The workmanship in attaching them to other ironwork involves extra cost.

LATTICE GIRDERS.

The ordinary lattice or trellis girder has its top and bottom members composed of plates and angle-irons, much in the same way as a plate girder. At regular distances apart, vertical stiffeners unite the two flanges, and a series of diagonal bars, crossing each other, fill up the intermediate spaces. Between



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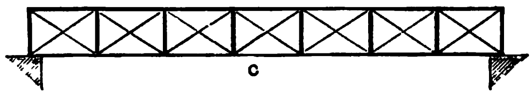
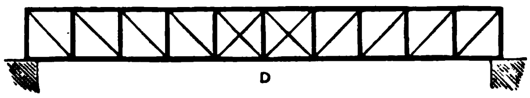
girders of this sort and plate girders there is not much difference in principle, as the web of a lattice girder is really like a plate in which openings have been cut, both having the same kinds of stiffeners. If between small plate girders and lattice girders the preference is sometimes given to the latter, it is because of their more pleasing appearance, and not on account of any material advantages which they afford. In large girders, however, the lattice system allows in the construction of the web a nearer approach to be made than is possible in plate girders to the area demanded by the shearing forces, and allows also the omission of the joint plates which are necessary in a plate web. The lattice work also presents a smaller resistance to the wind, and allows free access of light. Lattice girders cost about the same as plate girders.

Both plate and lattice girders are found not to be economical structures when the web exceeds a certain depth, because the material necessary to stiffen a solid or perforated web by vertical stiffeners (the only purpose of which is to enable the web to resist the shearing strains directly like a column, and prevent it buckling, and so becoming subject to transverse strains) is, generally speaking, somewhat wastefully applied. It is better to concentrate the numerous points of action into a few of greater individual strength, either by a combination of vertical struts and diagonal ties, or by a system combining diagonal struts and ties. This method, fully developed, leads to two distinct systems, that of the single *Trellis* and the single *Warren* girder. (The words "trellis" and "lattice" have generally a similar meaning, and it is perhaps rather an arbitrary use of the former word to adopt it as a distinctive title for the girders C and D, shown below in the diagram. But as the word is frequently used in these pages, it should be understood to mean a girder divided into bays or rectangles by verticals, and having diagonals which only cross once between the verticals. The term "lattice girder," on the other hand, is here intended to describe a girder having diagonals at any intervals, and crossing each other without reference to vertical members.)

TRELLIS GIRDERS.

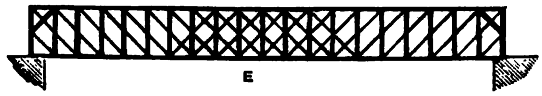
The web of the single *Trellis Girder* consists of vertical struts and diagonal ties; the former composed of L, T, I, or ⊔ irons, or a combination of them with plates; the diagonal ties usually only of flat bars.





If the weight of the structure itself is considerable, as compared with the moving loads, some of the diagonals may be dispensed with, as shown in the diagram D; and, indeed, in almost every case where they are all inserted, as in C, it is for the sake of uniformity in appearance only.

As this is the simplest possible form of trellis girder, and is lighter than either the plate or lattice girders, it is necessary to state how the application of the theory is limited. In proportion as the single members (struts) are made strong and massive, the places of connection must be of considerable dimensions; and cases occur where a flange, which is in other respects suitable, will not offer sufficient surface and strength to form such a connection. These cases lead to the application of the double and perhaps even the treble system of trellis, which allow a considerable reduction in the size of the individual connections.

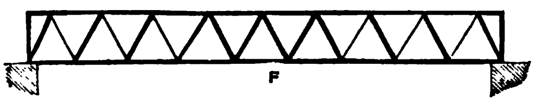


E

In structures of this kind, however, the great number of members is sometimes inconvenient, and towards the centre of the girder, where the strains are small, the members may be in excess; and it must be left to the designer to steer as best he may between the two evils of making the flanges too heavy and the verticals and diagonals too numerous. On the other hand, an advantage is obtained by the arrangement of the diagonals affording a hold at their centres to the verticals where they cross, and thus allowing the latter to be made lighter than if—under otherwise equal circumstances—they were quite free. The angle of 45°, which theoretically is the best for the diagonals of trellis girders, is also convenient in practice; but in some cases a flatter angle proves the more economical. (See "Trussed Girders.") It is not easy to see, however, that a more acute angle than 45° can ever be of advantage, although girders have been sometimes so constructed. The cost per ton of these girders is rather more than that of lattice girders.

WARREN GIRDERS.

The second kind of girder alluded to on page 61, as derived from the lattice system, is the Warren girder.* This name is usually given to a girder whose web is formed by a



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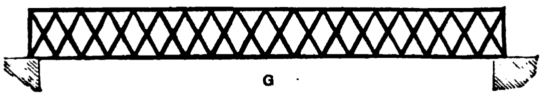
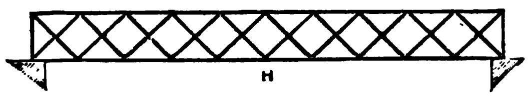
single triangulation of bars at an angle of 60° to each other. It is, however, convenient to extend this name to angles more or less than 60°, though angles other than 60° or 45° are seldom adopted. There is always a strut joining to a tie except

* The system of girders known in this country as the "Warren" is generally recognised on the Continent by the name of "Neville," who was the first to construct girders of the kind. The system was afterwards adopted in England by Captain Warren.

at one point, *i.e.* at or near the centre where a tie joins a tie, or a strut joins a strut; because at that point the total load is separated into two portions, one of which is supported by one abutment, and one by the other. As this point travels a certain distance under the different circumstances of a moving load, all the diagonals lying within these limits have to be constructed as struts.

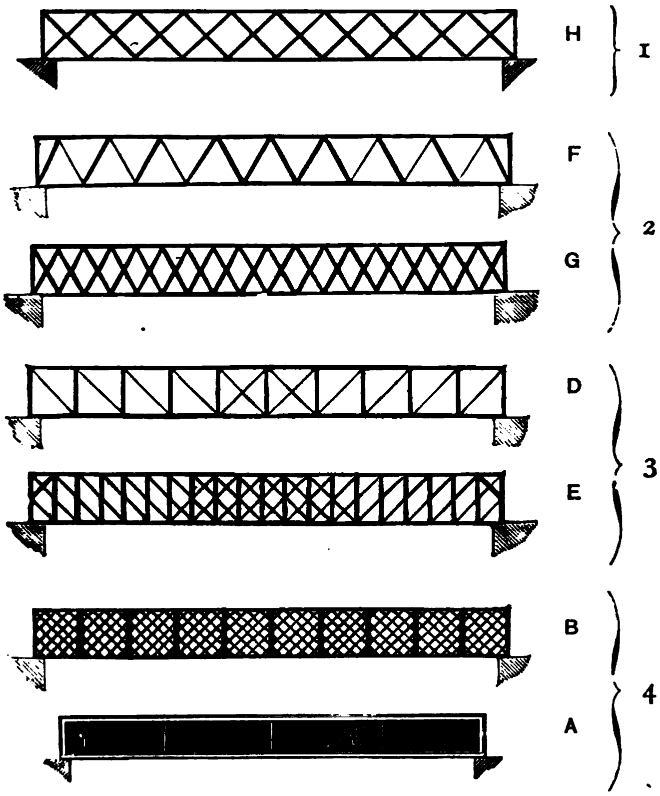
Everything that has been said about doubling the system, under the head of *trellis girders*, is applicable here. The annexed sketches illustrate the double system of Warren girder





of 60°, and that of 45°. (See Bridge Example No. 30.) Girders of this class are often constructed with pin connections (see page 70), which involve a higher price per ton than for any of the kinds previously described. When so made, from £19 to £22 may be taken as the cost.

In regard to the comparative merits of the systems which have been hitherto described, much more might be said than is compatible with the purpose or limits of this book; but with reference to the comparative weight of iron which theoretically is necessary for the various kinds of girders, the classification on page 64 may be given, No. 1 being the lightest, and the others in the order shown; but this is only if the systems are compared under equally favourable circumstances; that is to say, the load should be on the top flange, or if on the bottom flange the girders should be high enough to allow of overhead bracing, thus requiring no special addition to the web for maintaining the upper flange in position. (See "Lateral Stability of Girders," page 75.) It is generally only in girders of considerable size that the order of theoretical weight, shown on page 64, can be made to apply. The practical considerations that prevail in small spans, and in special cases, will often entirely change the order given on page 64.



See page 63.

CONTINUOUS GIRDERS.

Girders with parallel flanges do not exhibit, when continuous over two or more spans, any features which exclude them from the classification already made. Their peculiarities consist in a more complicated distribution of strains than exists in independent girders, economy in weight of material, and certain facilities in the erection, which are mentioned in Chapter XII.

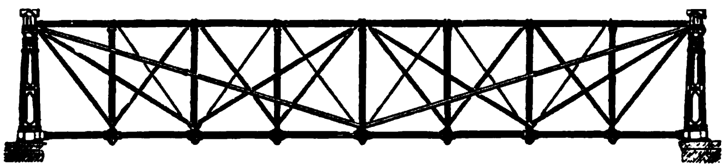
TRUSSED GIRDERS.

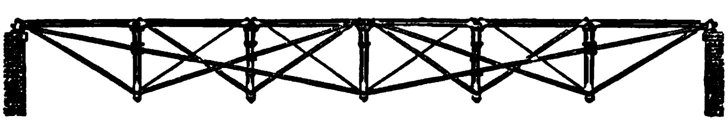
In addition to what has been here stated concerning girders with parallel flanges, a kind of trellis girder must be mentioned, which is called a trussed beam in those cases where it is loaded on the top flange. The most simple illustration of its principle is given by bisecting the top flange in its

length, and supporting the point thus indicated by a vertical strut and two ties, the latter forming an angle of 45°, or one flatter than 45° with the horizontal line. Two or more of such trusses can be arranged together, in which cases it is necessary that the top flange shall form one beam, and that the points where the diagonals join the verticals at the bottom shall be connected by a horizontal tie.

Between this kind of girder and that described as the single trellis, there is no essential difference, the peculiarities consisting in the exceptionally small number of vertical struts; the flatness of the angle formed by the diagonals, and the construction of the top member, as in itself a girder, sustaining a number of cross bearers in the space between every two vertical struts.

A modification of this kind of truss has been adopted by A. Handyside and Co. as specially suitable for those new colonies and foreign countries where transport is difficult, and skilled labour rare and expensive. (See Bridge Examples Nos. 23 and 28.) The system is used with advantage in spans up to 120 feet, carrying moderate loads; and bridges so constructed are easily erected, on account of the fewness of members and the simplicity of the connections.



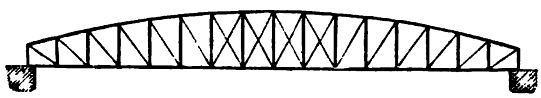


A girder, not unlike the one described as a trussed beam, is that known in America as a bridge girder according to Fink's system. The chief peculiarity of this girder is that it forms a complete truss even without a horizontal bottom member, the latter being always omitted when the platform of the bridge rests on the top member. Bridges of this kind have been erected at a low cost; and for this reason, and on account of their light appearance, the system is much approved by some engineers. But, on closer investigation, the cheapness of these structures is found to be not so much due to the peculiarity of the combination as, firstly, to the great depth of the girders in proportion to their length; secondly, to the use of cast iron in all compressed parts; and, thirdly, to the unusually high strain which the material is made to resist. If in these points the bases of comparison be made identical, it will be found that the trussed beam previously described, or even the ordinary trellis girder, will be preferable, because less expensive.

CURVED GIRDERS.

4. A fourth classification of girders has yet to be made by dividing those which have their flanges parallel from those that have not. All systems hitherto described may belong to either of these two classes; but as, in the cases of all the girders previously mentioned, it has been assumed that the flanges are parallel, some girders with curved flanges which are not parallel may be now noted as exceptions. These are—

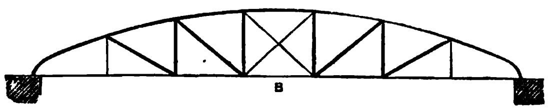
a. The ordinary girder (plate, trellis, &c.) with curved top flange. This is seldom used with advantage, except when



its dimensions are so large that at the springing of the arch there is sufficient height from the platform of the bridge to allow a bracing across the latter to commence there without obstructing the traffic.

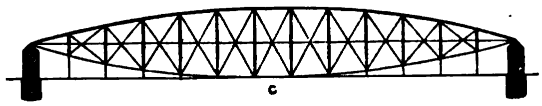
b. The parabolic curve, or bowstring girder, consisting of a top flange following the curve of a parabola, the springing of which starts from and is firmly united to the end of the horizontal member. The best proportion of the rise into the chord is 1 to 7. When the girder is loaded by an equally distributed weight, the top flange may be considered as a parabolic arch;

the bottom flange has an equal strain throughout its length, and the verticals act as ties strained according to the amount of weight in each bay. The diagonals have not to resist any strain

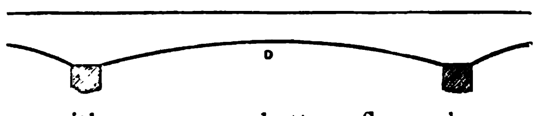


except when the uniformity of the load is disturbed, and then only to a small extent. The near approach to uniformity of strength in the various parts, under the above-mentioned conditions, renders the bowstring the lightest of all girders; but as the great variations in the length of parts, the curving of the top flange, and the variety of angles which occur at the junctions, offer exceptional difficulties and expense in the manufacture, these may be said to balance the advantages which are offered by the reduced weight of material which the system allows.

c. The fish-bellied girder consists of an upper and lower flange, each having the parabolic curve, but in opposite directions. In regard to the proportions and the uniformity of strains



it most resembles the bowstring girder, and has been used to advantage in cases where, owing to large span, the quantity of iron in the bridge formed an important item in the total load to be carried by it, and where any reduction that could be effected in the weight of iron has a material effect in diminishing the strains upon the structure.



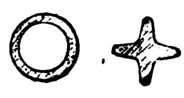
d. Girders with a concave bottom flange have never been used except when continuous over several spans. In such circumstances they offer the advantage of a greater clear headway below the bridge than girders of the same strength and weight with parallel flanges. (Bridge Example No. 19.)

Besides these forms of girders, there are others with flanges not parallel to each other, which may be more properly classified as trusses for roofs, and they are referred to under that heading.

CHAPTER VI.

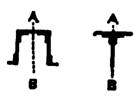
THE PARTS OF WROUGHT-IRON GIRDERS. RIVETS. LATERAL STABILITY OF GIRDERS.

REFERENCE has been made at page 56 to different kinds of flanges, the sections of which were there classified as T shaped or trough-shaped. For flanges which are always in tension, these shapes have equal strength, but for those in compression this is not the case.* The resistance of the strut will be great when the material of the section is placed as much as possible away from the neutral axis, and small when it is concentrated about it. In accordance with this, the resistance of the trough-shaped flange is great as compared with that of the T shaped one, just in the same way as a hollow column is superior to a stancheon of equal sectional area. The T shaped flange may of course be improved by adding material at the extremities, as in Fig. 5, page 56, but the greater part of the material will necessarily have to remain at or near the neutral axis. The same principle applies to the vertical or diagonal struts shown on page 69.



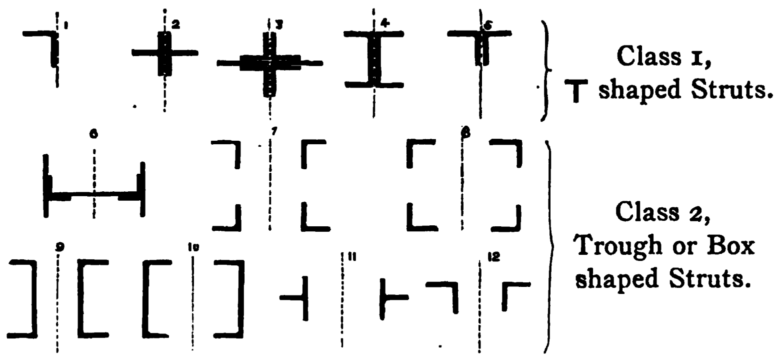
T shaped flanges generally have verticals or diagonals of similar shape attached to them (Class 1), while the trough-shaped flange allows the use of verticals or diagonals having tube or trough-shaped sections (Class 2). There are great advantages in favour of the latter kind in regard to strength. The strain to be taken by the strut is much more equally distributed over its section than in a T or + shaped member, some parts of which have to resist a greater strain than is due to their proportion of the total sectional area, while some parts are subjected to a comparatively lighter strain. These deficiencies in the hands of a

* The resistance of a strut is in proportion to the moment of inertia of its cross section, taken on an axis which for flanges of most girders is the vertical centre line AB. In other words, the moment of inertia depends on the distribution of the material in regard to the neutral axis.



skilful designer may to some degree be modified by a proper choice of dimensions and distribution of materials.

The construction of parts which under all circumstances are in tension requires little comment. When no special reasons

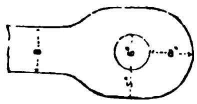


have to be considered, flat bars, as the most simple form of rolled iron, are always used, and among these a peculiar kind is made, having enlarged ends to receive a single pin or bolt of the strength of the whole bar. These are called links, because, if several of them are connected end to end, they may compose a flexible chain. These links are chiefly used for the tension members of Warren and trussed girders. The link-head should be made of such a form that there is no liability to break at any point of it sooner than through the bar. In some of the earlier structures, such as suspension bridges where links were employed, the dimensions were not so arranged, the heads being nearly, if not quite, circular, and the diameter of the head, as well as of the pin hole, was made too small. The circular shape does not in itself involve any insufficiency of strength, but it is not the shape which requires the least material. Considerable attention has been given to this subject, and the experiments which have been made may be said to have solved the problem in its chief points. The following is the result which has been arrived at for links when the head is not thicker than the other parts of the bar :—*

* These proportions are the result of experiments made by Messrs. Howard, Ravenhill, & Co., of London, a firm which had considerable and special experience in the manufacture of wrought-iron links.

If the width of the bar	=	1.
The diameter of hole should	=	·75.
The two sides of the head together	=	1·25.
The back of the head	=	1.

So, for an 8 in. link, the dimensions should be as in sketch.



For links of this description a superior quality of iron is generally used, an average of 25 tons, and a minimum of 22½ or 23 tons breaking strain per square inch, being a customary standard. In the bridges given as examples, Nos. 22 and 30, the links were of this sort, and were also ductile enough to elongate 1⅜ in. or 1½ in. per foot before fracture, and to endure 12 or 13 tons strain per square inch without any permanent set *—the elasticity of the iron, when the strain had been removed, enabling it to recover its original form, although it had been stretched by the 12 tons $\frac{1}{100}$th in. per foot.

In girders of moderate size the bottom flange is sometimes constructed of links made in lengths equal to two bays, each hole in a link forming with the diagonals the lower point or apex of a triangle. The total strength of the member is formed by placing one, two, three, or more links side by side, the number or the thickness of the bars increasing towards the centre of the girder. Links are connected to each other, or with other parts of a girder, by means of a turned pin fitting accurately into the hole or eye.

There are differences of opinion among engineers in regard to the "pin system," and the advantages which it offers as compared with riveting. It is the facility for transport, and for the erection of a bridge in a foreign country, which the pin system affords, rather than any supposed permanent advantage, that induces its adoption. The difficulty of riveting girders together in a country where skilled labour is unattainable is sometimes so great as to forbid the introduction of iron bridges altogether, and any plan, therefore, by which the necessity for riveting is saved is, in such cases, often gladly made use of. In "Warren" and other girders, the parts can be made so exactly as to be interchangeable, and the pins can be fitted so accurately as to render the erection on the site a

* See note, "Permanent Set," on page 11.

very simple matter, and one in which it is almost impossible to go wrong. But the tight fitting of the pins is essential to the stability of the structure, and it is in the risk of inaccuracy in this respect, or in the fear that the pins may shake loose, that the objection to their use generally lies. In a railway bridge the passage of a train has a percussive effect, which has a tendency to produce a hammering of the pins, which in time will elongate the holes. Rivets, on the other hand, properly inserted, become part of a permanently solid structure. The conditions of manufacture and the quality of material and workmanship in a girder with pin connections are always—most properly—of the strictest kind; for unless these conditions are maintained, the destruction of a bridge would commence from the day it was erected.

RIVETS.

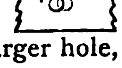
In a riveted girder it is desirable that the various parts be so put together that when finished it shall resemble, and possess as nearly as possible all the powers of, a beam constructed of one piece of iron. On this the strength of the entire structure depends, and it is necessary therefore that the work be accurately fitted together, and that each rivet shall completely fill the hole made to receive it. If this result be not obtained, the girder must, when loaded, necessarily bend to an undue extent, and, after this deflection, will not be elastic enough to resume its original form when the load is removed, thus showing more *permanent set* than would occur in a girder properly made. Riveting is best effected by the careful use of a steam or hydraulic machine, which, with one stroke, presses the heated rivet and completely fills with it every interstice in the iron which it enters. This is fully shown when a rivet has to be removed. If it has been hammered in by hand, it is easily driven out when the head is cut off; but if it has been machine-riveted, it is generally necessary to *drill* it out, so completely has it become part of the iron into which it was forced.

The superiority of machine-riveting lies in the distinctly different effects which result from the different kind of blows. A small weight falling with a considerable velocity a great number of times may produce the same aggregate result as a heavy weight falling once with a less velocity, but the effect worked by the former is chiefly in the particles nearest to the tool (the hammer, the rivet-point, and the surface of the plate), while with the latter the effect is transmitted to the more distant or interior particles. Another illustration of this principle is seen in pile-driving (see "Erection of Bridges"), when the effect of a heavy ram falling a moderate distance is compared with that of a light weight with a longer fall.

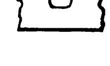
A rivet should be heated throughout its entire length, and when inserted should be as hot—and for hand-riveting hotter—at the head than at the point. The blows of the hammer are not felt so severely at the head as at the point, and as at both it is necessary to swell out or "upset" the rivet to fill the hole entirely, extra heat and ductility at the hilt allow the blows of the hammer to have due effect.

The shape of the rivet-head should combine the greatest strength with the least amount of metal, and it is not unusual, when a structure is designed, to prepare a detail drawing of the rivet-head that is required.

Rivet-holes are generally *punched* through the iron; but during the last few years many engineers have required that the holes in certain parts of a girder shall be *drilled*. Much misunderstanding exists upon this subject. By drilling it is intended, first, that more exactness shall be attained in the position of the holes, and second, that the iron shall not be damaged as with a punch. With regard to the first point, much depends on carefully setting-out and good workmanship, for, whether holes are drilled or punched, they can be done well or badly. No doubt the scandalous manner in which riveted girders have been made by careless or inexperienced workmen, has tended to make engineers demand what they consider surer methods. But if holes are drilled in each piece of iron separately, as is done in punching, there is of course the same risk in one case as in the other, that when the different pieces are put together the holes will not properly coincide. When this occurs the workman has no other course



but to cut the holes with a drift, or to rimer out a larger hole, and then to insert the rivet in a space which is too large for it. As the number of plates through which



one rivet has to pass increases, the possibility of all the holes not exactly meeting also increases, and in cases of this sort the risk is without doubt diminished by having the holes drilled through all the thicknesses of iron at once after the girder has been framed together, or by first having small holes punched in the separate pieces, and then rimered out through all the thicknesses of iron after the pieces are put together. If carefully executed, however, in good iron, with a powerful machine, there is no reason why punched holes should not suffice. In punched holes the shape of the punch and die produces a hole the sides of which are not quite parallel, and some of the advantages of a countersunk hole are obtained. Drilled holes are not always circular, an irregularly-shaped drill or an imperfect machine producing an oval hole. The edges of drilled holes are so sharp as to increase the cutting effect on the rivet, and to render what would in a punched hole be more of a tranverse strain a severe shearing strain.

With regard to the second point referred to, iron ought to be of such quality that a hole may be punched near the edge without cracking the surrounding parts. A great deal of inferior (Welsh and other) iron will not endure this ordeal, and it is largely owing to the many instances of failure in this respect that have occurred that the demand for drilled holes has arisen. Engineers having found that bad iron exists and is used, have tried to guard against it by stipulating for good quality; but too often this is done by simply asking for a high breaking strain, and for this only. The consequence is, that iron-makers who have an inferior material to deal with have met the demand by rolling iron, which, while enduring a high tensile force without fracture, is so brittle that holes cannot be punched in it near the edge without evident damage. At the present time manufacturers of girders who use such iron may prefer to drill the rivet-holes. Where uncertainty exists as to the quality of iron that will be used, some safeguard may be obtained by having the holes drilled, but the extra cost involved would more than pay the difference necessary to obtain good material. In girders having many thicknesses of iron riveted together, drilled holes add but slightly to the cost as compared with that of punched holes. The sound appearance of iron round a punched hole is one very sure test of quality. If engineers, instead of specifying a high breaking strain, would enforce only a moderate figure, but accompany it by a sufficient test for ductility and elasticity, they would probably obtain a material better adapted for their purpose than much which is now used. But so long as tenders are accepted at prices so low as to render it impossible to give good iron and workmanship without loss, hardly any amount of supervision will protect a buyer from that inferior quality for which alone his purchase-money is an equivalent.

It is difficult to punch holes of a diameter less than half the thickness of the plate.

As an almost universal rule rivets should have to endure a shearing or transverse strain only. Bridges have sometimes been made in which cross girders have been attached to the main girders by rivets, in such a way that the whole weight is upon the rivet-heads in tension. This—especially in railway bridges—should be avoided as unsafe, although it is right to state that this opinion is opposed to that of some engineers. In the erection of bridges, rivets have sometimes to be inserted which, from their position, render the use of the hammer difficult; or the rivet may be nearly cold. In these, as indeed in ordinary cases, a careless or unscrupulous workman may not give a proper head to the rivet, and it is obvious that this is of more consequence where the stress is on the rivet longitudinally than when there is a shearing strain only.

The arrangement of rivets in a structure, and particularly in the connections, sometimes requires a great amount of skill, and it is hardly saying too much to state that the value of a design can be measured by the fitness and symmetry of its connections.

LATERAL STABILITY OF GIRDERS.

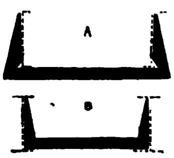
A strut or column of a given length and section is liable, if it be not held in position within its length, to bend sideways, and ultimately to collapse under a certain compressive strain. If the same strut be made twice as long, only one-fourth of that strain is required to produce the same effect; if three times as long, one-ninth of that strain, and so on. The top flanges of girders may in this sense be regarded as struts, and as they are usually of great length as compared with the area over which the section is spread, their liability to bend or ultimately collapse sideways must be specially considered in the design. A top flange whose sectional area is calculated in the same way as that of a bottom flange, according to an ordinary diagram of strains, must therefore be held in position at certain intervals. In bridges this is effected in three different ways :—

1. In bridges where the platform rests on the top flange, by simply connecting the flanges of the girders by the platform itself, and by the addition of some cross-bracing below the platform where the girders are high.

2. In bridges where the platform rests on the bottom flanges, by bracing across the bridge from one top flange to another in those cases where the girders are deep enough to allow the necessary head-room for traffic under the bracing.

3. In bridges where the girders are not high enough to allow the second plan, by constructing uprights on the platform which act as vertical cantilevers.

The first and second methods offer no difficulty, but the third requires more careful consideration. If the girders are constructed according to the trellis system, or the plate system with vertical stiffeners, the cross girders should be placed in one plane with the verticals, and connected to them so as together to form a ⊔ shaped frame, with strong corners. Thus, if the diagrams A and B each represent the cross section of a bridge, the dotted lines being the main girders, then the black lines show the ⊔ shaped frame, the upper ends of which are able to hold the top flanges in position. Under these circumstances, of course, the cross girder must be designed with due regard to the double purpose it has to fulfil. If the girder is constructed according to the lattice system, without verticals to meet the ordinary diagram of strains, either special uprights have to be constructed at certain intervals, or the diagonals and their connection with the platform must be such as to enable them to act as cantilevers vertically. This can be done if the flanges of the main girders have a trough or box section (see page 56), and the struts consequently have the qualities of a well-built girder. The Czernowitz Bridge (Example No. 29) gives an instance of this somewhat unusual method of holding the top flanges in position, though there it is effected in other ways at the same time.

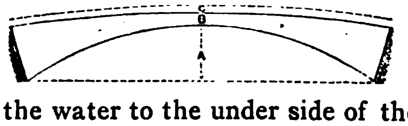


CHAPTER VII.

ARCHED BRIDGES.

In the preceding pages, various systems of girders have been described and classified according to their different kinds, and it may be convenient in leaving the subject to refer to the qualifications of girder bridges generally, as contrasted with those of arched bridges, suspension bridges, and other structures. A girder, or rather a girder bridge consisting of a pair of girders with a platform between them, is a complete structure in itself —*i.e.* when laid upon two fixed bearings it is independent of any other stability in the supports than that which enables them to resist the vertical pressure or load. For this reason girder bridges are, generally speaking, the simplest as well as the safest structures, and those cases may be considered as exceptional where the use of such bridges cannot be justified.

Arched bridges and *inverted* arched bridges (generally called suspension bridges) are not independent structures—*i.e.* when laid upon two supports they are incomplete, the acting forces and the resisting forces not being in equilibrium. This is restored by creating a force or body of resistance at an angle with the vertical line, and such bodies are for arched bridges called abutments, and for suspension bridges anchorages. It is therefore at once apparent that arched bridges are out of place in cases where the construction of abutments offers great difficulties. Where the foundation-ground lies at a great depth below the road level, the abutments are necessarily expensive, and the cost of them may often be out of all reasonable proportion to that of the superstructure. In cases also where the roadway line is at too low a level to afford the height necessary for the curve of the arch at the crown, and at the same time allow the springing to be clear of the water, the arch system is



inapplicable. The necessary height may be taken as A + B + C. A is the height from the water to the under side of the structure, and is from $\frac{1}{10}$th to $\frac{1}{12}$th of the span. B is the depth of the arch at the crown, and is from $\frac{1}{40}$th to $\frac{1}{50}$th of the span. C is the thickness of road material. On the other hand, there are cases where the properties of an arch afford advantages over the girder, and these cases, affected more or less by other considerations, are:—

1. If the banks of the river or ravine are of rock, and thus form natural abutments. In this case it is generally found that the arch is a less expensive structure than the girder. This holds good also for a bridge of more than one span.

2. Deep valleys, with little or no water in them, may also be considered as situations where the arch would not be out of place, because *high* arches, with their springing points at the level of the ground, can be constructed, and this allows economy in weight and price as compared with a girder bridge. In deciding this question, however, in any given case, the relative cost of erection depending on local circumstances must be taken into account.

3. If the roadway material is very heavy. Macadamised stone, or other similar coverings, find a cheaper support on arches than on girders, other circumstances being equal.

4. If the natural beauty of the arch is taken into account. This consideration, although of an entirely different character from the first three, is mentioned because there are not only cases where a beautiful structure is required, apart from questions of expense, but because there are also cases where the scientific arguments in favour of girders and arches may be about equal, and where, therefore, purely æsthetical considerations should be allowed to decide.

Whether in a given case an arched bridge is a more economical structure than a girder bridge depends—leaving the cost of the abutments out of the question—upon the existence and magnitude of the transverse strains. If they are considerable, *i.e.* if the resistance of the abutments on the one hand, and the acting forces of the load on the other, are liable to great changes, arches should be avoided. If they are small, for instance, if such circumstances as are stated in paragraph 1 above, or as in paragraph 3, rendering changes in the moving load of less relative importance, then arches may be recommended.

Next to stone or brick, cast iron is the material best suited for the requirements of an arched bridge, because it combines great firmness under a compressive strain with a comparatively low price; or, in other words, because the cost of the unit of supporting power is smaller. For this reason also cast iron arches may properly be constructed with an abundance of material, which, combined with the natural hard skin or crust on the iron, renders them capable of long resistance to the influence of the atmosphere.*

Wrought iron has been used in the construction of arches chiefly, it may almost be said, where the æsthetical considerations in paragraph 4 have had greater weight in determining the design than the more economical ones referred to in paragraphs 1 and 2. That is to say, it is adopted in cases where the nature of the abutments, or the concurrence of moving loads great in proportion to the dead or constant load, produces considerable transverse strains, and renders a more elastic material than cast iron necessary. Wrought iron has also been used in cases where no other reason can be found for its adoption than a general dislike to cast iron, as referred to on pages 7 and 52.

There are sometimes cases where the risks of long or hazardous transport render the use of wrought iron expedient, where, but for these incidents, cast iron would be preferable. The occurrence of vibrations, which also justifies the preference of wrought to cast iron, need hardly be mentioned here, as it is only the consequence of an unfavourable proportion of the stationary to the moving load, which, as conveyed by paragraphs 1 and 3 on the preceding page, would be considered as an argument against the arch altogether.

In regard to the construction of details, everything that has been stated under the head of "Parts of Girders," particularly with regard to long struts, may be applied also to arches.

The abutments of arches are almost always constructed of

* Southwark Bridge, over the Thames, which is made entirely of cast iron, may be given as an example. It was erected in 1819, and consists of three arches, each the segment of a circle, the middle arch having a span of 250 feet, and the two end arches 210 feet each. As all the parts are accessible for painting, the structure, though subjected to a London atmosphere, has suffered little from decay, and sustains a heavy roadway and traffic.

masonry or brickwork. They have to transmit the thrust from the arch at its springing to the foundation-ground, and may be considered, therefore, as a continuation of the arch. Abutments should be considered in this sense; that is to say, the continuation of the *curve of equilibrium* should be constructed beneath the springing of the real arch (with due allowance for the weight of the masonry), and this masonry should hold the curve entirely, and even amply, enclosed in itself. In the best known structures this takes place without regard to the additional stability obtained from the weight of the earth, which may surround or cover the masonry.

While the bridge has a moving load equally distributed all over it, the strains caused by such a load are transmitted to the shore abutments, and the intermediate piers sustain a vertical load only. As, however, the traffic on a bridge is often unequally distributed—for instance, one span may alone be loaded—the intermediate piers must be made of sufficient stability to resist the whole of the horizontal thrust due to the maximum moving load placed upon one of the adjacent spans. For instance, in many railway bridges the moving load is not only great in proportion to the dead load, but also is often concentrated on individual sections of the bridge. The piers therefore require greater stability than in the opposite case—that of most roadway bridges—where the weight of the platform is generally great, and where one span is not likely to be strained with its maximum load while the adjoining span is entirely unloaded.

CHAPTER VIII.

SUSPENSION BRIDGES, COMBINED STRUCTURES, OPENING BRIDGES.

SUSPENSION BRIDGES.

SUSPENSION bridges are chiefly used for spans too great to be covered by arches or girders at a reasonable cost, and sometimes also in cases where, though the span is not excessive, only a roadway for foot passengers is required. Although girders can be, and have been, made as long as 500 feet, the weight and cost increases so rapidly with the span, that for road bridges beyond 300 feet the alternative of suspension bridges offers advantages worth consideration.

The liability of suspension bridges to undulating or oscillating movement when exposed to sudden and unequal loads has rendered their use for railways rare ; and it is only since, by the aid of modern improvements, stability and rigidity have been obtained in these structures—as will be presently described—that they have been considered equal to the peculiar strains caused by the passage of a railway train.

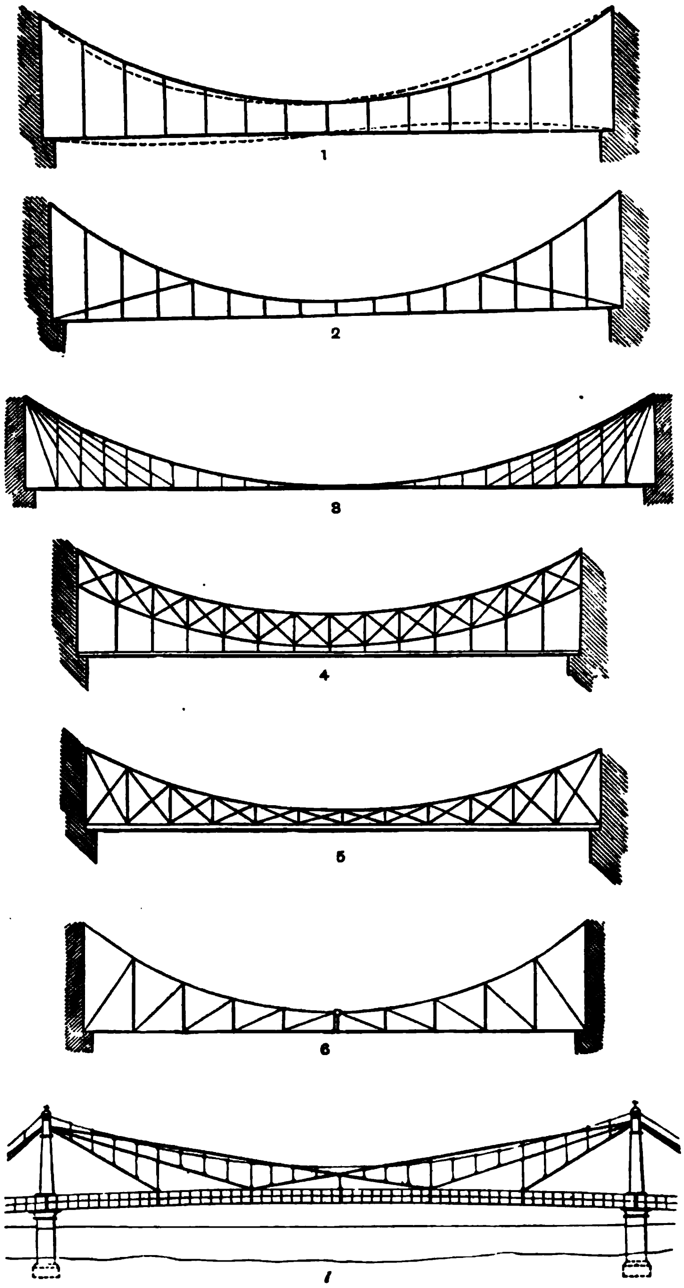
For the use of foot passengers only, light suspension bridges have been constructed over high-banked rivers, ravines, and other places where the cost of a rigid structure would be out of proportion to the simple service required. Although bridges of this kind, with a catenary chain of steel or iron, and with a platform of iron or wood, may be constructed at a low cost, yet the very lightness of the material which allows the economy renders the bridge liable to extreme undulation under a moving load, or when exposed to gusts of wind. In a very light bridge of this kind the weight and cost of the material necessary for lateral bracing, and for holding the platform down against the pressure upwards of the wind, may equal what is required for sustaining the dead and moving load. Greater stiffness may be obtained by using a flat catenary, but this improvement is arrived at by a more than proportionate increase in the weight of material.

In ordinary suspension bridges the roadway is suspended by hanging rods, from chains which stretch from pier to pier; the whole weight of the platform, and the moving loads upon it, being thus transmitted through the chains to the piers. Whatever the length of span, the platform forming the roadway is in all its parts of uniform strength; only the chains from which it is suspended increasing in strength and weight per foot as the span increases.

In such a structure the chain and the platform are flexible longitudinally, and this is shown whenever the bridge is loaded at one end more than at the other by a moving load, or is subjected to wind pressure above or below. In a bridge of one span, or of one complete span and two adjoining spaces shorter than half the middle span, the alterations of the shape of the chain are of the kind illustrated in Fig. 1, page 82, by the dotted lines, and varying in position with the moving load. The amount of deflection of one half of the span and the upward lift of the other half depend on the proportion of the equally distributed load to the accumulated load. Heavy roadway bridges, with a traffic nearly equally distributed over the span, will show smaller alterations in the shape of the chain than light railway bridges, where the traffic is of a very different character. To improve ordinary suspension bridges in this respect, and eventually to make them capable of carrying railway traffic, has been the aim of many engineers. The simplest improvement has been effected by keeping the two points of the curved chain which are most liable to deformation in their proper places by attaching them to the piers with short straight chains (Ordish's chains), as shown in Fig. 2.

A similar effect has been produced by Rœbling, in his large American railway and other bridges, by supporting the moving load at the dangerous points by straight chains extending from the abutments or towers, as shown in Fig. 3.

A method for rendering the chain itself rigid has been attempted by dividing it into two parts, placed one above the other, and bracing them together. A railway bridge according to this system (Fig. 4) has been constructed at Vienna



SUSPENSION BRIDGES.

bySchnirch.* Better than this, however, is a system according to which a single chain is connected to the platform by bracing, as shown in Fig. 5. This was adopted by Mr. P. W. Barlow in the construction of Lambeth-bridge,† and more recently with greater perfection in a footway bridge over the Main at Frankfort.‡ In the latter case (Fig. 6), the bridge is constructed so as to be entirely rigid, the chain being connected to a horizontal girder by means of vertical and diagonal members, which have to act alternately as struts and ties. At the centre of the span the girder is cut and the chain hinged.

Another mode of obtaining rigidity in suspension bridges has been adopted in the construction of a roadway bridge over the Moldau at Prague § (Fig. 7), and is known as Ordish's system. This bridge is 820 feet long, and has a clear central span of 492 feet. A girder is suspended at several points by inclined straight chains, which carry the whole of the load and the weight of the bridge.

These chains are retained in straight lines by being suspended from the curved chain by vertical rods. The load upon the curved chain under all circumstances being the same (namely, the weight of the inclined straight chains), the proper curve is always maintained both with equal and unequal loads on the platform. Bridges made on this plan are rigid and free from undulation, under all circumstances and all descriptions of traffic. It is, however, not necessary, according to Ordish's system, to keep the chains absolutely in a straight line, if other means are available to retain them under all circumstances in that curve which results from the weight suspended at the end of them and their own weight. (See Bridge Example No. 31.)

To estimate the relative merits of the systems which have been described would involve a distinct statement of the degree of rigidity which is required for various kinds of service, because the cost and complication of a design may counterbalance the advantages which it might afford as being the most rigid. Generally, it may be said that an increase of

* "Die Brücken in Eisen," page 205. Leipzic, 1870.

† "Humber's Record of Modern Engineering." London, 1863.

‡ *Allgemeine Bauzeitung.* Vienna, 1870.

§ *Engineer.* London, Nov. 6th and 20th, 1868.

rigidity involves also an increase of cost. Thus, other circumstances being alike, the braced suspension bridge (5) would probably be the most expensive; next, Ordish's (7) and Rœbling's (3); and so on.

For the application of these suspension structures as railway bridges, regarding the limits of span within which either system is most economically applied, the same order may be considered to prevail. As the moving load on any bridge compares with the dead load in a ratio which varies with the length of the span, the latter determines to a considerable extent the peculiar advantages of one system over another. Thus the braced bridge may be used for any span between 300 and 500 feet; Ordish's bridge for spans of 400 to 1,000; Rœbling's for spans of 800 to 1,600; and the ordinary suspension bridge for the largest spans. These figures are stated more as a means of comparison than as absolute limits, and because they also indicate indirectly those cases where the different systems may be applied to roadway bridges.

Ordinary suspension bridges, with more than one complete arch, cannot be used to carry a traffic the nature of which is to accumulate in certain places, because it would thus produce an excess of the horizontal strain in one span over that of the other; and the piers, not offering any considerable stability, would collapse.

With regard to the details of suspension bridges, of course many of the parts are of the same character as in other bridges, and the remarks on previous pages concerning wrought and cast iron girders apply here also. For the towers of suspension bridges cast iron forms the most appropriate material, and allows great scope for architectural design. The catenary chords or chains of suspension bridges form, however, an exceptional feature in construction, and are made in three different ways—viz. of links, of wire-rope, or of a laminated metal cable.

Chain bridges are the most common in Europe. The links which compose the chain were formerly manufactured by welding the heads to a flat bar; and the proportions of the heads are in most of the old bridges imperfect. At the present time the link is generally rolled together with the heads in one piece, and the proportions of the head have been improved. In a few instances (generally in large bridges) steel has been successfully used in the manufacture of the links. The form of links has been described on page 70.

Cable bridges are the most common in America. The cables are composed of iron wire, generally from $\frac{1}{5}$th to $\frac{1}{6}$th inch diameter, or No. 6 to No. 9, B.W.G.* Steel wire rope can be used for large bridges, but there is not much economy to be gained by it.

Cables made of hoop iron have been used in a few instances; but, as an easy process of manufacturing endless hoop iron has not yet been established, this peculiar form has been relinquished in favour of wire ropes. In cases, however, where the chain forms part of a girder—for instance, a fish-bellied girder—it has been made of flat bars bolted together, because it thus affords a better bold to the bracing of the girder. (Bridge at Mayence.)

COMBINED STRUCTURES.

In the classification of bridge structures which has been attempted in the preceding pages, a division into three elementary kinds of GIRDER, ARCH, and SUSPENSION bridges has been made. If the bridges described under any one of these headings, as supporting a load situated between two fixed points, be called *simple structures*, those other bridges, in which the features of two or more of the classes are united, may be called *combined structures*. This definition can, however, only strictly apply in cases where each of the two elements can, independently of the other, support part of the load. Thus, for instance, in some suspension bridges, the parapet is formed by a continuous girder, which adds to the rigidity of the structure; but this girder would not alone be capable of carrying any portion of the load, and therefore such a bridge could not be called a combined structure.

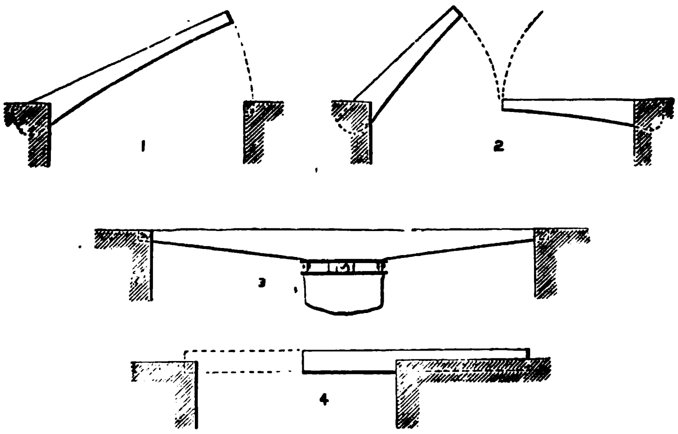
Although the number of combined bridge structures that have actually been made is small, the subject is one that has attracted considerable attention among engineers, and especially in cases of large span where all the items of weight are of great importance, and also in cases where for any reason the

* *B.W.G.*, Birmingham wire gauge.

construction of a simple bridge is difficult. The possible variations are many, because any one of the three elementary structures may not only be placed above or below, but may also be made to penetrate or pass through the other. Thus may be combined the girder and the arch; the girder and the suspension chain; the arch and the suspension chain; or the arch, the girder, and the chain.

OPENING BRIDGES.

In bridges over navigable rivers it is often necessary that one or more spans be made to open for the passage of vessels, and the methods of effecting this are various. Where the opening is of small width, say not exceeding 25 ft., the moving portion is generally made in one, and for larger openings in two pieces.



A hinged platform, like that formerly used in drawbridges, is probably the most usual, and Fig. 1 shows a single, and Fig. 2 a double, opening of this sort. The platform may be lifted by chains from towers or by means of gearing, in either case the process being assisted by counterbalance weights.

By another plan the vertical movement is avoided, and the opening bridge swings horizontally, as in Fig. 3, where the counterbalance is obtained by letting the bridge move on a central pivot, thus affording an opening on each side of a mid-channel pier. In any case where the opening bridge swings horizontally, an arrangement similar to that of a railway turntable is adopted, by which the pivot is relieved from the overhanging weight. (See Bridge Example No. 10 A.) Another method is to make the opening span slide backwards and forwards in a line with the bridge, as in Fig. 4.

For large openings in docks, caissoons which float out of place for the passage of vessels are frequently employed. So also in pontoon or boat bridges, one span of the bridge may be removed when required for the passage of vessels.

Girder bridges are best adapted for opening spans, because in an arched bridge, where the continuity of the roadway is destroyed, it would be necessary to make the mid-channel piers serve as abutments. In a suspension bridge, an opening entirely free above is impossible; but if a vessel can pass under the catenary chain, an opening might be constructed near one of the towers, or an opening *in* one of the towers might be made below the saddle of the chains, as is done in the suspension bridge over the Seine at Rouen.

CHAPTER IX.

BRIDGE PLATFORMS AND ROADWAY MATERIALS. CONCRETE. METALLING. STONE PAVEMENT. WOOD PAVEMENT. ASPHALTE. IRON ROADWAYS.

ALTHOUGH the general design of a bridge includes all parts of the structure, the platform and the roadway surface require special consideration. Wrought iron, cast iron and timber, singly or in combination, are the materials used for the platform; while the nature of the traffic, the comparative cost of different materials in the neighbourhood of the bridge, and the strength of the platform for sustaining a load, together determine the material of which the road surface shall be formed. The importance of this last consideration will be seen from the following figures, which give the approximate average weight per cubic foot of roadway material:—

	Lbs.		Lbs.		Lbs.
Iron	480	Burnt Brick Ballast	90	Broken Granite	93
Dantzic Fir	45	Ditto, Compressed	110	Ditto, Compressed (Macadam)	120
Oak	58	Hard Asphalte	140		
Concrete	115—130	Gravel	120	Granite "Setts" or "Pitching"	160

THE PLATFORM.

The superior strength and endurance which iron has over timber, does not tell to so large an extent with regard to the platform, as in the girders or other principal parts of the structure; and, in those foreign countries where timber is cheap and imported ironwork dear, the entire platform is often made of wood, both in railway and road bridges. If a road bridge is narrow, the floor may be composed of strong planks whose ends rest on the main girders, or, by another and stronger method, of cross-beams from one girder to the other, upon which planks are laid to form the roadway. But, in these cases, the main girders should be united by iron tie-rods or stays. In railway bridges, wooden roadways involve the risk of fire from the cinders of the locomotives, unless the surface is protected by iron plates, sprinkling of gravel, &c.

In any but small bridges, however, it is seldom that the entire roadway is made to depend upon timber; and it is usual to have numerous longitudinal girders or cross girders upon which the timber platform can be laid. If in this way there is a complete framework of iron, a light, strong, and quiet roadway may be obtained, even in the largest bridges, by making the platform itself and the road surface entirely of wood. As the strength and endurance of such a road depends greatly upon the manner in which it is made, care should be taken that the planks are of such a size, and are so laid, as to distribute the load upon the iron structure to the best advantage. Where there is much traffic under a bridge, and it is desirable to prevent leakage from above, the planks should be "tongued" together, [redacted] and the joints caulked as in a ship's deck, the timber thus arranged lasting longer than it otherwise would do. But it is not always an easy matter to prevent leakage through the platform of a railway bridge, and special precautions are always necessary to prevent it.

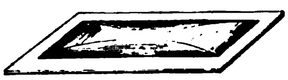
In railway bridges where timber is placed between the iron girders and the rails, the rest of the platform is in many cases left uncovered. Where the roadway surface is composed of ballast, metalling or stone, considerable strength is of course necessary to sustain such materials.

Although, for the sake of economy and lightness, timber is often used for a bridge platform, greater strength and endurance are given to the entire structure by making the whole floor of iron. In wrought iron, a platform may be made of either flat, curved, corrugated, or "buckled" plates. Flat plates, if properly stiffened by L or T irons, make a firm and efficient roadway; and in bridges of small span, where the structure is composed of numerous parallel girders, the roadway plates can be so riveted to the girders as to form part of their upper flanges, giving the necessary sectional area there needed.

Additional strength and stiffness is given to wrought-iron plates by curving or corrugating them, and when thus shaped they are admirably adapted for sustaining a roadway. Curved plates may be laid with either the convex or concave surface upwards, the strength in each case being nearly the same.

The great strength which is given by corrugation, even to thin iron plates, is well known; and the stiffness which renders them so suitable for the sides and roofs of buildings is equally effective for supporting the load of a bridge platform. The "pitch," or width between the corrugations, is generally greater than in roofing sheets, 10 in. or 12 in. being ordinary dimensions; the iron is also made thicker than for roofs.

The platform of a road bridge, or even for light railway traffic, may be made without cross girders by bending corrugated plates so as to give them the form and strength of an arch across the bridge, while the corrugations afford the necessary stiffness longitudinally. When the roadway is on the top of the main girders, a platform of this kind can be trussed and braced to the girders; where the roadway is below, the arch can be tied and trussed.

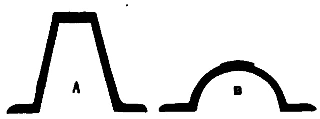
The advantages afforded by a curved surface are also obtained in Mallett's "buckled plates,"  which receive their shape from a mould or die into which they are pressed, and, as they are curved in both directions, a number of them placed together may be considered as a system of groined arches, whose thrust is taken by the flat margin which encloses each plate. As the strains which one of these plates has to sustain under the pressure of a load are "self-contained" within the plate, only a few rivets are required for connecting it to the framework of the bridge. Buckled plates cost from £13 to £16 per ton,* without including the expense of punching holes and other labour in joining them to the bridge.

Although curved, corrugated, and buckled plates are stronger than ordinary flat plates of the same thickness, the special circumstances of each case must determine whether it is expedient or economical to use them. In estimating the cost of a bridge, flat roadway plates would be included at about the price per ton of ordinary girders, and at a cheaper rate than girders of a light or expensive kind. A higher rate would be incurred if a roadway were made of curved, corrugated, or buckled plates. On the other hand, there is sometimes a saving effected as compared with flat plates in the amount of riveting required. In small bridges, or where the size of the plates is small, owing to the closeness of the framework, flat plates would be suffi-

* When ordinary bridge plates are selling at £12 per ton.

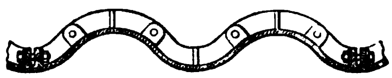
cient, and with any but extremely heavy road material and traffic, need only be of moderate thickness. To economise by using the stronger curved forms, it would be necessary to reduce the thickness of the latter enough to counterbalance their greater area when measured on the curved surface, as compared with the flat plates, and their greater price per ton. But although a less thickness in the curved plates would afford sufficient strength in the first instance, it is not expedient to have very thin plates in which deterioration by rust and wear would tell too severely, and which would permit vibration. For instance, flat plates $\frac{1}{4}$ in. thick, if of moderate size and properly laid, will safely carry heavy loads; and although curved plates $\frac{3}{16}$ in. thick might afford equal strength, the reduced metal would be too light for a permanent structure. In those cases, however, where it is a convenience to use large plates, or where the road material is heavy and the traffic severe, the stronger forms of plates should be preferred.

Wrought iron **I** joists and other similar kinds of rolled iron are more used in France than in England, and this has led to the manufacture there and in Belgium of sections specially recommended for floors and bridge roadways. There is no



doubt that among the infinite variety of situations where secondary girders are needed, sections other than the simple **I** section may sometimes be preferable. The inverted trough forms—of which the engraving shows two examples, and which are made both deep and shallow, and of various proportions—might be stronger than the **I** form as cross girders in cases where each girder had to stand alone without intermediate bracing; and the advantages of trough-shaped girders are duly stated at page 57. But for small spans across bridges, the facility for connections must be considered, and it is often found cheaper and easier to use small riveted girders instead of rolled joists. In Bridge Example No. 6, a system of riveted cross girders is described, which much resembles the trough form shown by Fig. B on this page.

A very strong and enduring platform may be made of cast iron; but this material is seldom adopted, except in cast-iron bridges. Castings of a furrowed or corrugated shape afford immense strength, and are suitable for carrying a heavy road material. The castings should be bolted together, and the



joints caulked with iron cement in the same way as a cast-iron tank. Curved or groined plates of cast-iron, made somewhat similar in shape to wrought iron buckled plates, but with flanges, may be used in the same manner. In some cases, instead of having the entire area of iron, the platform may be composed of flat brick arches springing from cast iron girders in the manner that is frequently adopted for warehouse and other floors (Bridge Example No. 7).

It is always a matter of difficulty to keep a bridge roadway perfectly water-tight, and nothing tends so much to the deterioration of the ironwork as the constant dripping of water upon it. As it rarely happens after the roadway is once formed, that the platform sustaining it is conveniently accessible for inspection, care should be taken to protect the ironwork as far as possible from corrosion. One or two good coats of tar, therefore, should be applied hot; and where it is applied to wrought-iron it should be of such consistency as to be elastic, and not to crack under a slight deflection of the platform.

CONCRETE.*

On platforms constructed of iron plates, and upon which a roadway of stone or macadam is to be placed, it is necessary first to make a bed or level surface for the road material. Nothing can be better for this purpose than concrete, which, when properly made, is hard and homogeneous, distributing over the area of any plate the pressure that may come upon individual points. The thickness of the concrete layer depends upon the kind of road material which is to be placed on it, and the nature of the traffic to be sustained. The thickness ranges from 4 in. to 12 in., and in deciding upon the thickness within these limits, of course the dead load which the bridge is calculated to bear, in addition to the moving load, is of primary importance.

* See foot-note on page 35.

When properly made, cement concrete is impervious to wet, and will protect iron from corrosion. Good concrete is made of 1 part Portland cement to 6 or 7 parts of gravel, ballast, or shingle — the sand amongst these materials being equal to about 1-4th of the whole. Strict supervision should be exercised to ensure that the materials are of the right quality, and properly mixed. The shingle or ballast should be free from dirt or clay, and a small proportion of broken bricks, in moderate-sized pieces, may without disadvantage form part of the mixture. The porous nature of bricks makes them adhere firmly to the cement, and a conglomerate mass of great strength is produced. The concrete should be mixed dry, and the water added at the last moment. It was formerly considered an advantage to deposit concrete by letting it fall from a height of about 20 feet, but this plan is now abandoned, and it is better to mix the concrete on the spot, and at once apply and level it to the required thickness.

In England, cement concrete laid in place costs from 12s. to 15s. per cubic yard, according to the quality and proportion of the cement, and the facility with which the other materials can be obtained. Lime concrete costs from 6s. to 10s. per cubic yard. Portland cement costs from 1s. 8d. to 2s. per bushel.

In some iron bridges constructed by A. Handyside & Co., as part of the new Holborn Viaduct, London, where very heavy traffic has to be sustained, the roadway was formed of granite "setts" laid upon concrete specified by Mr. Haywood, the Engineer of the Corporation, as follows:—

"The foundation for the granite pavement is to be formed in the following manner:—A layer of concrete 9 in. thick, composed of six parts ballast to one of Portland cement of the best quality, ground extremely fine, and weighing not less than 110 lbs. to the imperial striked bushel, is to be first spread over the iron covering plates. The surface of this layer of concrete is to be carefully levelled and well grouted with liquid cement, so as to form a perfectly smooth surface. When it is completely dry and set, a composition of tar, asphalte, and tallow, mixed in such proportions that it shall not be brittle, but always be slightly soft and elastic under all conditions of temperature, shall be spread over the concrete in two thicknesses, amounting altogether to ¾ in. This asphalte is to be turned up or flashed against all faces of iron, stone, or brickwork to a height of 6 in. The concrete and asphalte as described are to be laid with such falls and inclinations towards the channel of the carriage-way or otherwise as may be directed, so as to drain off any water that may get through the granite paving stones. Over the surface of the asphalte is to be spread a layer of fine ballast, 3 in. thick, for bedding the paving stones."

METALLING, OR MACADAM.

The word "metalling" has become a generic name for various materials used in the formation of roads. The great improvements of MacAdam fifty years ago rapidly became general throughout England, and were also introduced on the Continent with great success. The principle of his system, which is known as *macadamising*, is described as follows:—"For the foundation of a road it is not necessary to lay a sub-stratum of large stones, as it is a matter of indifference whether the substratum be hard or soft, and if any preference is due it is to the latter. The metalling for roads should consist of *broken stones* (granite or flint is the best), carefully spread; and, as this operation is of great importance to the future quality of the road, the metal is not to be laid on in shovelfuls to the required depth, but to be scattered shovelful after shovelful till a depth of from 6 to 10 in., according to the quality of the road, has been obtained. The road is to have a fall from the middle to the sides of 1 in 60, or 1 in 40, according to the width and gradient, and proper gullies are to be provided at the sides."

This system as applied to bridges requires some modification. Where broken metal is laid on a bridge, some other material should come between the hard stones and the platform, and, as previously described, concrete serves this purpose if its weight be not too great. As concrete if once broken up will not again unite, it is necessary that the traffic shall never come into immediate contact with it, unless a special surface concrete be made for the purpose.

In practice, the materials used as metalling vary very much. In London, broken Guernsey granite is almost exclusively used; and flint—whole or broken—foundry slag or cinder, whinstone (basaltic rock), and other hard materials are used in different localities. Where clay, chalk, or earth forms a considerable proportion of the material, the road will be dusty in dry weather and muddy in wet weather, and will soon be destroyed. A *little* chalk, or chalk and clay, is sometimes no disadvantage.

Upon a bridge platform of wood or iron, concrete may be used as a substratum for the metalling, or if not concrete, then 2 in. of ashes or of sandy gravel or ballast fine enough to pass through a sieve with ½ in. meshes. Upon this basis either of the following may be laid:—4 to 6 in. of broken granite, flint or other hard stone, in pieces of such a size that they will pass through a ring 2½ in. diameter; or 2 in. of burnt clay ballast, ½ in. of chalk or lime, and 4 in. of broken granite or flint. Upon the metalling 1 in. of gravel may be placed, and, if possible, the road should be well rolled.

A considerable saving in weight and in the necessary strength of the bridge may of course be effected by using wood, instead of the ballasting or "macadam;" but it is in bridges of long span only that this saving becomes a matter of importance. A reduction in the dead load affects the solidity and stability of the structure much more in a small bridge, where the dead load is small, than in a bridge of long span, where the dead load is great as compared to the moving load. (See "Loads and Strains on Bridges.") In bridges which have to carry heavy traffic, and where a strong and solid roadway must be provided, great care is necessary in using light materials, such as wood and asphalte.

A good macadam road should become hard and almost impermeable to water. It is not so much the weight of passing vehicles, as the width of the wheel tires that determines the endurance of the road, as heavy loads on broad tires will roll or consolidate the metalling, while narrow tires will cut it up.

STONE PAVEMENT.

In towns and other places where there is a constant and heavy traffic, the streets are generally paved with stone. Cubes or "setts" of granite from 3 to 6 in. wide, 7 to 20 in. long, and from 6 to 9 in. deep, are laid closely side by side upon a substratum of concrete or broken stone compressed into hard macadam, and the surface is grouted with lime and sand. A depth of 9 in. is the maximum even for the heaviest traffic in the streets of London, blocks 7 in. being sufficient for ordinary service, and 4½ in. the minimum anywhere. In London, a pavement of new Aberdeen granite 3 in. wide and 9 in. deep costs 16s. to 17s. per superficial yard, exclusive of concrete or other substratum. A pavement of this sort, under a heavy and concentrated traffic such as that of Cheapside, must be renovated, and the stones redressed and relaid, every five or six years; but on ordinary roads, granite pavement, if properly laid in the first instance, will last from ten to thirty years. When laid upon bridges there should be a concrete substratum, not less than 6 in. thick, between the platform and the stone. A heavy road material of this kind is best adapted for short spans, for cast-iron arched bridges, and for other situations where the dead load may with advantage compare largely to the moving load.

WOOD PAVEMENT.

In wooden bridges, or those for temporary use, the road surface is often formed of planks, and it is usual to lay these at right angles or diagonally across the platform. But in road bridges, however planks may be laid, it is difficult to keep the surface in good condition, and the wear and tear is excessive under any but the most moderate traffic.

The ordinary method of forming a roadway for permanent use is by laying blocks from 4 to 7 in. deep, close together, with the grain of the wood vertical. Oak, or rather hard timber, was formerly considered the best, but it has been found that fir, although not so hard, is better, and that its longer fibre renders it more durable than oak, and not so slippery.

As under constant traffic the blocks will sometimes become loose, different plans have been tried for holding them together. Octagonal or hexagonal blocks have been fitted together so as to give homogeneity to the whole, and prevent lateral movement. The same result is sought by pinning or morticing the blocks together, and many ingenious and complicated methods of this kind have been attempted. In a large area the density of the blocks will vary, or the ballast, concrete, &c., below, may not be equally solid at all points, and some of the blocks, under the pressure of a heavy load, will sink down and make an uneven roadway. To prevent this, the plan has been adopted of making the pieces of the shape shown in Fig 1, so that the pressure upon any one piece is to some extent borne by the adjoining piece. A considerable improvement on this plan is

1 2 3 4

effected by making the blocks of the shapes shown in Fig. 2, so as effectually to unite them against the downward pressure of a load.

By the methods above described, the blocks are laid close together; and as, under certain circumstances, a wood pavement may become slippery, it is by some engineers considered that a better foothold for horses may be obtained by leaving a gap between the blocks. Figs. 3 and 4 illustrate one of these methods, the blocks being laid about ¾ in. apart, and the spaces between them filled in with cement or mortar. But cement or mortar once disintegrated—as in this case is likely—will not again unite, and for cohesive purposes becomes useless.

A pavement, which seems to unite the supposed advantages of those shown in Figs. 2 and 3, has been used with some success in America, and has been, since 1871, on trial in London and other European cities. The arrangement of the blocks, and the process of laying them, may be thus described: Planks ¾ in. thick, having been dipped in tar, are laid across the road upon a bed of concrete, or upon previously existing hard macadam, and a second layer of similar planks is laid longitudinally. Dantzic fir blocks, 9 in. long, 3 in. wide, and 6 in. deep, are then laid end to end across the street upon the planks, and a long strip of wood, ⅞ in. square, is nailed to the bottom of the blocks and to the planking. This strip of wood forms a distance-piece, separating one row of blocks from another, and as the parallel rows are laid there are, of course, gaps ⅞ in. wide between each. Into these gaps or spaces small grit or gravel (without sand) is inserted, and driven in by blows from a mallet; and liquid tar is poured upon the gravel so as to soak into it. By this plan the pressure upon any one block is divided by the planks over a considerable area of the substratum; but the planks are an obstruction if trenches or small openings in the roadway have to be made for repairs of gas-pipes, &c.

If the platform of a bridge is of timber, the planks may be protected by some chemical process, such as kyanising, burnetising, &c., or should be well coated with tar. The paving blocks should not be placed directly upon the planks, but upon a layer of tarred felt, or on tar, or tar asphalte, so mixed as to be elastic during a low degree of temperature. The roadway of the Albert Bridge (Bridge Example No. 31) is laid in this way. The blocks should be rectangular, and may either be laid close together or with spaces between the rows, filled in as described above. If according to the latter plan, they should be nailed down to the planks. Even for light traffic 4 in. should be the minimum depth of the blocks, and 6 in. is sufficient for the heaviest vehicles.

A timber platform is more exposed to dry rot with a wooden pavement than with most kinds of macadam, as the latter material generally keeps the timber equably moist. It is an advantage that the under side of the platform is open to the atmosphere for ventilation ; and to reduce, as far as possible, the risk of dry rot at the places where the timber is joined to the ironwork, tarred felt should be placed between at all bearing points.

For a pavement of wood blocks on an iron platform, it is necessary to cover the ironwork with some material on which the blocks can be bedded. Nothing can be better for this purpose than a layer 2 or 3 in. deep of ashes, well saturated with tar. If the platform is made of curved or corrugated plates, the hollows can be filled up with ballast or concrete, and the ashes placed on the level surface thus obtained. If ashes are not available, fine gravel or ballast may be substituted.

For bridges of small span, or where the moving loads are severe, and where, for these or other reasons, it is desirable to add to the stability of the structure by a considerable dead load, 6 to 12 in. of concrete, macadam, or ballast, may be placed on the iron platform below the wood paving. In this case the blocks may be fixed on planks, or according to any of the other methods described on page 97.

With careful treatment, a wood pavement may be made to last a long time in a cold or temperate climate. When first laid, the surface should be well tarred and sprinkled with fine gravel, and this should be repeated occasionally, and at any time during a frost, to prevent slipping. The gravel will be forced into the wood, and will harden and preserve it. The accumulation of mud should be prevented.

The weight of Dantzic, or similar fir suitable for road paving, varies according to the dryness of the wood, &c., from 38 to 48 lbs. per cubic foot. In calculating the load upon a bridge platform, a weight of about 50 lbs. should be assumed, to allow for the water which the wood will absorb.

The price of wood paving depends on the value of timber in the locality of the bridge. In London, wood pavement laid in place, but exclusive of concrete or other foundation, costs from 11s. to 15s. per square yard.

ASPHALTE.

Asphaltum is one of the varieties of bitumen found in many parts of the world, and generally in the nature of rock. Though it has long been used for paving, asphalte, as it is usually termed, has not always been successfully applied, and for a long time was not considered a suitable material for road-paving, except for very light traffic. This was probably owing to the proportion of pitch mixed with it, which rendered it soft in hot weather, and to its unskilful treatment generally.

In Paris, and other continental cities, the right application of asphalte seems to have been discovered before it was adopted in England, where its real value has been acknowledged only since 1869. The success which has since that date attended its use in London and other places, renders it probable that it will for the future be largely used for road-making in towns.

The asphalte used in England is of more than one kind, the Val de Travers, the Pyrimont Seyssel, and the Limmer, being the kinds principally tried in London. That of the Val de Travers is of two kinds—the compressed, and the liquid or mastic asphalte. The former is brought to England in its natural condition of mineral rock, and is made into powder; this powder, having been heated, is laid upon concrete, and is compressed by heated irons into a homogeneous mass. The liquid or mastic is a mixture of asphalte with mineral tar and small grit (from gravel or shingle), and is applied as a hot paste. It is in this condition also that the other asphaltes named above are applied.

In London, for the heaviest traffic, a stratum of concrete, 6 in. to 9 in. thick below the asphalte, has been adopted; but for less severe service it would not be necessary to use more than 5 in. of concrete; this thickness, for instance, on the iron platform of a bridge would suffice. The asphalte itself is laid 2½ in. thick for constant heavy traffic, and 1½ to 2 in. for ordinary traffic. On side-paths for foot-passengers, asphalte ½ in. thick laid on 3 in. or 4 in. of concrete is sufficient.

The weights of the different kinds of asphalte named above do not differ much, and that given on page 88 may be taken as the maximum. Where a bridge is made for heavy road traffic, it will be seen that a considerable saving in weight can be effected by using 6 in. of concrete and 1½ in. of asphalte, as compared with 10 in. of macadam, or 6 in. of concrete with 7 in. granite "setts."

In London, the cost of laying 2 in. asphalte on 6 in. concrete is from 13s. to 18s. per superficial yard, and of these prices 2s. may be taken as the value of the concrete. Mastic asphalte in blocks can be shipped abroad for £5 to £6 per ton, and one ton, mixed with 33 per cent. of "grit," will suffice for 14 yards 1½ in. thick.

The qualities which recommend asphalte are—the smoothness of surface, which renders traction easy; the diminution of noise; and, for bridges, its moderate weight as compared with stone. The headway below a bridge may be increased, or the gradient rendered easier, by a reduction in the thickness of the road material. (See diagram on page 76.)

Sufficient time has not yet (1876) elapsed since asphalte was laid in London* to prove how long it will endure the heaviest traffic; but the fact that it has for four years been used in Cheapside, is sufficient evidence of its strength for less severe service. There is no doubt that the thickness of the asphalte becomes considerably reduced when in use, but it is not yet clearly known whether this is owing to attrition only, or in some measure to the compression which is claimed for it by its advocates.

* The advantages and cost of asphalte as compared with stone pavements, so far as can be gathered from their use in London and Paris, are fully stated by Mr. Haywood, the Engineer to the City of London, in his Report to the Streets Committee of the Corporation upon "Granite and Asphalte Pavements," July, 1871, and in his Reports on "Carriage-way Pavements" in 1872 and 1873.

On a level surface, in dry or wet weather, asphalte, if kept properly clean, is not more slippery than stone, but special arrangements for washing and cleaning are necessary. For steep ascents, traction on asphalte would be difficult, and if the gradient were such as to render brakes or drags necessary, the grinding action of the locked wheels would be injurious to the asphalte. In the City of London, 1 in 60 is the steepest gradient for which asphalte is permitted.

Asphalte cannot be successfully laid or repaired in frosty weather. It has been proved to be free from danger by fire.

The roadway of the arched bridge shown in the frontispiece (Bridge Example No. 25) is covered with asphalte.

IRON PAVEMENT.

For countries where there is a difficulty in procuring any of the road materials here referred to, an iron platform can be designed so as to carry the traffic directly upon the iron. In these cases, a special arrangement of the road plates is necessary, and a proper foothold must be provided for passengers and animals.

Cast iron blocks of a suitable shape and size and with a roughened surface, have been used as a substitute for granite pavement in London. Blocks of this kind can be sent to foreign countries where ordinary materials are wanting, but can only be used on bridges capable of sustaining a heavy dead load.

CHAPTER X.

LOADS AND STRAINS ON BRIDGES.

ON page 23, in describing what information concerning the *service required* in bridges was necessary for making the design, reference was made to the loads upon railway and road bridges. The thorough investigation which such a subject demands cannot be attempted here, but the following additional remarks may be convenient, in connection with the descriptions of bridges in the preceding and following pages.

The greatest moving load for railway bridges depends on the weight of the heaviest locomotive used on the line, on the distribution of this weight on the several axles, and the position of the axles in regard to the body of the engine and tender. The ordinary moving load depends on the composition of the trains. The Board of Trade regulations for railway bridges in England require that, under the test-load, the tensile strain on the wrought iron shall not exceed five tons per square inch. Most of the railway companies in Europe have their scales of moving loads determined for various spans. Thus it is usual to base the maximum moving load on the weight of a train composed of two of the heaviest goods engines with tenders, placed funnel to funnel, and followed by a sufficient number of the heaviest goods waggons to cover the bridge. The average load per lineal foot on a bridge span, produced by such a train, will be greater if the span is small than if it is large, because the engines are the heaviest part of the load. It must also be remembered that the weight of an engine is often unequally distributed upon its wheels, and, therefore, on the bridge. Sometimes the test train is entirely of locomotives. The highest strains which, under the above conditions, will be induced on a square inch or square centimetre of cast or wrought iron in tension, compression, and shearing, should be stated when the bridge is designed.

The greatest load on roadway bridges is that of a crowd of people distributed uniformly over the roadway and footpaths. It is sometimes asserted that people may be packed so closely that their weight upon each square foot would amount to 140 lbs. If it were generally admitted that such a load may have to be supported by roadway bridges, it would not be difficult to establish simple and distinct rules for their strength. But such a general agreement does not exist, and instead of making the basis for calculation a load which is all but impossible, engineers generally endeavour to ascertain the actual load which may come on a bridge. This, however, depends greatly on local circumstances, and the consequence is, that many different opinions exist on the subject. There are, however, as many different opinions as to the extent to which the square inch of iron may fairly be strained under the assumed load, and it is necessary that the two points should be considered together. The lowest figure for the greatest distributed load is given in the rules of the French Government, namely, 42 lbs. on the square foot, the highest perhaps in those of the Austrian Government, 96 lbs.; while in England the corresponding amount varies between 60 lbs. and 90 lbs. But the strain to which the resistance of the square inch of wrought iron is limited also varies, and is in France about 4 tons (600 kilogrammes per square centimetre), in Austria 6 tons, and in England 5 or 6 tons.

Applying these figures now to a bridge of common dimensions, say 100 feet span and 30 feet wide, with a timber platform, the whole superstructure weighing 66 lbs. per square foot, the total weight of the bridge when loaded, according to the French rule, will be $66+42=108$ lbs., and according to the Austrian rule, $66+96=162$ lbs. per square foot. For every ton strain upon the iron will be counted according to the former 108 divided by $4=27$ lbs., and according to the latter 162 divided by 6 also$=27$ lbs. on the square foot, so that it will be seen that, in the case of a bridge of this particular description, it is quite immaterial which rule may be applied. At the same time it will be safer, that is, it will make the bridge stronger, to apply the Austrian rule for lighter bridges than 66 lbs. per square foot, and the French rule for heavier ones. Taking a fair average of the rules observed in the best English structures, it may be set down as follows: Moving load per square foot of roadway surface, 80 lbs. Tensile and compressive strain per square inch of wrought iron, 6 tons. To make this rule coincide with the afore-mentioned standard rule of 27 lbs. per square foot for every ton strain per square inch, the corresponding weight of the structure would be 82 lbs. per square foot, 80 lbs. + 82 lbs. being equal to 6×27. In the case of a lighter bridge there would be less, and in case of a heavier one more than 27 lbs. on a square foot to every ton per square inch. But this is exactly what should be, viz. that light bridges should be constructed relatively stronger than heavy bridges, because the stability of the bridge depends very much on the proportion which the dead load bears to the moving load. In a bridge of small span there is a liability to vibration under heavy traffic, which renders it necessary to anchor the superstructure to the piers or abutments, while in a bridge of long span, the weight of the superstructure itself will afford the necessary stability.

It is evident also that a sudden or accidental increase in the moving load will tell more severely in the small bridge than in the large one, as will be seen by the following example: A small bridge, whose superstructure weighs 60 lbs. per square foot, and with a moving load of 80 lbs., has a total working load of 140 lbs. A larger bridge, having a superstructure weighing 200 lbs., and a moving load of 80 lbs., endures a total working load of 280 lbs. Each bridge is constructed so as to have under the above-named circumstances a strain of 6 tons per square inch on the iron. But if by some accidental circumstance, the moving load is increased to 100 lbs. per square foot, the smaller bridge will have the total load increased to 160 lbs., or an addition of 14 per cent.; while the larger bridge, under the load increased from 280 lbs. to 300 lbs., will only have an addition of 7 per cent. That is to say, the actual strain upon the iron in the small bridge will be increased to about 6 tons 17 cwt., and in the large bridge only to 6 tons 7 cwt.

To compare the strength of two bridges from this point of view, it is only necessary to assume a certain moving load per superficial foot, and then to state what strain the iron should be called upon to resist when such a load is placed on the bridges. According to some engineers, the safety of a bridge is a figure indicating how many times the assumed moving load may be put upon the bridge until the limit of elasticity * or the breaking point of the iron is reached, and it would appear as if by such a statement of that figure a sounder criticism of the strength of a bridge would be arrived at than by any of the ordinary rules. For instance, when it is required that the moving load be 75 lbs. on the square foot, and that threefold safety is to be provided for, it would be implied that a load of 225 lbs. (75×3) per square foot must be carried before the limit of elasticity is reached. Taking a bridge whose superstructure weighs 66 lbs. per square foot, and which is made of iron having 11 tons per square inch safe limit of elasticity, it would follow that 225 lbs. + 66 lbs. = 291 lbs. would represent the total load per square foot corresponding to this strain of 11 tons per inch.

It is of course as necessary in road bridges as in railway bridges to provide for the concentrated load of heavy vehicles, and now that the use of large traction-engines on public roads is becoming extended, this is particularly important. While, therefore, the total load on the structure may be amply provided for, by allowing for a crowd of people over the entire surface, the cross girders and other separate parts must be strong enough for a local pressure greater than the average amount per square foot. As has been already explained, such concentrated loads tell more severely on small bridges than on large ones, and must be provided for accordingly.

In the United States, both road and railway bridges are made lighter than in England. This difference is not owing to any general waste or misapplication of material in the English structures, but rather because a less margin of strength for safe working and permanent endurance is considered sufficient in America.

* See foot-note on page 11.

CHAPTER XI.

TRANSPORT OF BRIDGES. CARRIAGE BY RAILWAY. CARRIAGE BY CANAL. TRANSPORT BY SEA. MARINE INSURANCE. CONVEYANCE TO SITE.

It is important when designing a bridge, to know what facilities exist for the transport of the ironwork from the place of manufacture to the site of erection. The distance to be travelled, the means of conveyance, the size, shape, and weight of the various pieces, together determine the cost of carriage, and in many instances the proportion which this bears to the final and complete cost of the bridge is considerable.

It is often the case that bridges must be designed with special reference to the incidents of transport, and in riveted girders it is especially necessary that the joints shall be arranged so as to afford facilities for division. The cost of carriage is sometimes greater than the cost of manufacture; and although a bridge may be well contrived for the service required of it when erected, it will sometimes be found economical even to incur extra expense in manufacture to save expense in transport. In plate girders and in the upper and lower flanges of lattice girders, the joints in the plates and L irons are sometimes distributed so as to involve long overhanging pieces when temporarily divided for carriage; and although these can be protected to some extent by timber and careful packing, the rough usage to which the pieces are often subjected involves the risk of damage not easily repaired. "Through and through" joints may in many cases be advantageously adopted, although they may at times occasion a slight extra weight in cover plates. Bridge Examples Nos. 22 and 27 afford instances of this kind of joints.

CARRIAGE BY RAILWAY.

In this country the railways afford great facilities for the conveyance of ironwork. Pieces up to 14 feet in length can be conveyed on one truck, and by the use of two or more trucks joined together, pieces 50 feet long can be carried in the same manner as long trees or timber. On railways of the ordinary English gauge, pieces 9 feet wide and 9 feet high may be carried; but all these dimensions are liable to modifications on certain railways to suit the curves and bridges. Where two or three trucks are used for the carriage of long pieces, and the total weight is so small as not to afford a fair load to each truck, higher rates are usually charged as a compensation. Generally, however, a sufficient total weight may be obtained by placing on the waggons, in addition to the long pieces, some of smaller size. Where bridges are intended for erection upon the railway itself, girders of considerable size may be carried directly to the site, as in the case of some railway bridges erected by A. Handyside & Co. in Russia (Bridge Examples Nos. 11, 16, and 18), where it was desirable to avoid as much as possible labour at the sites. Upon the Continent of Europe the railways —with the exception of those in Russia—are nearly all of one gauge, and ironwork can be carried through different countries without being transferred from one set of trucks to another.

CARRIAGE BY CANAL.

Transport by canal, though less rapid than by railway, is very useful in many cases, and has been much accelerated of late years by the use of steam tugs instead of horses. Ironwork placed upon a boat at the manufactory can be conveyed to distant towns, or alongside a ship in a dock or river, without transhipment on the way. Light castings or other damageable goods are, in a canal boat, free from the risks of breakage, which in railway transit are occasioned by the concussion of the trucks while shunting. The boats generally employed upon canals are long and narrow, and are known as "fly-boats." They are of from 16 to 22 tons burthen, and will carry packages 40 feet long, 7 feet wide, and 8 feet high. Barges of greater width, and of much larger tonnage, are used on some canals, at most ports, and on navigable rivers, but on many of the inland canals the locks are too narrow to admit these boats. The cost of transport by canal is generally the same, or rather less, than that by railway between the same places.

TRANSPORT BY SEA.

The conveyance of goods by sea is very cheap as compared with land carriage, and it is very much owing to this fact that England can compete so successfully in all cases where goods can be sent by ship. It costs less to send ironwork from London to Australia by sea, than from Glasgow to London by railway. Facilities for the carriage of heavy goods have much increased during the last few years, and the shipment from England of bridges, locomotives, and other railway material, is on so large a scale and forms such an important item in the total exports of the country, that ships and steamers are now more commonly than formerly constructed to carry pieces of considerable weight and size.

The cost of transport by steamer is almost always dearer than that by sailing vessel, and, in either case, various considerations determine the rates of freight. As in most other departments of business, large quantities may be usually conveyed at lower rates than small quantities, and where the amount becomes very great, the alternative of chartering a special vessel becomes possible. Where the pieces and packages are of such moderate size and weight that vessels of small tonnage can carry them, sailing ships may be chartered to convey lots of not less than two or three hundred tons. For short coasting voyages, small vessels may be chartered for very much less quantities. For voyages where the rates of freights by regular traders are high, chartering or other special arrangements can often be made with large steamers or sailing ships for the conveyance of 500 tons and upwards. Much of course depends on the nature of the voyage, and the chance of a profitable return cargo for the vessel. Where homeward freights are very profitable, the number of vessels engaged is far in excess of what is needed for the outward carrying trade, and in these cases freights from England are very low. It also frequently happens that the general cargo of a ship is of such a light nature that ironwork is accepted at very low rates of freight, because of its utility as ballast. The rate of freight for ironwork from London to Calcutta, or to Melbourne, is, for the above reasons, sometimes as low as 10s. per ton.

The official "tons register" of a ship are much below its carrying capacity or "tons burthen." Thus a vessel of 500 tons register will take in actual cargo 700 tons weight, or 1,000 tons weight and measurement. (See page 110.)

The process of loading and discharging heavy ironwork is much accelerated and cheapened by the use of powerful steam cranes, which now exist at all large ports. When very heavy pieces, such as from 5 to 20 tons weight have to be lifted, it is necessary that the vessel shall come alongside the quay so as to make use of these cranes, but moderate weights can be lifted by the "ship's tackle." All vessels above 100 tons burthen have the means of lifting one ton in weight, and in large steamers and sailing vessels, which are now almost invariably fitted with steam cranes, or winches, the tackle can lift from 2 to 5 tons either by the ordinary hoisting apparatus, or by derricks specially erected for the purpose. Of course, whatever weights can be lifted into a ship by its own tackle can be lifted out again; but as on certain voyages the goods have to be transhipped into smaller vessels or lighters, it is necessary in these cases that, at the final port of discharge, cranes of sufficient power shall be accessible. Considerable difficulty is often experienced in unloading heavy ironwork at places where the vessel has to lie in an open roadstead, and transfer her cargo to lighters and rafts.

At all the principal ports in England, lines of railway are brought to the quay side, and waggons can be unloaded close to the ship. It is sometimes the case, however, that certain dues have to be paid on goods entering by land, which cannot be levied on goods coming by water, so that it may in these cases be cheaper to transfer the goods from the railway waggons to barges outside the dock, and to bring them alongside the ship in the same way as those brought by canal.

The size and shape of packages are often of as much importance to a shipper as their weight. There is no rule for the dimensions of hatchways, and they vary not so much with the size of the vessel as with the nature of the trade in which it is engaged. A ship of 500 tons may have a hatchway as large as that of a 1,000 ton ship. 7 ft. by 5 ft., or 9 ft. by 6 ft., are ordinary sizes for a ship of 500 tons register, and 10 ft. by 7 ft., and 12 ft. by 9 ft., for one of 2,000 tons. Steamers—unless built specially for passenger traffic—have generally still larger hatchways. In shipping long pieces, they have to enter in a slanting direction, so that the maximum length which can be admitted is determined as much by the height between decks as by the size of the hatchways. If of moderate width and thickness, pieces as long as 40 feet can be conveyed by sea. Ships which carry timber have ports cut in the bows, through which pieces the whole length of the hold can enter; but such ports are unusual in any but timber ships. Sometimes the hatchways of a vessel are cut, or otherwise enlarged, to allow special cargo to enter; but shipowners are averse to this, and, when they consent to it, demand considerable compensation. In vessels not used for passenger trade, the lower decks are generally removable, so that large pieces of cargo may be more easily stowed. The deck beams, however, generally remain, and if these are cut (which is sometimes permitted) considerable expense is involved. In iron and composite ships, the deck-beams are of iron (rolled joists), and can be cut, and afterwards re-united with fish-plates.

Packages whose shape or size prevents them from entering the hatchway, may be carried on deck; but there is then more than the usual risk of damage and jettison.* Deck cargo always involves higher rates for freight and insurance than for cargo carried in the hold.

It is usual to calculate the freight of ironwork by weight; but as the shipowner has the option of charging by the ton measurement of 40 cubic feet, instead of by the ton of 20 cwt., light and bulky packages sometimes involve considerable expense. In measuring cargo, the extreme outside dimensions are in all cases taken, so that projecting pieces or corners add to the calculated amount, and with round or irregularly shaped pieces the cubic content is calculated as being that of the parallel and rectangular figure which would enclose the package. All projecting pieces should therefore be avoided where possible, and in packing cases the battens should be placed inside, because, when placed outside, their thickness is added to the measurement all over the case.

As it is generally necessary to protect certain portions of ironwork with wood, and as, almost invariably, other portions have to be carried in cases, the wood and cases, thus needed, add considerably to the total weight of cargo. This extra

* *Jettison*—throwing overboard for the safety of the ship.

weight, or "tare," together with the occasional expense of tonnage by measurement as stated above, must be allowed for when estimating the cost of freight.

Where bridge-work has to be carried by sea, it is always best to arrange each shipment so that complete spans or other well-defined portions shall go complete in one vessel. If this is done, and the vessel be lost at sea, it will be known exactly what there is to replace, and as little inconvenience as possible will be caused in the erection of the remainder.

MARINE INSURANCE.

The premiums paid for Marine Insurance are determined by the direction and duration of the voyage, the time of the year, the age and class of the vessel, and the nature of the cargo.

Insurance on cargo can be effected in two ways: it can either be "*warranted free from particular average, unless the vessel be stranded, sunk, or burnt,*" or can be insured "*to pay average.*" In the first case, the underwriter is not responsible for any partial loss or damage unless one or other of the casualties recited in the clause occurs during the voyage. The second clause named protects the shipper or owner of the goods against all loss or sea damage, unless arising from some default of the shipowner, who would then be liable. It is hardly necessary to mention that the rates of premium are lower in the first case than in the second.

Ironwork is usually insured f.p.a. (free of particular average), as no underwriter would admit "rust" as the basis of a claim, except at a very high rate, and there is otherwise little or no risk of damage.

On many voyages, the premiums remain the same throughout the year; but to the Baltic and Black Seas, and North America, the rates, which are very low during the summer months, rise rapidly and largely towards the autumn and winter, the increase in some cases being as great as from 10s. per cent. in summer to £5 or £6 per cent. in winter.

CONVEYANCE TO SITE.

The conveyance of ironwork in foreign countries, from the port of arrival to the site of erection, is often a matter of con siderable difficulty. Where roads exist, carts can be procured or made sufficiently strong for the purpose; but where bridges and other ironwork are required for new or mountainous districts, special arrangements are needed, and for these situations the ironwork must be designed so as to allow division into small parts. Great ingenuity has been shown in doing this; but, as the whole principle of construction may be affected by these necessities of transport, it is of the utmost importance (as previously stated at page 24), that full and accurate local information shall be supplied before the design is made. In portable bridges for military and other purposes, facility of transport forms one of the chief features in the design.

In bringing ironwork up to the site of erection, labour will be saved if the pieces are conveyed in the order in which they are wanted, so that they can be unloaded and put into place at once. When ironwork has to be unloaded and stored, and then again moved to its place, extra cost is incurred, especially when the pieces are large or heavy.

CHAPTER XII.

THE ERECTION OF BRIDGES. STAGING. LIFTING MACHINERY. ROPES AND CHAINS. ERECTION OF BRIDGE PIERS. ERECTION OF THE SUPERSTRUCTURE. LAUNCHING OF BRIDGES. FLOATING BRIDGES TO SITE. COST OF BRIDGE ERECTION.

THE erection of a bridge, though the last process necessary in its construction, sometimes proves the most difficult, and allows of less certain calculation beforehand, as to time, trouble, and expense, than either the manufacture of the structure or its transport to the site. The various methods of erection that have been adopted are dependent for success on so many circumstances, that a full knowledge of each particular case is necessary in order to judge of comparative economy or safety. If there are difficulties to be overcome, it is of the utmost importance that they should be considered when the bridge is designed, and that the form of structure should not be decided on with reference only to the ultimate service that is required.

The erection of bridges is seldom entrusted to the workmen who make them, but to men who, though perhaps unfitted for the work of the factory, have acquired a peculiar skill in their own special business. Except in the very simplest cases the cost of erection is determined mainly by the ability of the man who superintends it; and the necessary knowledge is acquired only by experience. To those who are unaccustomed to moving and lifting ironwork, the mere weight and size of the pieces is often a great difficulty; and engineers and others who have erected bridges abroad, find that the work is sometimes actually impeded by the fears of the workmen. One man with a knowledge of his business, who is familiar with the many methods of unloading ironwork and moving it on rollers and wedges, and who can judge of the strength of ropes, chains, and timber, will soon by his example inspire even unskilled workmen with confidence, and enable them to work with promptness under his direction. As the lifting of heavy weights often tries the nerves even of practised erectors, the efficiency of the foreman is proved by the coolness and skill with which he utilises the means at his disposal, decides upon the best methods, and rapidly carries them out. What often appears as rashness to the uninitiated is really the natural confidence produced by experience; and nothing is more fatal to success than the timidity of a man who mistakes hesitation for caution, and who, by adopting half-measures at critical moments, incurs the risk of disastrous failure. As, however, an ignorant or reckless man may cause infinite mischief, care should be taken not to trust important or difficult undertakings to any but those who have shown their fitness in previous works of smaller extent.

STAGING.

The simplest method of erecting bridges is by first making a complete timber staging across the river or other opening which is to be spanned, and thus forming a convenient platform on which to build the ironwork. Where there are a number of spans, the scaffolding need only be erected for one or two at the same time, and, as the ironwork for these is completed, the scaffold can be removed and re-erected for the next span. By this plan the river channel is not much obstructed, and the work, as it progresses, furnishes a roadway for the carriage of the remainder.

For the erection of bridges over dry land, the requisite scaffold can generally be erected on trestles, or by sinking poles a few feet into the ground, but for bridges over rivers, piles are generally necessary. As the length of the piles and the expense of driving them, depend to a large extent on the nature of the stratum or strata into which they are inserted, a correct estimate of cost can only be made when the formation of the river bed is known. The cost of pile-driving is generally stated either at so much per lineal foot of insertion, or at so much per cubic foot of timber in the whole pile. A considerable portion of the labour is expended in moving the pile-driving machine from place to place, and in preparing the piles and putting them into position. The use of steam pile-drivers has rapidly extended during the last few years, and in large undertakings the economy obtained by them is very great. A heavy weight falling a moderate distance is more effective than a small weight falling a great distance, and the steam machines can work the heaviest rams at a speed which is not possible by any concentration of manual labour. Where a great number of piles have to be driven, the work is much facilitated by mounting the machine on rails and letting it run upon a gantry or tramway, prepared for it.

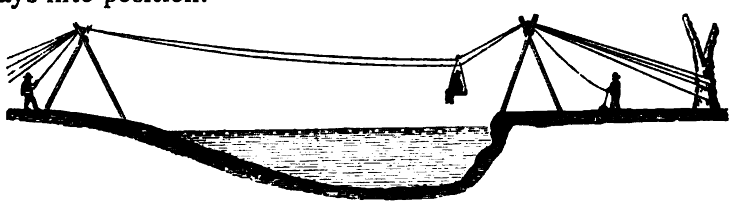
The numerous bridges and other public works that have been constructed during the last twenty years, have involved such an immense amount of pile-driving, that special attention has been directed towards economy in the existing systems. Not only have there been many ingenious inventions in the pile-driving machines, but valuable improvements have been made in the shape of the pile shoes, and the mode of fastening them to the piles. For works carried on in foreign countries, it is generally an advantage to send the iron shoes from England.

Considerable experience is necessary in order to drive piles well and cheaply. Only skilled workmen are able to judge the weight of ram which in any given circumstances will be most effective, and to know when the pile has reached the greatest depth possible. It sometimes happens that the driving is continued after the point of the pile has ceased to move, and when the only effect of the concussion is to crush the pile at some point in its length and render it useless.

In deciding upon the exact form of staging, it is necessary to consider what kind of timber can be obtained in the locality of the bridge. It not unfrequently happens that square balks or sawn timber of any sort cannot be procured, and in such cases, spars or trees have to be utilised. On the other hand, nothing but sawn timber—and that possibly of a light description—is obtainable in some countries where all the timber is imported. Sometimes there is the greatest difficulty in procuring timber at all, and the ingenuity of the engineer is taxed to erect his bridge without it, or to reduce to a minimum the quantity which must be brought with the ironwork to the site. Expense may in many cases be saved by bringing all necessary clamps, spikes, and bolts for the staging from England.

Where new iron bridges are made to replace old wooden structures, the old bridge can generally be used as a staging.

(Bridge Example No. 11 illustrates this method.) Or the temporary bridge which sometimes has to be built to carry the traffic till the new structure is ready, can be used as a staging, the iron girders being riveted together on it and pushed sideways into position.



Suspension bridges can be erected without staging by using a temporary rope bridge, such as is illustrated above, for supporting the permanent chains, from which, when properly anchored, the whole structure can be erected, or by using the catenary itself, when it is made of wire rope, as the temporary bridge. It often happens that suspension bridges are adopted because the formation of intermediate supports is difficult, and in such cases there would probably be, for the same reason, difficulty in erecting staging. Where, however, temporary timber supports can be constructed without very great cost, they are much to be preferred, as they are extremely useful for sustaining the platform of a suspension bridge till the chains are ready, and they also allow of a light pole scaffold being made to carry the chains themselves.

Certain systems of bridges, combining the girder or suspension principle with that of the cantilever, are specially advocated for the facilities they allow during the process of erection.

A temporary rope communication from shore to shore, such as is shown in the engraving on this page, is very convenient, even in cases where a permanent scaffold has ultimately to be erected; and if the stream is rapid, or the banks steep, men and material can by this means be conveyed across more safely and rapidly than by boats. Where a river is very deep, or where, for these or other reasons, pile driving is difficult, a temporary platform or bridge may be constructed of boats.*

* Temporary bridges of trestles, ropes, boats, or pontoons are rapidly made for military purposes, and the methods of constructing such bridges are very fully described in books on military engineering. Amongst others, the following may be quoted : "The Professional Papers of the Corps of Royal

Where a bridge is being erected over a river, life-buoys and ropes should be kept ready to protect life. A boat, provided with oars and easy to unmoor, should be attached to the staging in an accessible position.

Where riveting hearths or forges are placed on timber scaffolds, water should always be kept at hand for extinguishing fire.

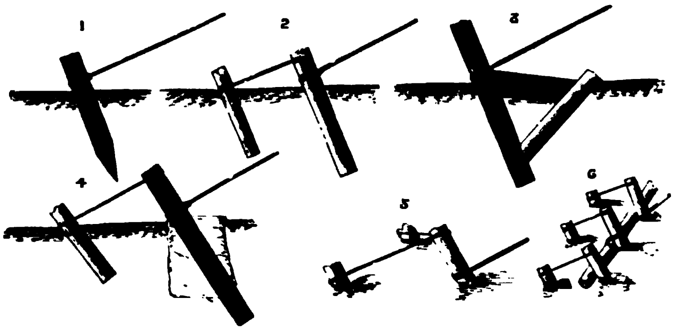
LIFTING MACHINERY.

The engraving on page 119 illustrates some of the methods by which ironwork is lifted. The single derrick (Fig. 1), when properly stayed or "guyed," is the most useful, and is the most generally employed. A straight tree, trimmed into a spar or mast, makes the best derrick, but such an one is not always obtainable, and squared timber must then be used instead. Balks, 8 in. to 14 in. square, are generally used; but for very heavy loads 16 in. or 18 in. balks can be employed. Where neither round nor square timber of sufficiently large dimensions can be obtained, a strong derrick may be composed of scaffold poles tied together by cords and wedges. The efficiency of a derrick depends as much upon the guy ropes or chains as upon the timber itself, and the proper adjustment of these guys is a matter of great importance. There should never be less than four guys, and when heavy weights have to be lifted, intermediate or auxiliary guys are generally added. Ropes or chains are generally used for guys, chains being preferable for heavy loads; but iron rods or wire rope are also employed, especially for a derrick which is permanently fixed.

In cases where there are no trees, posts, or buildings to which the guy ropes can be attached, the requisite anchorage must be provided, and the engraving on page 118 illustrates some of the methods of doing so. When a moderate strain only has to be resisted, a stake (Fig. 1) or a crowbar driven into the ground is sufficient; and, if necessary, the single stake can be strengthened by attachment to a second one

Engineers," London (annually). "Haupt on Military Bridges," New York, 1864. "American Military Bridges," Lieut.-Col. Cullum, New York. "An Essay on the Principles and Constructions of Military Bridges and the Passage of Rivers in Military Operations;" New Edition, London, 1853. "Aide Mémoire to the Military Sciences," London, 1853-62.

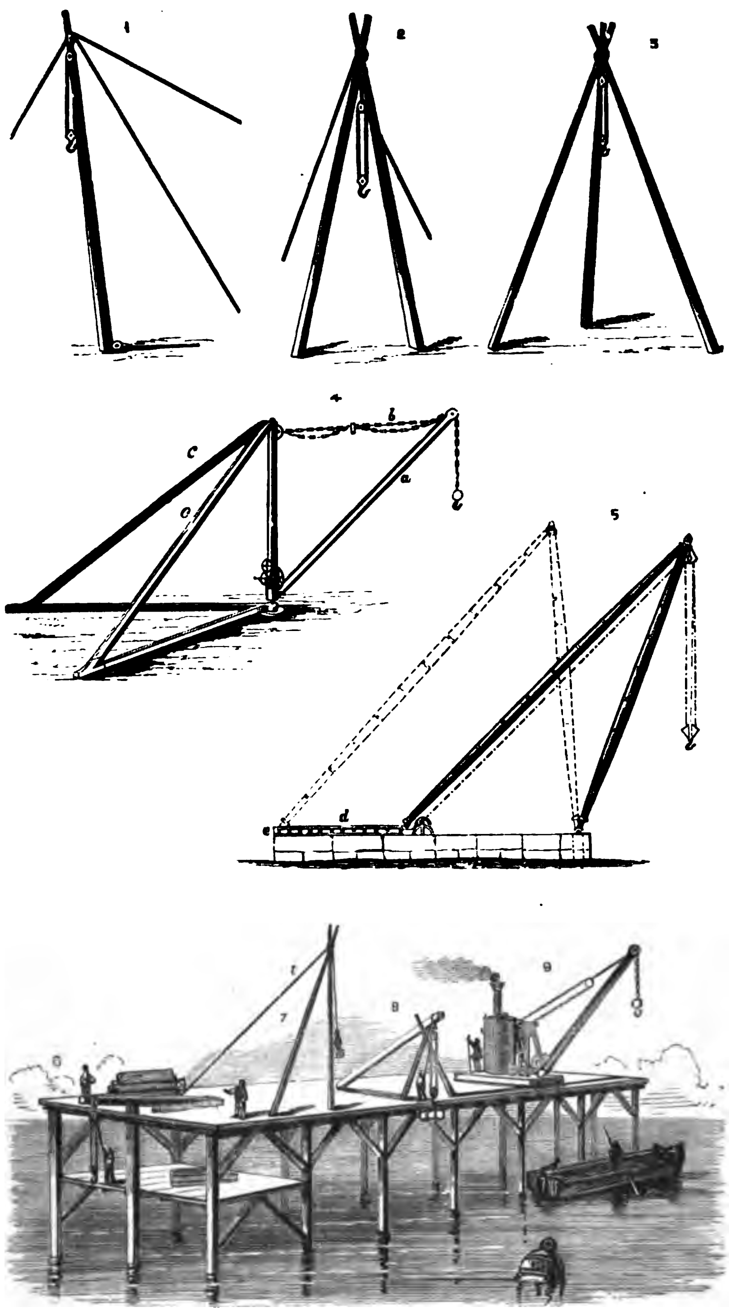
in front or rear, as Figs. 2 or 3. But for severe strains a stronghold is best obtained by fixing it in a hole (Fig. 4) dug for the purpose, the stake being placed in a slanting



position, with its foot under the unloosened earth. Stones may then be wedged above it, or a wooden sleeper laid horizontally upon it, and the hole filled in and rammed down. Where the ground is too loose to afford sufficient hold, or where the strain upon the guy rope is great, three stakes may be inserted, as at Fig. 5, or several stakes may be driven side by side, as at Fig. 6, so as to afford a united resistance to the pole laid behind them to receive the strain of the rope. A convenient and portable guy stake is formed from a round bar of iron, about 2 in. diameter, armed with a screw, which is inserted by turning the bar with a lever inserted through the ring-head, the ring serving also for the attachment of the rope. A ship's anchor, an iron plate or disc, or a frame of timber, properly inserted in the ground or sufficiently loaded, may serve as a holdfast. A crab or winch, sufficiently loaded or otherwise anchored to the ground, forms a convenient holdfast for a guy rope, as by it the rope can easily be tightened or slackened; this arrangement being especially useful for the back or principal guy, on which the greatest strain occurs.

A moderate weight can be lifted without guy ropes if the foot of the derrick is securely inserted in the ground; but in such a case the lift must be directly vertical, be to a limited height, and no adjustment or overhang of the derrick can be effected, as is possible when guy ropes are employed.

By means of pulley blocks and crabs of sufficient strength, loads as heavy as 100 tons—if their shape and size permit—



LIFTING MACHINERY.

can be raised by a single derrick; but it is only in peculiar and exceptional circumstances that very heavy loads are lifted, 5 to 10 tons being the ordinary limit of weight for a single derrick when there is a choice of other methods.

Great care and some experience are necessary to attach properly the pulleys at the top of the derrick, and otherwise equip it for service. To utilise the whole strength of the timber, the "centre of pressure" should coincide as nearly as possible with the axis of the derrick, and this condition is obtained by a correct adjustment of the pulleys at the top, by fixing the derrick vertically (it inclines slightly under the load), and by rounding the foot of the timber to prevent undue pressure on the edges of the base. In cases where the derrick has to be moved from place to place as the work proceeds, it is usual to "step" the rounded base into a thick plank or half-timber hollowed for the purpose, as by means of rollers the plank and derrick can be moved at will.

Where a very heavy weight is lifted by a single derrick, it is usual to employ more than one set of tackle. The necessary ropes become large and unwieldy for hoisting more than 12 tons, but a single set of chain tackle may be used for 50 tons, though it is convenient to employ two sets for all weights over 15 tons. The double tackle is not only useful in reducing the weight on each chain, but also in distributing the strains on the derrick, so as to allow the full strength of the timber to be utilised. For heavy weights, therefore, two sets of pulleys are attached to the top of the derrick on sides at right angles to each other, and the hauling rope of each is led through a separate "snatch" block at the heel of the derrick to a crab anchored to the ground.

Where a girder or other weight, which is long as well as heavy, has to be lifted, great care must be used in slinging it, and in keeping it steady while it is suspended. In these cases, two single pole derricks placed so that the load may be seized at different points are convenient.

Sheers, composed of two poles (Fig. 2), come next to derricks in usefulness for lifting ironwork, and form, for some purposes, a steadier apparatus, and one less dependent for security on the guy ropes, of which only two or three are needed. Sheers are particularly useful for lifting to a height beyond the reach of ordinary cranes; but they are not so convenient as derricks for moving from place to place.

Three-legs or tripods (Fig. 3) are entirely independent of guy ropes, and form a steady and (if required) a permanent crane. They are useful for unloading ironwork, as a cart can be placed directly under the tackle.

What is known as Henderson's Derrick (Fig. 4) is an ingenious arrangement of timber framing, by which the advantages of a permanent crane are cheaply and readily obtained. The horizontal timbers, from which the back struts *c c* spring, form, when loaded or secured to the ground, a counterbalance to the jib *a*, and allow very considerable weights to be lifted. The revolving jib is a long one, and as it can be raised or lowered at will by the back chain *b*, a large area is commanded by the crane; but, of course, the weight which may be safely lifted depends upon the angle or inclination of the jib.

Strong permanent sheers are employed in dockyards for masting ships or for lifting heavy weights, and a peculiar kind of such sheers is shown in Fig. 5. By means of machinery at *e* and a horizontal screw *d*, the sheers are pulled back to the position shown by the dotted lines, so that a weight lifted from a ship's hold can be deposited on shore. If the space is too limited to allow the sheers to be drawn back as above described, the same effect at the head of the sheers may be produced by lowering the inner leg into a recess or well. This arrangement has been carried out with success.

Fig. 6 shows a projecting beam to which pulleys can be attached for hoisting loads to a lower level than the beam itself. Fig. 8 shows an overhanging beam or "flying derrick," supported on cross timbers, and constructed mainly on the same principle as the overhanging sheers (Fig. 7), where two spars or masts are safely inclined when held by the backstay or strut *t*.

It is impossible even to record the numerous methods of making derricks or cranes in peculiar situations, and for special services. A sailor-like dexterity with ropes and spars is one of the accomplishments of a bridge erector, and cases are constantly occurring which tax his ingenuity to the utmost.

The steam-engine has been applied to so great a variety of cranes and other lifting apparatus, that machines so worked can be obtained for almost every kind of service. Fig. 9, on page 119, shows a steam crane mounted on a truck for running on rails. In most cranes of this sort the angle of the jib can be altered at will, so as to allow the necessary "overhang" for the service required; the lifting capacity becoming greater as the jib approaches the vertical line. Although in small undertakings it is seldom expedient to incur the expense of purchasing such machines, their use by contractors who possess them will often allow a saving as against the alternative cost of hand labour. In countries were labour is cheap but fuel dear, the use of steam-engines is often precluded by the great expense involved; but for large works, manual labour, however it may be concentrated, can seldom compete with the steam machines.

Where the pieces of ironwork in a bridge are heavy, the erection is greatly facilitated by the construction of a travelling crane to traverse the entire area of the new structure. The cost of a travelling crane is considerable, and it should only be made in those cases where the expense will be covered by the saving of labour which its use secures. Only where the cost can be defrayed by a moderate charge per ton over the whole structure, or where there is a special necessity, is its adoption advisable, and hence it is generally only in bridges of considerable length, that the expense is justified. There are different kinds of travelling cranes, and the choice must depend on the weight of the bridge pieces and the height they are lifted. The ordinary kind consists of a fixed staging, or gantry, carrying a cross bridge, which moves with the lifting crab upon it. In another kind, known sometimes as the "Goliath," illustrated above, the whole structure travels on rails, laid upon the ground or upon a raised scaffold; this form of structure having the advantage of occupying less space than an ordinary travelling crane.

Where weights are very heavy, or the work is of considerable extent, and likely to occupy a long time in execution, or under a combination of these circumstances, steam winches upon the traveller will be found of great advantage. The longitudinal and transverse movements of either travelling crane or "Goliath," as well as the hoisting and lowering, can all be worked by one engine, and controlled by one man.

ROPES AND CHAINS.

The length of ropes is measured by the foot or by the fathom (6 ft.); the size by the circumference in inches; and they are sold by weight.

Ropes are made of "green hemp," or manilla, and both sorts may be tarred, if they are to be exposed to constant wet. The tarring somewhat impairs their strength, but renders them durable. The strength of ropes is calculated by the makers, according to the number of "strands" and "yarns," the yarn being the technical name for the thick threads into which the hemp is first twisted. One yarn requires, according to its quality, 1 cwt. to 1½ cwt. to break it. A rope 3½ in. in circumference, made of three strands, each strand having 20 yarns, will break at about 3½ tons, if the rope be new and in good condition. Ropes of higher quality are made for special purposes.

The following table shows approximately the weight and strength of different-sized ropes:—

Circumference in inches ...	2¾	3	3¾	4½	5½	6	6½	7	7½	8½
Weight in pounds per fathom	2	2¼	4	5	7	9	10	12	14	18
Breaking strain in tons ...	2	2½	4	6	8	10	12	14	16	22

In actual use, from 1/3rd to 1/5th of the above strains is considered proper, the strain decreasing as the ropes get older.

Ropes should be kept as much as possible from wet and dirt, and especially from lime; and, when not in use, should be properly coiled and placed under cover. They should not, however, be kept too dry, as they then become liable to dry rot. After they have remained long in store, it is well sometimes to uncoil and ventilate them. If they have lain by for a long time, they should be carefully examined and tested before use, to ascertain if any strands are broken, or if they are weakened by decay. New ropes should be stretched before using.

The length of a chain is measured by the foot or fathom, the size by the diameter of the iron of which it is made, and it is sold by weight. The kind of chain suitable for cranes is known as the "short link," and of this various qualities are made, the best being defined as "best best crane chain, tested." The importance of having strong, well-made chain in ships has led to the adoption by the Admiralty of official tests, and the standard of quality thus set up is used by all chain-makers. The following table shows approximately the test-strain and the weight of different sizes :—

Diameter of iron in inches ...	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$
Proof strain in tons	$1\frac{5}{8}$	$2\frac{1}{4}$	3	$3\frac{3}{4}$	$4\frac{5}{8}$	$5\frac{5}{8}$	$6\frac{3}{4}$	$9\frac{1}{8}$	12	$15\frac{1}{4}$	$18\frac{3}{4}$	$22\frac{5}{8}$	27
Weight per fm. in lbs.	9	13	18	22	27	30	39	50	64	81	101	114	141

The test strain is considerably within the limit of elasticity of the iron, and is of more use for proving the workmanship than the quality of the iron. In actual use, a load not exceeding one-third to one-half the test-strain is generally considered proper by engineers.

Chains, before being used, should be laid out straight on the ground, and all kinks or twists removed. Chains should be kept painted, and, if allowed to become rusty, the rust should be knocked off, and a coat of paint applied.

There are differences of opinion, amongst those engaged in bridge-erecting, as to whether ropes or chains are best fitted for hoisting purposes. Very often a personal preference for one over the other is the result of failures or accidents that have been witnessed with the one and not with the other, and which may have been caused by inferior quality, or other exceptional circumstances. As a general rule, and for all but moderate weights, chains may be said to be best. They are best suited for slings, and for permanent cranes ; they are also better adapted than ropes for very heavy strains, where a rope strong enough for the purpose would be large and cumbersome ; they are also not so much deteriorated as ropes by exposure to the weather, and by dirt or grit. On the other hand, ropes are better for "guy" stays for light weights, and they are easier to handle and to tie. It should be remembered that chains and ropes have only a limited lifetime; and, after a certain amount of wear and tear, special precautions should be taken to avoid accident.

Care should be taken to obtain pulley-blocks of good quality, with hooks properly formed. It not unfrequently happens that the hooks break with weights much below the capacity of the pulleys. Some bridge-builders prefer to make their own pulley-blocks, even if they buy the rest of their tools. It is an advantage in iron blocks to have brass pulleys, which do not corrode and damage the ropes.

Workmen should have clear instructions as to the maximum weight that the ropes, chains, crabs, cranes, screwjacks, and other lifting machinery entrusted to them can bear with safety. All engines and machines should be kept clean, dry, and well oiled.

ERECTION OF BRIDGE PIERS.

Where masonry piers have to be built in a river, it is almost essential that a pile scaffold should be constructed, so that the necessary operations can be conducted from a fixed platform. If a system of iron cylinders or caissoons, as described in Chap. III., be adopted, they can be suspended and lowered into place from strong beams fixed overhead; or a travelling crane, which generally is more convenient, can be constructed for lowering the iron pieces into place, and for loading the caissoon. If the pier be built in this way, or within an ordinary wooden cofferdam, the requisite pumping and excavation can be expeditiously performed from the staging. Sometimes there is no other staging than the cofferdam itself, the piles being driven and all other operations conducted from barges, pontoons, or rafts. Directly the cofferdam is completed, or the caissoon sufficiently forced into the ground as to become moderately tight, the process of clearing out the water can be commenced. If the quantity of water is small, and there is no leakage to overcome, large buckets or "skips," hoisted by an ordinary winch or by a steam crane, will suffice; but the most effective method, and that generally adopted, is pumping. Centrifugal pumps will lift enormous quantities of water in a short time, and overcome even considerable leakage in the caissoon. They are not well adapted for *emptying* a caissoon, because they require a certain head of water over the inlet or suction. What is known as Woodford's centrifugal pump has been successfully used for emptying caissoons, and keeping them free from water as the excavation proceeds. These pumps differ from the ordinary centrifugal kind, in that the discs revolve horizontally and that the pump is placed at or below the water level. The shaft or spindle of the disc is carried to the platform level in an iron frame, which also supports the pipes. As the frame, pipes, and spindle are all made in lengths of exact and similar dimensions, additional lengths can be quickly added at the top, as the depth of excavation increases, and as the pump requires to be lowered. A pulley is fixed upon the spindle at the top, and is driven by a belt from a portable or other engine on the platform. The pump just described is sometimes objected to where excavators are at work, as occupying too much space, the frame being about 3 ft. square.

Centrifugal pumps of all kinds work most effectually, and give the best results as compared with other systems when the lift is of moderete height. Although centrifugal pumps are used to lift as high as 80 ft., they are most commonly employed for lifts of from 5 to 40 ft.

Chain pumps are often used, and will lift more than 100 ft. They are suitable for pumping water which contains mud, sand, weeds, or other obstructions which would derange ordinary pumps. Where there is room for them (which is very often, as with Woodford's pump, not the case), they may be said to be the best for clearing cylinders.

If after a caissoon or cofferdam is emptied of water, mud remains which is too soft for men to stand in it to fill "skips" or buckets, an ordinary dredger can be used for removing it.

If the depth from the ground or working platform is moderate—say not more than 20 ft.—a "bag and spoon" dredger (Fig. 1) can be used. This consists of a sheet-iron bucket or a leather bag over a steel or iron frame, and it is guided by a long handle and lifted by a crane.

Several ingenious self-acting "skips" or boxes, of which

Figs. 2 and 3 show an example, have been invented, by which the mud or other "spoil" can be removed from a deep cylinder or caissoon. "Misers" and other well-sinkers' tools are sometimes used for the same purpose.

With regard to the various systems which have been successfully adopted for building piers under water, and which have

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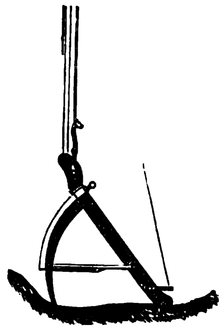

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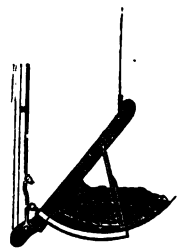

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been described in Chap. III., in small undertakings the expense is often disproportionate to the size and weight of the structure. The cost of apparatus and preparation, the necessity for skilled labour and superintendence, all tell heavily on a small undertaking, and in many cases unforeseen incidents will occur that affect the success of approved methods when repeated under new circumstances.

The methods of inserting screw-piles have been described at pages 29 and 30.

ERECTION OF THE SUPERSTRUCTURE.

In putting together the ironwork of a bridge, it is of course necessary that the pieces be arranged in exactly the same positions as they occupied when fitted together at the manufactory. To ensure this similarity, care must be taken that the proper level or camber be given to the temporary platform on which the ironwork is to be riveted. If the rivet or bolt holes do not at first exactly coincide, it should not be too readily assumed that the work is wrong, but the levels or camber should be examined, and, if need be, adjusted till the pieces fit accurately. The value of good workmanship is now manifest; for, if the bridge has been carelessly made and badly put together, the defects are detected, and these cannot be remedied except by enlarging the holes, and thus risking an increased deflection and permanent set in the bridge.

In erecting lattice or other open girders, the pieces forming the bottom boom or member should be first laid in their places, and temporarily united by "service-bolts" through the rivet holes. The riveting should follow as soon as possible, and at the same time the upper parts of the girder be put together. In all cases sufficient "service-bolts should be inserted as the work advances, to unite the pieces into one. By doing this, the girders or parts of girders will carry their own weight at the earliest possible moment, and if the ironwork is brought on to the platform only as it is wanted, no unnecessary loading will be given to the timber staging. These precautions are especially necessary over rivers subject to floods or other accidents that may damage the staging; for the period within which the ironwork is exposed to danger is thus reduced to a minimum, and if the staging be carried away, the ironwork will be left safe behind. The Czernowitz Bridge (Bridge Example No. 29) was erected on staging over a river subject to floods, and great care was used in watching the signs of their coming, and in strengthening the scaffold for resistance. When the bridge was half completed, a very heavy flood suddenly occurred, and there was only time to insert a few cold rivets into the holes unfilled by "service-bolts" when the river increased to a torrent, and, bringing with it trees and wooden houses, carried the scaffold entirely away. The girders, with only a few of the joints riveted, were not damaged at all, and suffered no injury from deflection. Where, however, there is no risk of accident of this sort, there are cases where a scaffold may be rendered steady by the judicious disposal of ironwork or other weight upon it.

Great vigilance should be exercised with regard to the riveting, as the joints that have to be connected at the side are generally of the first importance. *Every rivet* inserted at the site should be examined and sounded, after the workmen have left it, to ascertain if it fills the hole and has a well-formed head.

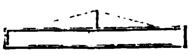
One of the principal arguments in favour of the "pin system" (see page 70) is found in the security it affords that the final connections on the site will be made exactly as they were prepared in the workshop, and in the consequent absence of the risk that attends riveted joints imperfectly executed.

In those cases where there are differently sized rivets supplied with the bridge, there should be careful supervision to ensure that each sort or size of rivet is used only for its intended place; because, if workmen are indiscriminate in their choice, there is a risk of scarcity when the work approaches completion that cannot easily be remedied. From 10 to 25 per cent. extra of every kind of rivet should be supplied, to make up for those which are burnt, spoilt, stolen, or lost.

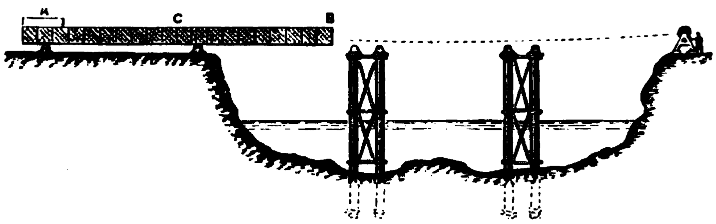
LAUNCHING OF BRIDGES.

There are various situations in which the construction of staging is difficult or perhaps impossible, so that even in cases where bridges are much needed, they have never been erected. Deep and rapid rivers, rivers or ravines where the bridge is erected at a high level, rivers subject to violent floods, or tides, or to floating ice or trees, are all cases requiring special consideration as to the form of bridge and the mode of erecting it. Where a bridge is of several spans, the piers can often be constructed (either of cylinders, iron columns, or masonry) by the use of strong scaffolding firmly braced together, the pier itself, as it is built, giving strength to the staging. This method can sometimes be used in rivers, where a staging for the superstructure would present so great an obstruction to the stream, and be so high, as to be costly and unsafe.

The process of launching girders into their places from the shore has been tried with success under different circumstances, and affords facilities for the erection of bridges without staging. The continuous girders A B (page 130) may, together, be of such strength that girder B will carry itself as a cantilever in the position shown in sketch. This strength may sometimes, if necessary, be obtained by making certain parts heavier and stiffer than is needed in the permanent structure, the extra expense so involved being set against the saving in scaffolding. A counterbalance weight at A may be sometimes added. In some cases the requisite strength may be obtained by temporarily trussing the



girder by chains, and so assisting it to resist excessive deflection at the outer end. The chains should be tightened by union screws, or by a "Spanish windlass." Where the girders are not continuous, they may be temporarily united at C. In launching girders, the bottom flange



should run upon rollers, and the rivet heads must not be allowed to form an obstruction. This may be effected by grooving the rollers to clear the rivet heads, or by attaching the rollers to the girders, or by fastening a rail to the girder and letting it run upon fixed rollers. The girder can be hauled over by a crab or winch, and a wire* rope is best for this purpose when the weight is considerable. Another plan is to fix a "snatch block" to the pier and pass the rope round it, so that both ends are on the same shore. One end of the rope is then attached to the girder, and the other to the crab. By this means the strains on the pier are to a certain extent balanced, because the strain of the rope has a tendency to pull the pier towards the shore, and the forward movement of the girder pushes the pier from the shore. According to this plan it is necessary that one end of a girder shall have reached the pier before the strain of the rope towards the shore commences.

The piers may be temporarily stayed, guyed, or strutted to resist the side pressure. When the girders are high, and there is a risk that they may fall over sideways during the process of launching over, they may be protected from this danger by fixing them in wooden cradles or frames, with a wide base. If the weight be not so great as to forbid it, additional safety may be obtained by pulling over the girders in pairs, connected together either by the permanent cross girders or by temporary timbers. The stability thus afforded is particularly useful where the bridge spans a ravine or valley exposed to violent wind.

Hydraulic presses may be used both to lift the girder and to

* Wire-ropes cannot be wound on drums of small diameter.

push it forward. Sometimes the process just described may be facilitated by the use of derricks, which take some of the weight of the girders; but in such cases it is often difficult to find anchorage for the guy ropes of the derricks. "Warren," or other trussed girders, whose bottom flanges are constructed to resist a tensile strain only, are not suitable for hauling over.

In long spans, where the distance between the piers renders the hauling difficult, a light staging may, if practicable, be erected midway between the piers to take some of the weight. As the pressure upon this staging only occurs when the girder is being dragged over, no serious damage need be apprehended from floods, as of course the girder would be moved only at a time when there was no risk. As a modification of the plan just described, girders of moderate length may be partly sustained by a temporary trussed wooden bridge, which, besides carrying its own weight, is strong enough to sustain so much of an iron girder as to enable the latter to overhang the shore without damage from deflection. In hauling over girders, a lateral thrust may be induced upon the piers, which should therefore be strong enough to resist this temporary stain. Masonry piers are best adapted for the purpose, but groups of iron piles may also be stiff enough. Very high piers, or those formed of two or three iron columns only, would require strutting, or might be maintained in position by strong guy chains; but the expense of this might sometimes more than balance the saving which the hauling-over plan gives in comparison with the ordinary erection on staging. The thrust upon the piers may be greatly reduced by the skilful adjustments of the rollers, and the necessary forward movement may be given to the girders by rollers on the piers, turned by a winch or gearing.

FLOATING BRIDGES TO SITE.

The outer end of a girder, or of a pair of girders, may be placed on pontoons and floated to a mid-channel pier, while the inner end moves on rollers on the shore.

Bridges can be floated to their site, and raised by cranes or by hydraulic pressure to their places. The latter plan was first adopted when the Britannia Tubular Bridge was erected over the Menai Straits in 1849. The two centre spans, each of 460 feet, and 1,800 tons in weight, were built at the water's edge, from whence they were floated off on pontoons to the base of the towers which formed the piers, and which had grooves or recesses made to receive the ends of the girders. These were then elevated gradually (supports being built under them as they ascended), by powerful hydraulic presses, to the requisite height, 102 feet above high water.*

In the case of some of the large bridges constructed over the rivers or estuaries in Holland, and in other places, the girders have been built upon platforms, erected to a proper height on barges by the shore, and then floated to their places, so that at high tide they were rather above their ultimate level, and, as the tide fell, were deposited in their permanent positions on the piers.

Many ingenious plans have been contrived for the erection of bridges in difficult situations, and for the rapid construction of temporary structures for military purposes.† The exigencies of each case must determine the best mode of procedure; but as each new plan adds to engineering experience, the examples from which suggestions may be borrowed are constantly increasing.

COST OF BRIDGE ERECTION.

The cost of bridge erection may be divided into four items—1. *Scaffolding;* 2. *Tools and Plant;* 3. *Labour;* 4. *Superintendence.*

1. *Scaffolding.*—The quantity of staging needed of course depends upon the design of the bridge and the nature of the site. As has been seen in the foregoing pages, certain processes of erection require very little staging, and the saving in this item may compensate for extra expense in other respects. Where staging is necessary, it may be possible to economise by using the same timber for different spans of the bridge in succession. Against this plan, however, must be considered the advantage afforded by having a complete scaffold from the commencement, which can serve as a roadway for the transport of material, and if required, as a temporary bridge for traffic.

* A full history of the design, manufacture, and erection is contained in "The Britannia and Conway Tubular Bridges," by Edwin Clark, who assisted Mr. Robert Stephenson, the engineer. Weale, London, 1850.

† See foot-note on page 116.

Where a number of bridges have to be erected near together, the same timber may serve several times, and the cost may be reckoned in each case only as for "use and waste." Even where there is one structure only, a return may be obtained by the sale of the timber at the end of the work, but it is seldom that much dependence can be placed on this.

As previously stated at page 113, it is very necessary, where bridges have to be erected abroad, that the requisite kind of staging and the cost of timber should be considered in determining the best form of structure.

2. *Tools and Plant.*—In calculating the cost of tools and plant for the erection of bridges in England, the "use and waste," or wear and tear, need only to be provided for. For very small undertakings, the cost is seldom calculated as a separate item, the charge for labour being generally estimated at a price high enough to cover the expense. But for work abroad, for which tools have to be sent specially, not only the cost of wear and tear, but the entire value of the tools must be provided for.

3. *Labour.*—Under good superintendence, the proportion of skilled to unskilled labour need be but small. Great care is necessary in putting together the various parts of the structure precisely as they were fitted in the workshop, and this being done, the rest is comparatively easy. The art of riveting is soon learnt by imitation, as has been proved during the erection of some of the structures described in the following pages, where unskilled European workmen, and even Indians, none of whom had any previous experience whatever in ironwork, were employed under English foremen. The expense of labour both in England and abroad is, of course, to a large extent determined by the nature of the design. Sometimes the system of construction is complicated, or a large amount of riveting may be necessary, and some of it in very awkward situations. As stated on page 70, it is desirable to avoid such designs in cases where skilled labour is expensive. It is then more economical to spend a larger sum in the first cost of a structure specially arranged to insure facility in erection.

It is in this item of labour that the losses due to bad workmanship are felt. It is no exaggeration to say—as will be confirmed by many engineers abroad—that for every shilling saved in the workshop by the false economy of cheap and bad workmanship, five to twenty shillings will be spent in alterations and corrections on the site of erection, where everything has to be done by hand labour under great disadvantages.

Unskilled workmen may, in most countries, be obtained at lower rates of wages than in England, and sometimes the rates are very low. As a general rule, however, it may be stated that whatever be the nominal rate of wages, the actual ultimate cost is about the same in all countries.

4. *Superintendence.*—This in England is generally included in the cost of labour, manufacturers having in their employment foremen of experience, who are accustomed to the management of men and the erection of ironwork. Abroad, on public works, or at other places where the erection is entrusted to resident engineers, the supervision need not involve any special or extra expense. But where the manufacturer is not only required to supply the ironwork but to erect it abroad, the cost of supervision adds considerably to the expense. No small share of the reputation attained by English material and workmanship in foreign countries is due to the skill and perseverance of the English foremen who superintend the erection, and efficient, trustworthy men obtain very high wages. The manufacturer must also, in many instances, incur the expense of providing a financial agent and correspondent. For these reasons, it is only in large contracts that the manufacturer can undertake, at a reasonable cost, the erection abroad. It is also necessary to have a price high enough to include the interest on money, and remuneration for risk, where a considerable part of the total contract price is left unpaid until the final completion of the work.

It would of course be valuable if to the foregoing items of expenditure the probable cost under each head could have been added. But every new case has to be considered by itself, and no more can be stated than that the total cost of erection of bridges in England varies from £1 10s. to £5 per ton, and that in foreign countries the higher figure is sometimes exceeded. These very wide limits embrace almost every kind of site and structure, but they are liable to occasional exception in very special cases.

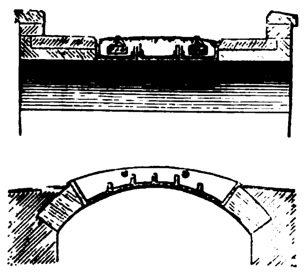
CHAPTER XIII.

EXAMPLES OF BRIDGES. SPANS UP TO 60 FEET.

THE bridges enumerated and described in the following pages were all constructed by A. Handyside & Co., at Derby, and in many cases were also erected by them on the sites. As the total cost depended in each case on the current price of iron, the expense of transport, and other varying circumstances, a statement of the actual prices for which the bridges were sold would only mislead. The costs that are given are, therefore, based upon the prices of cast and wrought iron, stated on pages 7 and 13, *i.e.* £4 per ton for pig iron, and £12 per ton for wrought iron plates,* include only the transport of the structure to an English port, as London, Liverpool, or Hull, and are exclusive of the cost of erection. (See Erection of Bridges, Chap. XII.) The examples begin with the smallest, and proceed regularly to the larger spans, this being the most convenient order for reference.

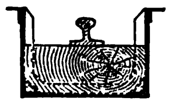
The current prices of iron that prevail at any particular time cannot be taken as an absolute guide for determining the cost of finished work. Other causes—especially the price of fuel, the rates of wages, the hours of labour, the repetition of parts and consequent economy—must also be taken into consideration. For fluctuations in the prices of iron during the last thirteen years, see page 4, *ante.*

Example No. 1.—A small cattle arch or bridge for carrying a single line of railway over a roadway 12 ft. wide, the span of cast iron being 8 ft. 6 in. This kind of bridge is sometimes adopted where the headway below the bridge is limited, and where, if the rails were placed on the top of the arch (on a brick arch for instance), they would be too high. In



*** These rates were assumed in the first edition of this book in 1873, and it is considered undesirable to alter them in 1876, although the current rates at the later date, and the corresponding prices of bridges, are much lower.**

an ordinary brick arch, springing from abutments, three cast iron troughs 12 in. deep, are built so that they form part of the arch. The rails are laid on longitudinal timbers in the troughs formed by the two outer castings, and the space between is filled up with ballast. The total weight is 46 cwt., costing about £12 10s. per ton. A similar method of economising height or headway is sometimes used with wrought iron girders for small spans, as in Fig. 2.



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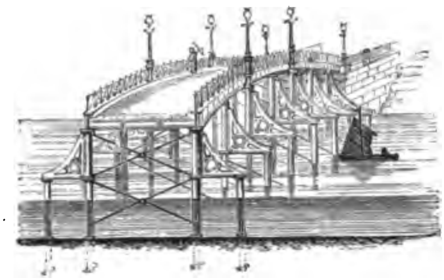
Example No. 2. — Girders for carrying a single line of railway in South America, of 5 ft. 6 in. gauge, over small openings of 4 metres (13 ft.) Two ordinary plate girders, 12½ in. deep, and 9 in. wide, each carrying a beam of timber 4 in. thick, upon which the rail is fastened, are connected by **T** iron-bracing. Several spans of this size were made continuous over a series of brick piers, and the weight of ironwork in each span, exclusive of rails, was 25½ cwt., costing about £19 per ton. Except in the depth of girder, the bridge is similar in all respects to Example No. 3, illustrated below. Where a complete platform is desired, the rails, instead of lying on longitudinal timbers, may be placed on cross sleepers, laid close together to form a floor, and projecting beyond the girders, so as to make the total width of the bridge 10 ft. or 12 ft.

Example No. 3.—Girders for carrying a single line of railway, 5 ft. 6 in. gauge, over openings of 6 metres (20 ft.) This is for the same railway as that in Example No. 2, and the ironwork is the same in every respect, except dimensions. The engraving on this page shows the relative positions of the rail, the timber, and the girder, and also the connection of the cross-bracing. The girders are 21 in. deep, and 9 in. wide, and each span weighs 54½ cwt.

Example No. 4—A road bridge, 236 ft. long, erected at Osaka, Japan, over one of the numerous navigable rivers intersecting that country. To illustrate the mode of construction, a cross-section through the bridge is shown in the engraving.

There are eight spans of 30 ft., and the roadway is 18 ft. wide. Owing to the supposed soft and yielding nature of the river bed, each pier was composed of four columns, screwed into the



ground, so as to give a wide base, and strongly braced together to resist concussion from boats. The columns, or screw piles, are of cast iron, 1 ft. diameter, with an average total length of 29 ft. from the under side of girders. In each span there are two wrought iron main girders, 2 ft. 3 in. deep, fixed directly over the columns, and upon these, cross girders are placed at every 5 ft. 10 in. to receive the timber roadway.

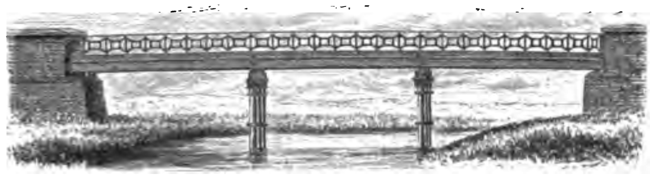
The railing is composed of wrought iron panels, with cast iron standards.

The total weight of the bridge (exclusive of lamp pillars) is—

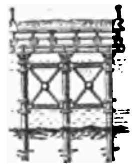
Cast iron — 39¼ tons, costing about £13 per ton.
Wrought iron, 51¼ „ „ £19 10s. per ton.

This bridge was designed in England, with an inadequate amount of information as to the site (see page 22), and was made rather heavier and stronger than was necessary. Under ordinary circumstances the spans might be made larger, and the screw piles less numerous, with advantage and economy.

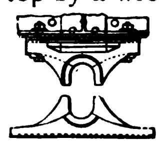
Example No. 5.—A road bridge in three spans of 33 ft., for carrying cattle, waggons, and other traffic, over a river in Buenos Ayres. The shore abutments are of masonry, and each mid-channel pier is formed of cast iron columns or screw



piles 18 in. diameter, and 1 in. thick, braced together. These columns are made in lengths of 10 ft. with short length sinserted in the middle and at the top where the bracing is



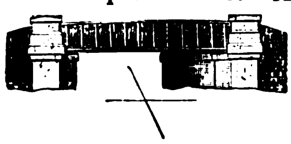
fastened, the total length of each column being 23 ft. At the foot are screws, with blades 3 ft. 6 in. diameter, the column below the screw being armed with teeth, as in Fig. 2, page 28, for penetrating the calcareous-argillaceous stratum on which the bridge stands. The three columns are united at the top by a wrought iron cross girder, 18 in. deep, upon which are



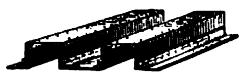
placed six cast iron hinged shoes to receive the six longitudinal girders carrying the roadway. By means of these hinged shoes, the pressure is always on the centre of the columns, even if they should be slightly out of perpendicular.

The longitudinal girders are 2 ft. deep and 7¾ in. wide, and upon them are laid flat roadway plates, ¼ in. thick, riveted to the girders, so that they form an effective part of the area of the top flange. On the two outside or face girders, strong cast iron fascia mouldings, or curbs, 16 in. deep, act as barriers to the road metalling, and at the same time receive the parapet railing, which is composed of cast iron standards and wrought iron panels, made strong enough to withstand the outward pressure of a crowd of cattle. The clear width between the parapets is 21 ft. There are 17¼ tons of cast iron in the piers, costing about £13 10s. per ton; 16¾ tons of cast iron in the superstructure, costing £16 per ton, and 47 tons of wrought iron in the superstructure and the pile bracing, costing £19 10s. per ton This is a very strong bridge, and one of similar size could, under ordinary circumstances, be made of rather less weight.

Example No. 6.—A railway skew bridge 34 feet clear



span, and 15 feet wide, on the Midland Railway, near Mansfield. The two main plate girders are each 37 feet long, and 5 ft. 6 in. deep at the centre, and are divided into bays of 2 ft. 10 in., by gussets, or stiffeners of plates and L irons. The top flange is 1 ft. 1½ in. wide, and of the section shown in Fig. 5, page 56; the bottom flange being 1 ft. 6 in. wide, with the outer L irons omitted. The entire floor is composed of cross girders, arranged as in Fig. 2, so as to form a corrugated surface, each trough or girder being 1 ft. 6 in. wide. The sleepers and rails lie upon a level roadway of ballast. Cast iron gutters and down pipes are placed under the bridge for carrying off the water. The two main girders weigh 10¼ tons, and the total weight of iron in the bridge is 21 tons, costing about £20 per ton.



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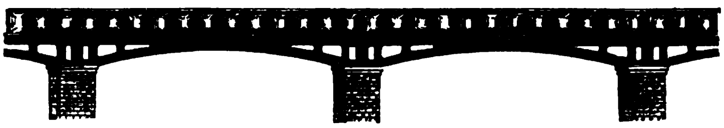
Example No. 7.—A cast iron road bridge over the railway at Nottingham, 175 feet long, in five spans of 35 feet. In each



span there are ten arched ribs or girders, springing from stone piers. These main ribs are each cast in one piece, and are crossed by short "skewback" cast iron girders of the section shown in Fig. 2, on which brick arches are built to carry the roadway. A trough is formed in the centre of the bridge for gas and water-pipes, and this trough is covered by "buckled" plates.* The bridge is 37 feet wide between the parapets, which are composed of cast standards and wrought iron plates.

2

The weight of the brick arches and road material, while giving solidity to the structure, of course increases the necessary weight and cost of the ironwork. It is difficult in this case to separate the cost of the cast and wrought iron. The total weight is 314 tons, and the average price would be about £12 10s. per ton.

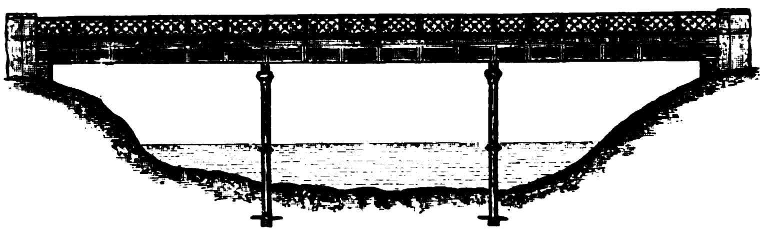
Example No. 8.—A cast iron skew-arched railway bridge for carrying a single line of the Midland Railway, near Mansfield. This bridge is formed of four cast iron arches, or ribs, with a clear span of 35 feet 6 in. between the springing points. The ribs are each made in two pieces, united by flanges and bolts at the crown of the arch, at which point the two outside

* "Buckled plates." See page 90.

ribs are 1 ft. 11 in. deep, and the two inside ribs 1 ft. 4 in. deep. The ribs are strengthened by wrought iron cross ties. The clear width between the parapets—which are made of cast iron

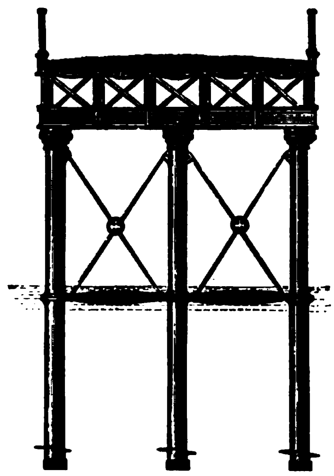
panelled plates—is 14 ft. 6 in. The roadway is formed of cast iron plates resting upon the bottom flanges of the ribs, and the rail sleepers are bedded upon ballast. The bridge weighs 34½ tons, costing about £12 10s. per ton.

Example No. 8a.—A road bridge over the river Don, near Sheffield, for carrying ordinary road traffic. The bridge is in three equal spans of 39 ft. supported at the shore ends on stone abutments, and in mid-channel on iron piers, each pier being composed of three iron columns 16 in. diameter, 1 in. thick. Each of the columns is made in two lengths, united by faced



1.

flanges and eight 1⅛ in. bolts. The lower length of column has cast upon it a screw 3 ft. 3 in. diameter, and below the screw-blade the end of the column is serrated, as shown in Fig. 2, page 28. The two columns of each pier are braced together by horizontal cast iron struts and wrought iron diagonal ties. The tops of the three columns in each pier are connected by a wrought iron girder 21 ft. 7 in. long, 18 in. deep, having a $\frac{3}{8}$ web, and each flange is formed of a plate 12 in. by $\frac{1}{2}$ in., united to the web by L irons 4 × 4 × $\frac{1}{2}$. This girder acts as a sill to receive the main girders forming the superstructure of the bridge. There are in each span six similar main girders, as shown in the cross section, Fig. 2. Each girder is 2 ft. 6 in. deep, having a $\frac{3}{8}$ web, an upper flange formed of a plate 14 in. by $\frac{7}{16}$ in., and a lower flange of a plate 12 in. by $\frac{5}{8}$ in., united to the web by L irons 4 × 4 × $\frac{1}{2}$. The web is stiffened at intervals of 6 ft. 6 in. by vertical T irons, 6 × 3 × $\frac{7}{16}$. The main girders are braced together at intervals of 13 ft. by cross bracing of 4 in. × 4 in. × $\frac{1}{2}$ in. L irons, as shown in section, Fig 2. The platform of the bridge is formed of curved plates with the convex side downwards, each plate being 6 ft. 6 in. × 3 ft. 4 in. × $\frac{5}{16}$ in. thick, riveted to the main girders; and upon this floor concrete and macadam together about 15 or 16 in. thick are placed. An outer curb or cornice of cast iron, 18 in. deep, retains the macadam, and forms a base for the parapet, which is formed of a light lattice framework, 3 ft. high, with cast iron ornaments riveted on, and with a cast iron handrail.



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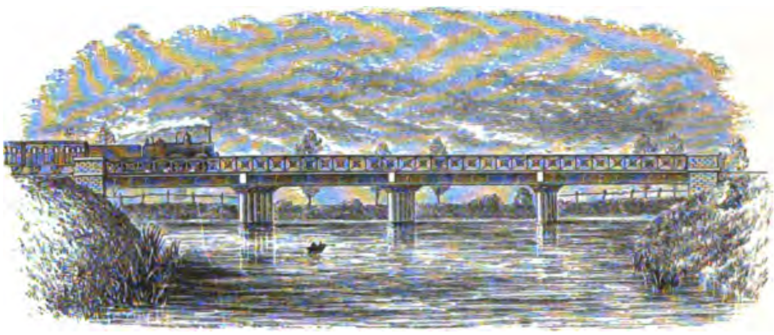
This bridge was calculated to carry safely a dead load of about 150 lbs. per square foot of concrete and macadam, and a moving load of 112 lbs. per square foot, or 25 cwt. per foot lineal of bridge. The weight and value of the bridge may be taken as follows:—

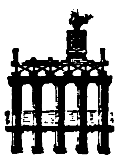
Cast iron in screw piles, bracing, and cornice	22 tons.	£12 per ton.
Wrought iron in girders, flooring, and bracing	80 tons.	£19 10 per ton.

Wrought and cast iron in parapet railing, 240 ft., 12s. per ft.

In England, such a bridge as this would cost about £3 5s. per ton to erect.

Example No. 9.—A railway bridge over the river Derwent, near Derby, designed by Mr. John S. Crossley, for carrying





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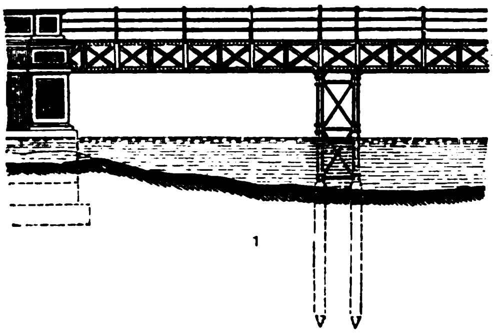
the main line of the Midland Railway where the traffic is constant and of the heaviest kind. The bridge is in four spans of 45 ft., is for a double line, and has a clear width of 26 ft. between the parapets. The shore piers, or abutments, are of masonry, and each of the three river piers is formed, as in Fig. 2, of five screw piles, the distance from the under side of the girder to the point of the pile being 25 feet. The piles are hollow tubes of cast iron, 2 ft. diameter, and $1\frac{1}{4}$ in thick, with screws 4 ft. 3 in. diameter, these screws descending through 1 ft. of loose silt into 7 ft. of gravel. The total height of the column is divided into three lengths, the joints being formed with internal flanges and bolts. A cast iron sill or girder unites the tops of the piles, and upon this girder cast iron shoes or bearing blocks carry the ends of the main girders. There are six main girders in each span, and only the two outer girders are directly above the centres of piles. These girders are of the ordinary plate kind, 2 ft. 9 in. deep, with the top flange 1 ft. 4 in. wide, the lower flange 1 ft. 6 in. wide, and there is cross-bracing between the girders. The floor of the bridge is of timber, and the rails rest upon sleepers in the ordinary way, each rail being directly above a girder. A light wrought iron handrail, with cast iron standards and coping, forms a parapet. The weight and value of the bridge is as under :—

Cast iron — 95 tons, costing about £12 10s. per ton.
Wrought iron, 113 tons, at £20 per ton.

Example No. 10.—A road bridge over the river Axtapha, in the Caucasus, Russia, 360 feet long, designed by M. Auguste



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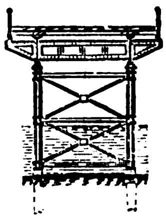

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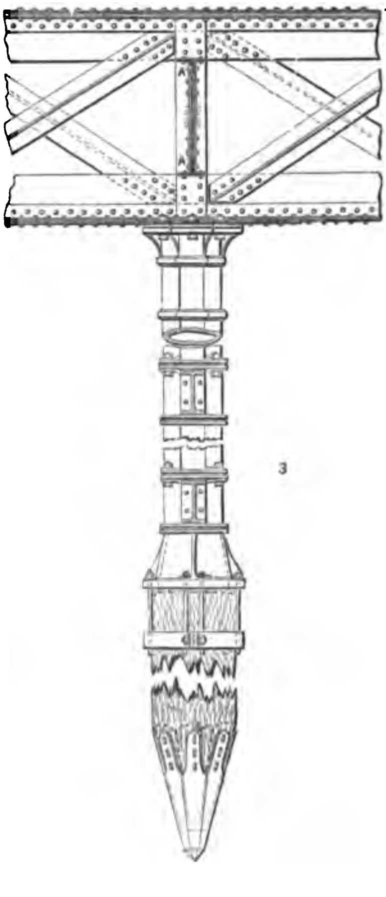
Seseman, and consisting of eight spans of 45 feet. Fig. 1 shows part of the side elevation; Fig. 2 a cross-section, and Fig. 3 a part of the main girder, with one column of the pier. Each pier is formed of four cast iron columns, made in short lengths, with a total height of 16 ft. 6 in. These columns are octagonal, 12 in. diameter, and rest upon wooden piles, driven into the bed of the river. The superstructure is carried by two lines of main girders continuous over each two spans, and placed 14 ft. apart. These girders are 3 ft. 6 in. deep, the flanges being made of two 3 in. L irons, riveted to a web plate 9 in. deep. The cross-girders AA, are 2 ft. deep, of ordinary plates and L irons, and occur at every 10 ft. in the length of the bridge. They pass through and are connected to the main girders in an ingenious manner (Fig. 2), so as to form part of their



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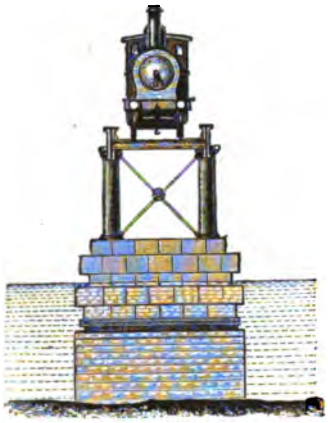
vertical struts at each alternate 5 ft. bay. The cross-girders have a total length of 23 ft. 4 in., and the width of the bridge between the railing parapets is 21 ft. 9 in., the railings being simple round bars attached to cast-iron standards. The roadway is formed of planking. The weight and value of ironwork in the bridge is as follows:—

Wrought iron in superstructure...	70 tons	£20 per ton.
,, in piers	7 ,,	
Cast iron in superstructure ...	$4\frac{1}{2}$,,	£14 per ton.
,, in piers	35 ,,	

This is a very light and cheap bridge, constructed with a light platform for moderate traffic. With a moving load of 40 lbs. per foot the iron would be strained to only 4 tons per square inch. A stronger and more permanent structure would be obtained by increasing the dead load on the platform and the weight of the ironwork in proportion.

Example 10a.—An opening bridge, carrying the Upsala-Margretehil Railway (a single line, 4 ft. $8\frac{1}{2}$ in. gauge) over the Gefle River in Sweden. A circular column of masonry, A, enclosed in an iron cylinder, is built in the bed of the river, and upon this is an iron bed-plate having a revolving table with central pivot and flanged wheels on a circular rail, arranged somewhat in the same manner as the balanced turntables used for locomotives. The central portion of the opening bridge rests on and revolves with the turntable. The bridge is formed of two plate girders, with an extreme length from B to B of 101 ft., the span between the supports (centre to centre) being 50 ft. 6 in., or the absolute span between the outer bearings of turntable to B, 44 ft. 2 in. The main girders, which are 3 ft. 5 in. deep at the central bearing, tapering to 2 ft. at B, are each formed of a web plate $\frac{1}{4}$ in. thick, with upper and lower flanges 12 in. × $\frac{1}{2}$ in., united to the web by L irons 4 in. × 3 in. × $\frac{3}{8}$ in. The two main girders are 9 ft. 9 in. apart, and the roadway is carried by cross girders, to which are riveted the rail-bearers, formed of two rails riveted back to back, which are thus made strong enough to carry the trains between the cross girders, forming, in fact, rail-bearer and rail in one. The cross girders are 10 in. deep, with web $\frac{1}{4}$ in. thick, a flange plate top and bottom 8 in. × $\frac{3}{8}$ in., with angle irons $3\frac{1}{2}$

in. × $3\frac{1}{2}$ in. × $\frac{3}{8}$ in. Below the rails the main girders are braced horizontally by diagonal bars, 4 in. × $\frac{1}{2}$ in. from the ends of alternate cross girders.



2.

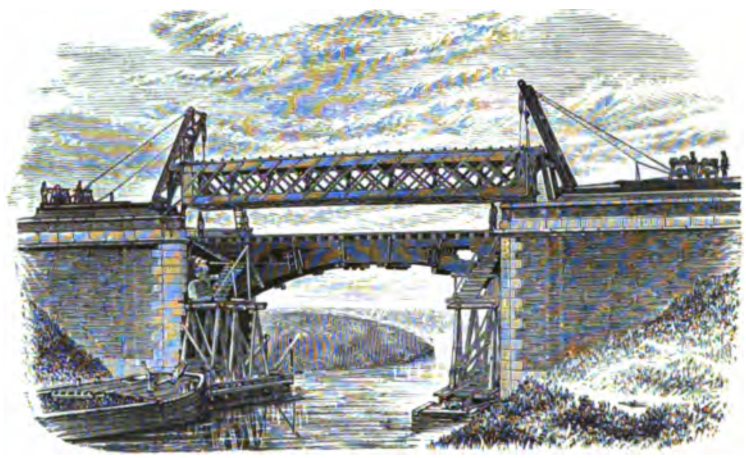
Each outer end of the revolving bridge is carried on a pair of cast iron columns, braced together, as shown in Fig. 2. From B to C are fixed bridges of 27 ft. span, formed of girders and rail bearers, in the same way as the revolving bridge.

The weight of the revolving bridge is as follows :—

Wrought iron, including rails ... ... / Ditto round central pier	$44\frac{3}{4}$ tons
Cast iron, in columns and bed plates	6 ,,
Turntable ironwork, exclusive of machinery... ...	$4\frac{1}{4}$,,

The average value is about £21 per ton.

Example No. 11.—This is one of seventeen railway bridges of various sizes, erected by A. Handyside & Co. over different rivers on the Nicolai Railway, between St. Petersburg and Moscow. There is a double line of rails, having a gauge of 5 ft.; the heaviest locomotive used, complete with tender and fully equipped, weighing 42 tons, on a wheel base of 40 ft. The moving load, which it is assumed the bridges will carry with a maximum strain on the iron of $4\frac{1}{2}$ tons per square inch, is $1\frac{1}{2}$ tons per lineal foot of bridge. The present example shows one of five similar spans carrying the railway over the rivers Sosninka, Wischera, Suika, Bourgha, and Khouba. The spans average 50 ft. in the clear, and the girders are 55 ft. long, and 6 ft. 3 in. deep, of the ordinary lattice kind. The upper and bottom flanges are generally alike, and are each formed of a web-plate (for the upper flange 2 ft. and the bottom flange



1 ft. 4 in. deep) and a plate 13 in. wide. The diagonal struts are strong T or L bars, and the ties flat or L bars, the engraving below showing their arrangement at one end of the girder.

The four main girders are strongly braced together, but there are no cross girders, as the rails are carried on beams of timber. The total width of the bridge between handrails is 24 ft. Except in the bed-plates on abutments, there is no cast iron employed. The wrought iron in each bridge is as follows:—

For main girders, Cross bracing, Handrailing,	28½ tons. Value about £19 per ton.

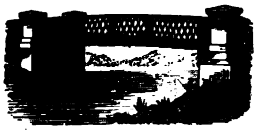
As all the new iron bridges on this railway were constructed to replace original wooden structures, the erection had to be specially arranged so as to interrupt the traffic as little as possible. The ironwork, which was sent from England in pieces, was put together in St. Petersburg on railway trucks, each pair of girders, with its cross-bracing, occupying three trucks The riveting was there completed, except at a few points where the trucks joined, and in this condition the bridges were sent down the railway to the various sites; the level nature of the railway, its freedom from short curves, and the absence of overhead bridges, rendering the line peculiarly suitable for this operation. On reaching the sites, the girders were lowered into position, the wooden structure having been previously cut away below, and the traffic on one line of railway only being interrupted.

The engraving on page 146 shows one of the girders while being lowered into position, and in the background the remaining portion of the old wooden bridge. Some of the larger spans erected in this way are given in Examples Nos. 16 and 18.*

Example No. 12.—One of two cast iron arched bridges, made by A. Handyside & Co., from the designs of Mr. S. Leach, the engineer of the Thames Conservancy, for carrying mounted and foot passengers over a canal 60 ft. wide. The

bridge has a clear span of 60 ft. between the abutments, with a rise of 3 ft in the centre, and is 10 ft. 7 in. wide. The arch is composed of separate trellis castings, 4 ft. high and 5 ft. 1½ in. long, faced at the ends and bolted together at the joints, with a ⅜ in. wrought iron gusset plate between them, to which plate the L irons which form the cross girders of the bridge are riveted. The roadway is formed of Mallet's buckled plates, riveted to the L iron bearers. There are 9 tons of cast iron and 5 tons 12 cwt. of wrought iron in the bridge, the total value of which is £250.

Example No. 13.—A road bridge, 60 ft. span, designed by



Mr. F. D. Bannister, engineer of the London and Brighton Railway, for carrying the traffic of a rural district over the river Arun, at Gritham, in Sussex. There are two main girders, 5 ft. 3 in. deep, of the ordinary riveted lattice kind, the flanges being of the section shown in Fig. 5, page 56, with a web 9 in. deep, and plates 1 ft. 3 in. wide. In the bottom flange the outer L irons are omitted. The bridge

* Some interesting information about the Nicolai Railway, and the construction of these bridges, is given in the pages of *Engineering* of June 2, 1871.

is 14 ft. wide; the cross girders are rolled joists 10 in. deep, placed 4 ft. 6 in. apart, and riveted to the under flanges of the main girders. Upon the joists flat plates are riveted, and these carry a roadway of metalling 6 in. thick, laid upon 6 in. of concrete. The main girders weigh 15¼ tons, the joists and the roadway plates 11½ tons, and the whole would cost about £20 10s. per ton.

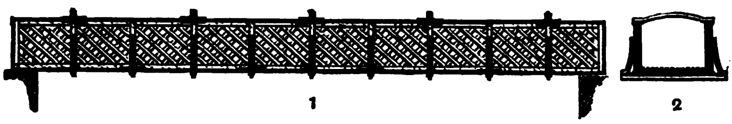
The cost of fixing such a bridge would, in England, be about £2 per ton.

CHAPTER XIV.

EXAMPLES OF BRIDGES CONTINUED. SPANS UP TO 100 FEET.

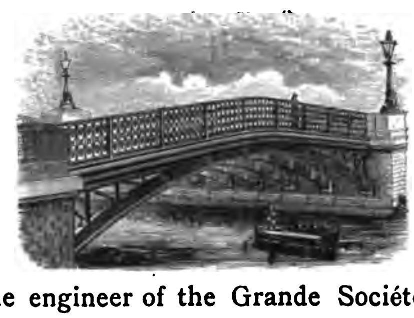
(For the assumed value of iron in the following examples see page 135.)

Example No. 14.—A foot-bridge over the Midland Railway at Nottingham, 68 ft. span and 8 ft. 6 in. wide. The two main girders are each 74 ft. long, and 6 ft. 10 in. deep, each flange being composed of a plate 11 in. wide and two L irons, between



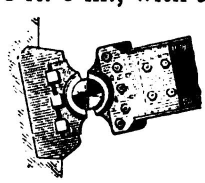
which the diagonals—bars 4 in. wide—are riveted. A flooring of longitudinal planks 4 in. thick is carried on cross bearers of T iron riveted below the girders at intervals of about 7 ft. 5 in. These T irons project at each end 1 ft. 6 in. beyond the girders (as shown in the cross section, Fig. 2), and are riveted to the stays or vertical stiffeners of the main girders. At five points in the length of the bridge an arched T iron, as shown in Fig. 2, connects the top flanges of the two main girders, and retains them in position. The ironwork in the bridge weighs 17½ tons, costing about £21 per ton.

Example No. 15.—A road bridge 73 feet 7 in. clear span over the Abvodnoi Canal, in St. Petersburg. This bridge was



designed by the engineer of the Grande Société des Chemins de fer Russes, as part of the road forming the approach to the Warsaw Railway Station.

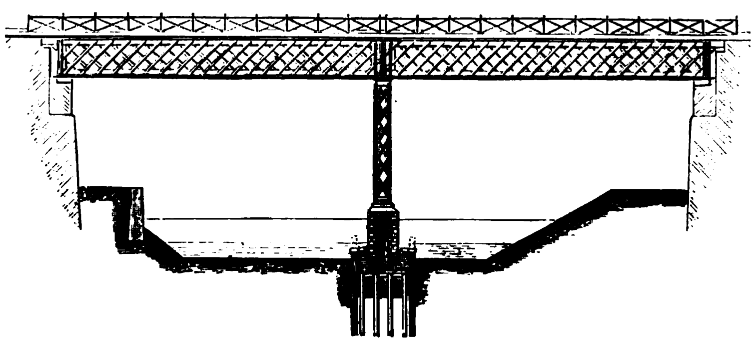
With the exception of the hinged shoes and the parapet railing, the bridge is almost entirely of wrought-iron, the parts being riveted together. There are twelve main ribs or girders, framed as shown in the engraving, and strongly braced transversely. The arch is very flat, the ribs having a rise of only 8 ft. 6 in., with a depth at the crown of 16 in. The ribs rest at



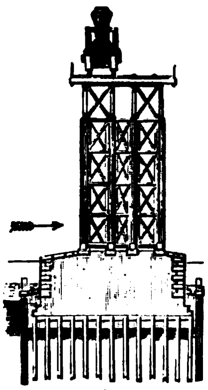
the abutments upon hinged gun-metal bearings, as shown by Fig. 2. The platform, which has a clear width of 69 ft. between the parapets, is made of buckled plates, and is covered with ordinary road metalling. The bridge was fixed by A. Handyside & Co., in the winter of 1869-70 on scaffolding erected on piles, driven through the ice to the bed of the canal below.

There are 142 tons of wrought iron and 19 tons of cast iron, the whole costing about £20 10s. per ton. Considering its great width, the weight for such a span is very moderate; and, owing to the system of construction, the bridge is rigid under severe or unequal loading.

Example No. 16.—This is one of the bridges for the Nicolai Railway, referred to at Example No. 11, and the service required is of course the same. Three bridges, for the rivers Peretna, Tschegrinka, and Beresaika, were made alike as follows: The total width of opening between the masonry abutments is



143 ft., and each girder—of the same kind as those previously described at page 146—is 47 ft. long, and 9 ft. 2 in. deep. The girders are riveted together over the centre of the piers, the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ends with projecting pieces as shown on page 146 resting on masonry abutments. There are four main girders in each span of each bridge, and they are braced together in pairs by diagonal bracing, as shown in the cross section, Fig. 2, the two pairs being connected by horizontal framing. The roadway is carried on the top of the girders upon transverse timbers, upon which a longitudinal timber decking is laid, the width between the hand-rails being 24 ft.

The piers consist of four built-up wrought-iron columns, square in "plan," and which may be described as box girders placed on end, and united by bracing. The necessity for using wrought iron in these piers arises from the circumstance that cast iron is an objectionable material * for the purpose, on account of the extreme degree of cold to which it would be subject in a Russian winter.† These columns average 30 ft. in height, and rest on a pier formed of masonry 16 ft. high, built on 2 ft. of concrete laid on and between timber piling. The height from the bed of the river to the underside of the girders is 42 ft. It will be seen in the cross section of the bridge, Fig. 2, that the masonry projects on one side more than on the other, this projection forming a cutwater facing the current, as a protection against floating ice. The dimensions of the stone pier are, at the base, 37 ft. 5 in. long by 11 ft. 6 in. wide. The weight of iron in each bridge is as follows :—

Eight main girders, bracing, handrail, 104 tons; costing £19 per ton.
Four main columns of pier, 21 tons; £19 10s. per ton.
Cast iron in small planed bed plates, 3¼ tons; £16 per ton.

Example No. 17.—A railway skew bridge, 74 ft. clear span, and 15 ft. wide, on the Midland Railway, near Mansfield, and similar in all respects except dimensions to Example No. 6. The main girders are each 82 ft. long, and 7 ft. deep, and the total weight is 58½ tons.

* Forbidden by the Government regulations.
† See "Effect of Cold on Iron."

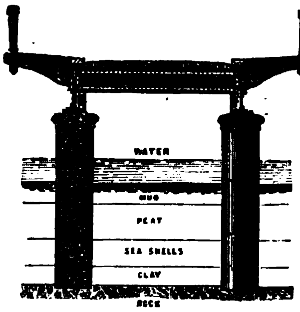
Example No. 18.—This is a bridge of one span over the river Tchernaya, and is one of those for the Nicolai Railway, referred to at Examples 11 and 16. It is in all respects similar to Example No. 11, except in the size of girders. The total width of opening between the masonry abutments is 75 ft., the main girders being 81 ft. long and 10 ft. deep. The wrought-iron in the bridge weighs 56 tons, and consists of four main girders, bracing between girders, and handrailing.

Example No. 19.—A road bridge over the river Nene, at Peterborough, designed by Mr. John Fowler, and erected in 1872. As will be seen from the engraving on this page, the bridge has the appearance of an arched structure in three spans, but in reality it consists of continuous girders throughout, of

which those over the centre opening are made to balance the smaller side spans, which act as cantilevers. By this arrangement no weight is thrown upon the abutments, as would have been the case had an ordinary form of construction been adopted; the abutments, therefore, have been made extremely light, and their cost reduced to a minimum.

The total length of the bridge between the faces of the abutments is 150 ft., divided into three openings, two of 37 ft. 6 in., and one of 75 ft. The total width is 30 ft., divided into a carriage way 21 ft. wide, and two footpaths 4 ft. 6 in. each.

The river bed and the strata below are of the kind usual in the fen country about Peterborough. After piercing through 6 or 8 ft. of mud, peat, and clay, a harder stratum of clay and sea-shells forming a friable rock is reached, and below this, again, there is rock firm enough for a foundation. Each abutment is supported on wooden piles driven down to the rock, and is made of concrete with a face of masonry.



The river piers are formed by sinking cast iron cylinders 5 ft. diameter and 1 in. thick, made in lengths of 7 ft., to a depth of about 14 ft. into the river bed, the average total height from the bottom edge of the cylinder to the under side of main girder being 22 ft. 6 in. The flanges of the cylinders were faced in the lathe, and a joint of red lead between each flange was sufficient to make a water-tight connection. The bottom end of the lower casting has a cutting edge, and with very little loading the cylinder sank as the soil was excavated within. After piercing the peaty clay, water was found in the harder stratum below; but this was easily overcome by hand pumping, and did not interfere with the workmen. A layer of concrete, 2 ft. thick, composed of 6 parts broken stones, bricks, and ballast, to 1 part of Portland cement, having been deposited, other layers in the proportion of 7 to 1 were deposited till the cylinders were full. Upon the top of the concrete, bedding-stones 3 ft. 6 in. square and 1 ft. 6 in. deep are placed to receive the girders.

The outline of the main girders is shown by the engraving, and they are of the kind alluded to at D, on page 67. Their height at the springing at the piers is 6 ft. 4 in., and at the abutments 5 ft, 9 in.; the radius of the arch for the side and centre spans being 57 ft. and 182 ft. respectively. Each girder has a single web ⅜ in. thick throughout, and the top and bottom flanges are made of plates ½ in. thick, increasing from a single plate at the ends to three plates in the centre.

The platform is composed of plate girders 1 ft. 6 in. deep, placed 5 ft. 10 in. apart, and upon them are riveted concave roadway plates ¼ in. thick, stiffened by **T** irons at the joints. The roadway is made of ordinary granite cubes or "setts," laid on concrete 3 in. to 5 in. thick.

Each footpath is carried on cast iron cantilever brackets, placed at intervals of 5 ft. 10 in. against the web of the main girder, to which they are tongued and secured by bolts. Upon cast iron plates resting on these brackets ordinary paving flagstones are bedded on concrete. The parapet is entirely of cast iron, formed of ornamental open-work panels and standards.

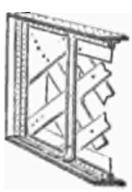
The weight and value of the bridge is as follows :—

Wrought iron in main girders, cross girders, and floor plates	86 tons;	costing £20 per ton.
Cast iron in cylinders ...	... 32 tons;	costing £12 per ton.
Other cast iron	... 44 tons;	costing £15 10s. per ton.

The abutments, concrete, and paving would cost about £1,100, and to this must be added the expense of erecting the ironwork—about £3 15s. per ton.

Example No. 20.—A skew railway bridge in two spans of 78 ft., designed by Mr. J. S. Crossley, for carrying the Mangotsfield branch of the Midland Railway over the river Avon, near Saltford. The bridge has a total clear width of 33 feet, which

includes, besides two lines of railway, a footpath 6ft. wide. Each span is composed of seven parallel girders 82 ft. long and 6 ft. deep, of an ordinary lattice kind, having the top and bottom flanges of T shape, 18 in. wide and 13 in. deep. Special strength and stiffness are given to the girders by verticals placed at intervals of 4 ft. 9 in., and each composed of two 5 in. channel bars, fixed back to back on either side of the web plate. (Fig. 4, on page 69.) The diagonals are all flat bars, from 4 in. to 6 in. wide. The main girders are braced together by diagonal bars of L iron. There are no cross girders, and the roadway is formed of timber laid across on the top of the main girders.

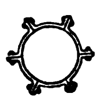


The centre pier of the bridge is formed of twelve cast iron hollow columns or piles, 2 ft. diameter, made in lengths of 9 ft. and fastened together by strong bracing. The piles have each a total length of 27 ft., and are screwed about 7 ft. 6 in. into the bed of the river, which is here composed of blue lias underlying alluvium. The columns are united at the top by a cast iron sill, upon which are bolted iron corbels for carrying the main girders. The railing is wrought iron of a simple pattern. The total weight is 112 tons of cast iron, costing £12 10s. per ton, and 240 tons of wrought iron, costing about £19 5s. per ton.

Example No. 21.—A railway bridge over the river Wye, at Whitney, in Herefordshire, designed by Mr. E. W. Hughes, for carrying a double line of ordinary English gauge. But for the

full width the piers only were completed, the superstructure at present being for a single line only.

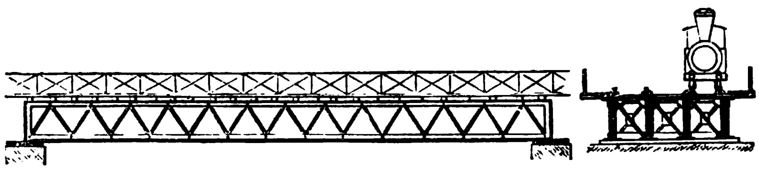
The piers are formed of riveted wrought iron columns (Fig 2), of a peculiar section, strongly framed together, attached at the lower ends to piles screwed into the river bed to a depth of from 12 to 20 ft. There are three main spans of 80 ft. each, and two shore ends of 44 ft. each, the latter resting on stone piers. The long girders are 8 ft. deep, and of the lattice form shown in the sketch, the top and bottom flanges being of ⊔ irons 8 in. deep, and covered by plates 14 in. wide. The diagonal ties are formed of flat bars, the struts of double T iron, and there is a strong horizontal bracing of tie rods tightly adjusted by screw couplings. The roadway is 13 ft. wide, of planking, carried on timber joists 9 in. by 6 in., and there is a considerable depth of ballast. This bridge was tested by a train of locomotives standing and moving upon it, and by a heavy running load.



2

The superstructure of the three long spans, including handrail, and of the two small spans, altogether weighs 96 tons, costing about £20 10s. per ton. The piers weigh 70 tons, and would cost about £17 10s. per ton.

Example No. 22.—A railway bridge (double line) of 84 ft. span, designed by Mr. Rendel for the East Indian Railway Chord Line. This is one of twenty spans made by A. Handyside & Co. in 1866-67, and erected in India during the following



year, and is of the single "Warren" type, as shown in the engraving. Each span consists of four main girders 90 ft. long and 7 ft. deep, having the top and bottom flanges of a trough section made of plates and L irons in the ordinary way, as shown in Fig. 2. The struts and ties are made of iron equal to a breaking strain of 24 tons per square inch, and are connected to the flanges by turned steel pins. The greatest accuracy was observed in the construction of the various parts, so that all should be interchangeable for all the bridges; and this, together with the smallness of the pieces, afforded great facilities for economical transport and erection.* The four main girders are firmly braced together, but there are no cross girders, the rails being directly over the main girders on a timber platform. Some of the spans were tested at Derby, first by a distributed dead weight of 105 tons, when the maximum deflection was ⅞ in., and then by a distributed weight of 178 tons, when the deflection was 1¾ in., and the permanent set ⅝ in. The locomotives running on the line weigh about 30 tons, on a wheel base of 15 ft. The bridges are entirely of wrought iron (except the still pins and cast-iron bed-plates), and each complete span weighs 64 tons, costing about £22 10s. per ton.

2

Example No. 23.—A road bridge 90 ft. span over the river Kura, at Tiflis, in the Caucasus, Russia. On page 65 reference was made to a kind of trussed bridge which had been adopted by A. Handyside & Co. for countries where transport is difficult and skilled labour rare and expensive. The present example

* See "Pin System of Connections," page 70.

shows one of these bridges, which has some peculiar features worthy of notice. The bridge consists of two main trusses, and in these it is of course essential that the principal or upper member shall be rigid along its whole length as a strut. But for transport it is necessary that the girder shall be divided into pieces, and the ordinary method of effecting this division is by leaving certain portions unfastened and riveting them together at the site with proper cover-plates. The workmen able to do this properly are not easily found in some districts, and the necessity for them is avoided in the present design. The upper member of the main girder is divided into five lengths, and each of these is planed at the ends so as to abut fairly against the cast iron struts (also planed) which come between them, and through which they are united by turned bolts in drilled holes. By careful and accurate fitting at the workshop, the putting together of the parts at the site is rendered easy, and there is no chance of bad workmanship there, as the bridge must be united properly, or not at all.

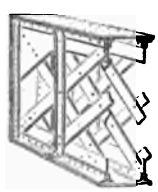
The main trusses, which are 9 ft. deep, are placed 18 ft. apart, and the width of the bridge between the handrails is 21 ft. The transverse girders are 22 ft. 6 in. long, and six of them are placed at equal intervals over the vertical struts and centres of pins. Besides these there are ten intermediate cross-beams of timber. The platform is composed of longitudinal planks 6 in. thick. The railing is made of flat wrought iron bars, with cast iron standards.

The bridge is calculated to sustain, in addition to its own weight, a moving load of 40 lbs. per square foot, with a strain on the iron of 4 tons per square inch.

This bridge, after transport by sea, was carried inland two hundred miles over a mountainous country to the site where it was erected, without difficulty. The lightness of the material and the kind of workmanship necessary involve a higher price per ton than is usual for ordinary girders, but the first cost is amply repaid by the economy in transport and erection.

The total weight of iron is 28¾ tons, costing from £25 to £27 per ton, according to the number of similar bridges made at the same time.

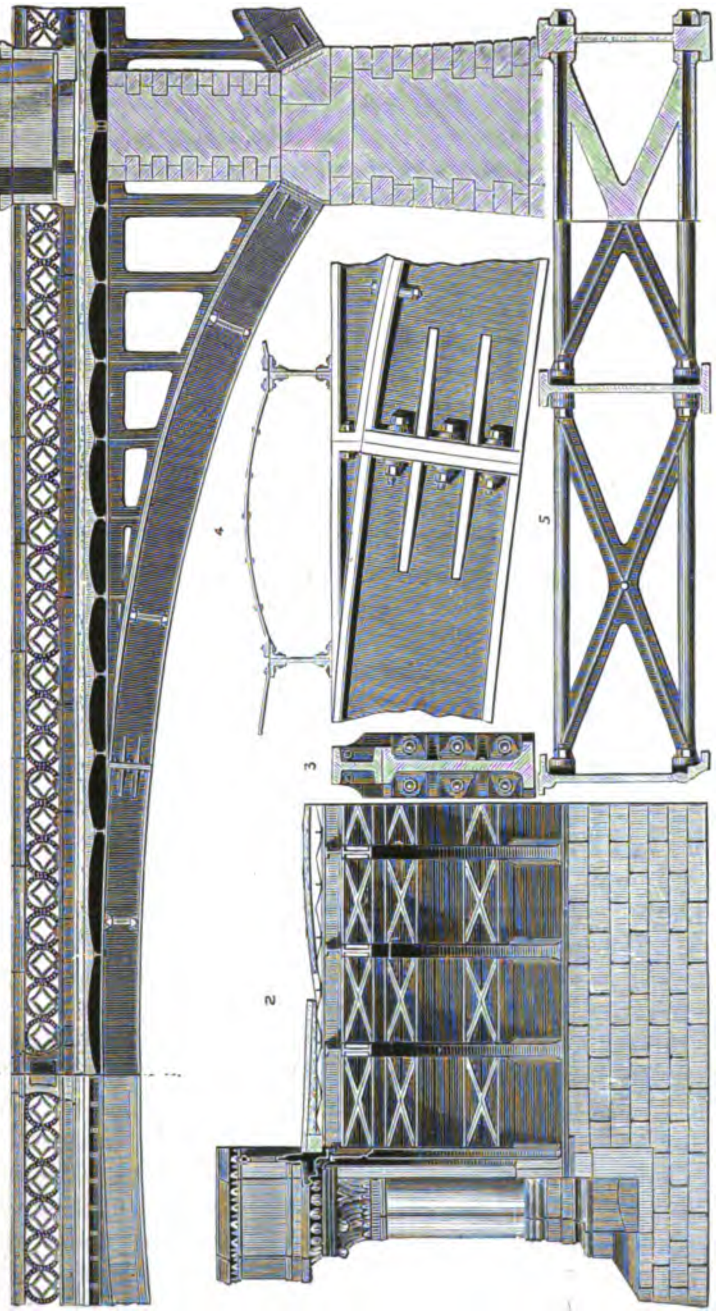
Example No. 24.—A skew railway bridge (double line), in two spans of 92 ft., over the river Avon, near Tiverton, on the Bath and Mangotsfield branch of the Midland Railway, and one of the same kind as described in Example No. 26. There are three main girders in each span, the two outside girders with a single lattice web, and the inside girder with a double web. These main girders are 97 ft. 9 in. long, and 8 ft. deep, with flanges 2 ft. wide and 1 ft. 4 in. deep; the stiffeners are strengthened with gusset plates projecting as far as the edges of the flanges. The cross girders are suspended from the bottom flanges of the main girders, the width of the bridge between the centres of main girders being 30 ft.



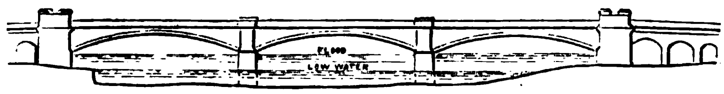
The centre pier of the bridge is composed of ten cast iron hollow screw piles, 2 ft. 6 in. in diameter, made in lengths of 9 ft., and with screws 4 ft. 3 in. in diameter. These piles are arranged in three groups, and are screwed about 7 ft. 6 in. into the bed of the river.

The total weight of wrought iron is 244 tons, costing £19 5s. per ton; cast iron, 104 tons, costing £12 10s. per ton; cast iron in ornamental brackets, 7½ tons, costing £20 per ton.

Example No. 25.—(*See Frontispiece.*)—A cast iron road bridge over the river Trent, at Nottingham, designed by Mr. M. O. Tarbotton. This bridge was erected in 1870-71, to replace a very old structure that was falling to decay, and which, by its numerous piers, rendered navigation impossible, and permitted dangerous floods. The new bridge has three spans each of 100 feet in the clear, making, with the stone arches of the approaches on either side, a total length of 700



EXAMPLE NO. 25. DETAILS OF BRIDGE AT NOTTINGHAM.



feet. The roadway of the bridge proper is level, and stands 27 ft. above the summer level of the river, with a clear width between the parapets of 40 ft. The carriage way is 26 ft. wide, and there are two footpaths each of 7 ft. The north, or Nottingham approach, has a gradient of 1 in 47, and the south approach 1 in 34.

The material of the large main arches is cast iron, and each arch has eight ribs or girders 3 ft. deep at the springing and 2 ft. 6 in. deep at the crown, the mean section being of an I form, 2 ft. 9 in. deep, with top and bottom flanges measuring 7 in. by $1\frac{7}{8}$ in., and 9 in. by 2 in. respectively. The form of section of the face ribs, and that of the ordinary ribs, is shown in Fig. 5. These ribs have bolted to them transverse wrought-iron girders, which carry the roadway platform; the latter is formed of wrought-iron curved plates and Mallett's buckled plates, riveted together with T and L iron stiffeners. Every arch has strong bracing frames (Fig. 5) to connect the several ribs together, and all the joints of the ironwork are planed true, and connected with iron pins or bolts, which were previously turned smooth in a lathe, and fitted into holes drilled—when fixed in place—through the ironwork. The face ribs are of an ornamental character, and are moulded on the lower edges and on the upper lines of the arches. The spandrels are recessed and moulded, and contain medallions of cast iron, fitted with geometric cuspings enclosed in moulded circles or tracery: the designs for the enrichments vary in each compartment, both in size and detail. Over the arches and spandrels, an ornamental moulded cornice of cast iron runs from pier to pier, and the lower part embraces a rich filling of conventional foliage, composed of leaves and lilies, also of cast-iron. The whole is surmounted by the parapet, which is of geometric and continuous design formed of cast-iron open work, with pateras or flowers at the intersections of the curved lines. The top member is moulded, and the lamp standards for lighting the bridge are designed as permanent features to correspond with the parapets, of which they form an integral part. The parapets of the north and south approaches, over the stone arches, are of similar design and construction to those over the iron arches; the lamp standards for lighting the approaches are dwarf columns fixed upon stone pillars. All the lamps are globes in one piece of glass, with copper finials and mountings, and supplied with gas in the usual manner.

In the construction of the abutments and piers, considerable difficulty was experienced with the foundations, in consequence of a sunken weir interfering with the formation of the cofferdams, and the excavation of the river bed. Much time was therefore lost in securing the foundations, especially as the floods, which in the earlier part of the work were very constant and heavy, contributed also to the difficulties attending the cofferdams.

There are two large main abutments which receive the iron arches, one on the north and the other on the south side of the river, and between these there are two piers, built entirely in the water. Another abutment receives the north flood arch, and on the opposite side are two piers and an abutment for the south flood arches. The residue of the north and south approaches is sustained by curved stone battering retaining walls. All the foundations in the river were built by the aid of cofferdams, and in the making of these divers were employed to destroy the old boats and remove the large blocks of granite and other material, so that the piling for the dams could be proceeded with. On the completion of the dams (which in the course of the building operations several times burst, in consequence of the entanglement of the piling with the old boats) the water was pumped out, and the bed of the river excavated down to the white sandstone rock, and the latter was also excavated to a depth varying from 2 ft. to 5 ft. to procure a solid and level base for the masonry. The foundations of the piers were constructed of large blocks of Derbyshire ashlar, cramped together with iron, and upon these the masonry of the piers was built up. The faces are formed of blocks of stone, filled up behind with rubble masonry, the whole being laid in ground Barrow lias lime and washed Trent sand. The abutments are similarly built, but the foundations rest upon Portland cement concrete.

The carriage roadway of the bridge is formed first of a layer of bituminous concrete, to protect the iron plates from oxidation; then of a foundation of Portland cement concrete, several inches in thickness; and finally, upon the concrete, of a layer of Val de Travers asphalte * from the quarries in Switzerland.

The bridge is made strong enough to carry the very heaviest traffic, as will be seen from the following description of the trial loads: The calculated strain upon the ribs in the centre was 1·4 tons when the bridge was loaded with a distributed weight of 2 cwt. per square foot all over the surface. The weight of each arch with the roadway, *i.e.* the permanent load, is about 450 tons, this being equal to a weight of rather more than 2 cwt. per square foot over the surface of the bridge. Then taking the greatest moving load at 2 cwt. per square foot, the gross weight of and upon each arch would be 850 tons. It is difficult to see how 2 cwt. of live load could be put on the bridge except by treating each pair of ribs as a line of railway, and placing locomotive engines thereon. There would then be eight engines on each arch, equal to 400 tons—2 cwt. per square foot. In the test, the surface was crowded with carts filled with granite, and passed along at all speeds, without sensible deflection or much vibration. There was rather more vibration with one cart loaded with two tons, than with six carts; the permanent or dead load might therefore be increased with advantage.

The weight of the ironwork in the bridge is as under:—

Cast iron:	
Main inside ribs	254 tons.
Spandrels for ditto	104 ,,
Face ribs	160½ ,,
Ornaments in face ribs	5 ,,
Cornice, coping, and parapet ...	112½ ,,
Bracing and other cast iron ...	60¼ ,,
Wrought iron	173 ,,
	869¼ ,,

The whole would cost on an average about £13 10s. per ton, and the erection about £3. The above weights do not include the railing on the approaches or the lamp pillars. The abutments, the piers, and the road material would cost about £13,500.

* "Asphalte." See page 99.

CHAPTER XV.

EXAMPLES OF BRIDGES CONTINUED. SPANS UP TO 150 FEET.

(For the assumed value of iron in the following Examples, see page 135.)

Example No. 26.—A skew railway bridge in two spans of 108 ft. over the river Avon, on the Mangotsfield branch of the Midland Railway. This is a bridge of the same series as Examples Nos. 20 and 24, but with the roadway on the bottom

flanges of the girders. Each span is composed of three main girders 112 ft. long and 9 ft. deep, of an ordinary lattice kind, with trough-shaped flanges (Fig. 8, page 56) 2 ft. wide and 13 in. deep. The flanges of the centre girder are 2 ft. 3 in. wide. The verticals, which occur at intervals of 7 ft. 6 in., consist each of four 5 in. ⊔ irons, one on each side of each web

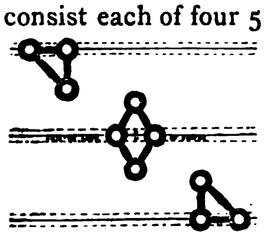


plate (Fig. 4, page 69), and braced between. The diagonals are flat bars riveted to the web plates of the flanges. The bridge has a clear width of 26 ft. between the outside girders. The roadway is carried on longitudinal timbers resting on cross girders 12 in. deep placed 3 ft. 9 in. apart. At the extreme ends of the bridge an ornamental bracket gives a finished appearance to each of the main girders.

The pier in the centre of the river is formed of separate groups of cast iron piles under each main girder. The piles or columns are each 2 ft. 6 in. diameter, made in lengths of 9 ft., and with a screw 4 ft. 9 in. diameter on the bottom length. These screw piles are inserted about 12 ft. into the river bed, and the total length of each is 31 ft.

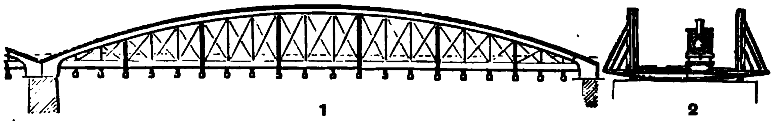
The weight and value of the bridge is as follows:—

Wrought iron in main girders	221 tons		
Do. in 80 cross girders	75½ ,,		£19 10s. per ton.
Bracing, &c.			

Cast iron in piers, &c., 118 tons, £12 10s. per ton.

Do. in six ornamental brackets, 7½ tons, £20 per ton.

Example No. 27.—The engraving represents one span of a long bridge carrying a railway and carriage roadway over the river Glommen, near Christiania, in Norway. There are in each span two main girders (that next the railway being



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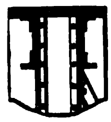
heavier and stronger than that next the carriage road) 122 ft. long and 13 ft. deep in the centre, the top or compression member having a trough or box section (as shown in Fig. 3)



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18 in. wide and 11 in. deep, and the bottom or tension member being of plates 12 in. deep. The verticals are ⊔ shaped, composed of two L bars and a plate (as shown in Fig. 4), and the diagonals are single 3 in. L bars. The bridge has a clear roadway 23 ft. wide, including the space occupied by a single line of railway with a narrow 3 ft. 6 in. gauge. The platform is formed of fish-bellied girders 1 ft. 10 in. deep in the centre, and placed 5 ft. 8 in. apart, projecting beyond the main girders (as shown in Fig. 2), so as to allow struts or stays of T iron to stiffen the top flanges of the main girders. The carriage-way is formed of longitudinal timbers laid on the cross girders, and the railway is carried on longitudinal plate girders or bearers 12 in. deep. The bridge is well braced, and is a very light and cheap structure for the service required.

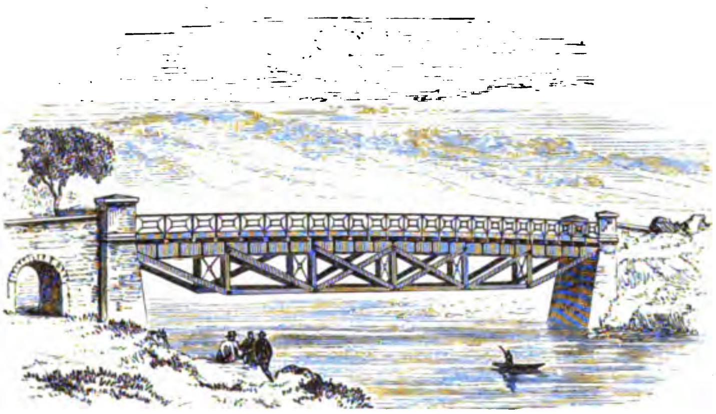
4

The weight of each span is made up thus:—

Main girders	43 tons	£22 10s. per ton
Crossgirders, bearings, bracings, &c.	24 ,,	

This bridge was erected in the winter on a trestle scaffold on the ice. The bridge forms part of a system of narrow gauge railways which is being established in Norway, and the locomotives and other rolling stock are proportionately light.

Example No. 28.—A road bridge over the river Lune, in Westmoreland, 116 ft. clear span and 12 ft. 6 in. wide, of the same general construction as Example No. 23, except that in this case the vertical struts in the main girders are of wrought

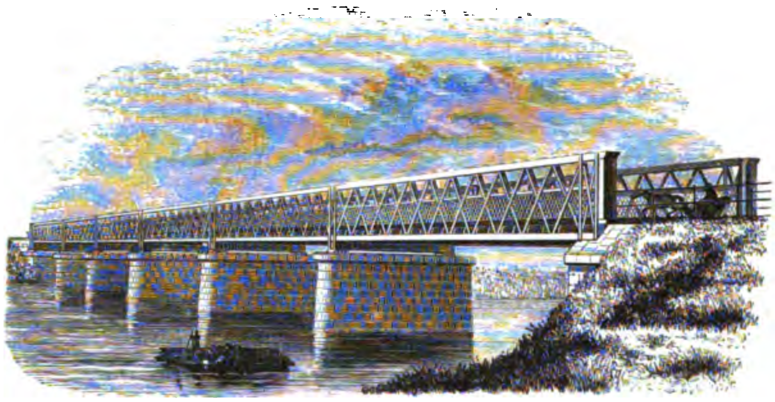


iron. The abutments are of stone, and the girders rest on cast iron bed-plates, planed to allow the girders to move, in case of expansion and contraction. The bottom flange is composed of tie bars 9 in. by $1\frac{3}{8}$ in., and the top flange of a wrought iron girder 1 ft. 7 in. deep and 12 in. wide, made in parts as described in Example No. 23. The vertical struts consist each of two ⊔ bars, 10 in. by $3\frac{1}{2}$ in., placed back to back, and braced together with flat iron ties. The cross girders are 12 in. deep and $8\frac{1}{4}$ in. wide, placed 6 ft. 7 in. apart on the top of the main girders. The roadway is composed of ordinary metalling on arched wrought-iron plates.

The weight of the two main girders is			16	tons.
,,	,,	cross girders	$5\frac{1}{2}$	,,
,,	,,	platform	20	,,
,,	,,	other ironwork	11	,,

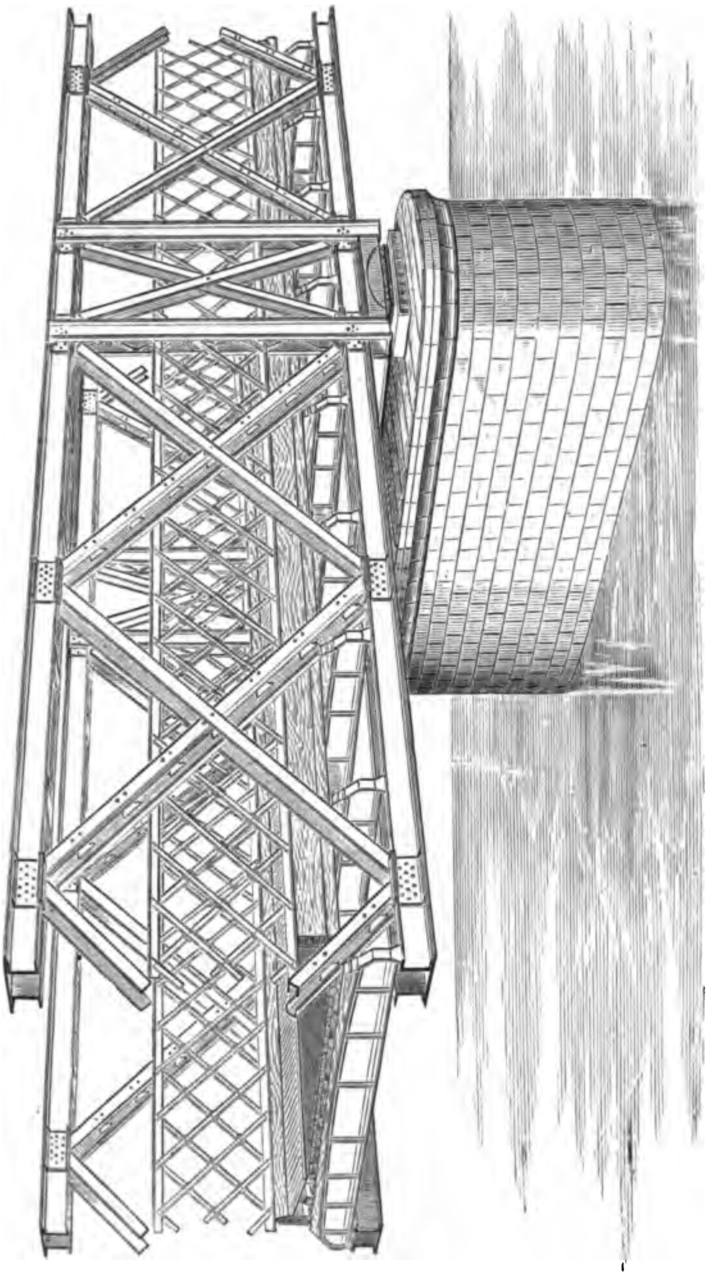
the whole costing from £22 to £24 per ton, according to the number of similar spans made at one time.

Example No. 29.—A road bridge over the river Pruth, at Czernowitz, the capital town of Bukowina, a district in the extreme east of Austria.



The cold in the winter is extreme, the temperature often falling as low as 20° below zero Reaumur, and, at the breaking up of the frost, enormous masses of ice come floating down against the bridges. Up to the year 1869, the whole of the traffic into Czernowitz, from a wide stretch of country around, had to cross the Pruth by an old and fragile wooden bridge. The inconvenience experienced at length caused the Austrian Government to take some active steps towards the construction of a new bridge. They resolved to have a permanent iron structure, and accordingly asked for designs and tenders from six manufacturers in Austria, Prussia, France, and England. The design of Mr. R. M. Ordish, as shown by the accompanying illustrations, was submitted with a tender by A. Handyside & Co., and accepted. The detailed engraving on the next page shows a cross-section of the bridge with a view in perspective of the girders, and their resting-point upon one of the piers.

The bridge is 762 ft. long, and carries a roadway and two footpaths, making a total width of 25 ft. between the centres of girders. There are six openings over the river, each 126 ft. from centre to centre of piers; the five piers and two abutments being of masonry, on concrete foundations. The main girders are continuous, of the kind shown in Fig. H, page 63, and are 11 ft. 10 in. deep. The flanges are trough-shaped (Fig. 7, page 56), composed of two large ⊔ irons 10 in. deep,



EXAMPLE NO. 29. BRIDGE OVER THE RIVER PRUTH, AT CZERNOWITZ.

and a flange plate riveted to them. The diagonals are placed at an angle of 45°, and consist of a pair of flat bars which form the ties, and a pair of ⊔ irons braced together which form the struts. Except at the piers, the main girders have no verticals, nor are they anywhere braced across the top flanges. Lateral stability* is given to the girders by a special arrangement of the parts to maintain the top flanges in position against side-bending. In the first place, the girders are continuous over six spans, and certain parts of the top flange (those over the piers) are always in tension, so that only the intermediate portions have to be held in position laterally. Secondly, at each pier the two main girders rest in strong ⊔ shaped frames, which resist any lateral movement and stiffen a certain length of the girder on each side. Thirdly, the top flange of the girder is made specially broad (2 ft. 2 in., which is 7 in. more than the bottom flange), so that the proportion of length to width in the remaining part of the flange is not excessive. Lastly, all the diagonal struts, which are constructed as girders, and which occur most frequently where, for this secondary purpose, they are most wanted, are connected to the cross girders of the platform by means of a trough-shaped flange, in a manner specially suited to resist any twisting action.

The cross girders are of wrought iron, 1 ft. 6 in. deep in the centre, and are placed 5 ft. 6 in. apart throughout the bridge. The parapet railing is of wrought iron lattice work, bolted at intervals to the main girders, and finished with a wooden handrail.

The roadway of the bridge consists of longitudinal timbers 7 in. by 6 in., placed about 2 ft. apart upon the cross girders. Upon these timbers is laid, transversely, 4½ in. planking, and upon this, again, rest oak blocks 5 in. thick. The footway is laid with 3 in. oak longitudinal decking, upon which the wearing planks are spiked. This forms a somewhat heavy roadway, but timber is exceedingly cheap at Czernowitz.

The two main girders rest upon roller bearings at each of the piers, each of these bearings being composed of three castings. The first, or upper portion, is fixed to the girder between the ⊔ frames, the underside of the casting being concave and

* See "Lateral Stability of Bridges," page 74.

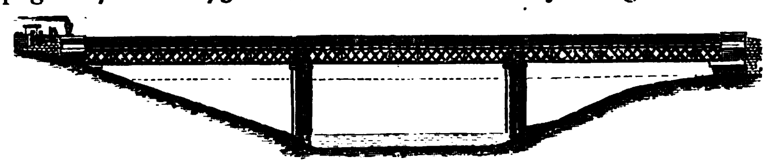
resting upon the second or intermediate casting, to which a corresponding convex shape is given. This arrangement allows for oscillation in the bridge from moving loads, and also ensures the central action of the load upon the rollers, and consequently upon the pier. The second casting rests upon eight cast iron rollers, each 4 in. diameter, the rollers moving upon a cast iron bed plate, bolted down to the masonry of the pier. The rollers are omitted from the bearings over the central pier, whilst the convex form is retained to provide against oscillation. The main girders being thus prevented from moving horizontally at this point, the expansion from increase of temperature radiates outwards from the centre, and extends the bridge equally at each end.

The ironwork of the Czernowitz bridge, erected complete, cost a large sum, as it was saddled with heavy expenses in the shape of expensive freights and long railway journeys; but it was cheaper than if made in Austria. The first span of the structure did not leave England till May, 1870; but the bridge was erected complete by the end of October. During the erection of the bridge a heavy flood brought down masses of *débris*, and amongst other things a timber mill, which entirely carried away the scaffold under one span. The ironwork, however, had been carefully prepared, so that it should carry itself, by the temporary fastenings of bolts and cold rivets in the rivet holes, and thus this span sustained no injury whatever.

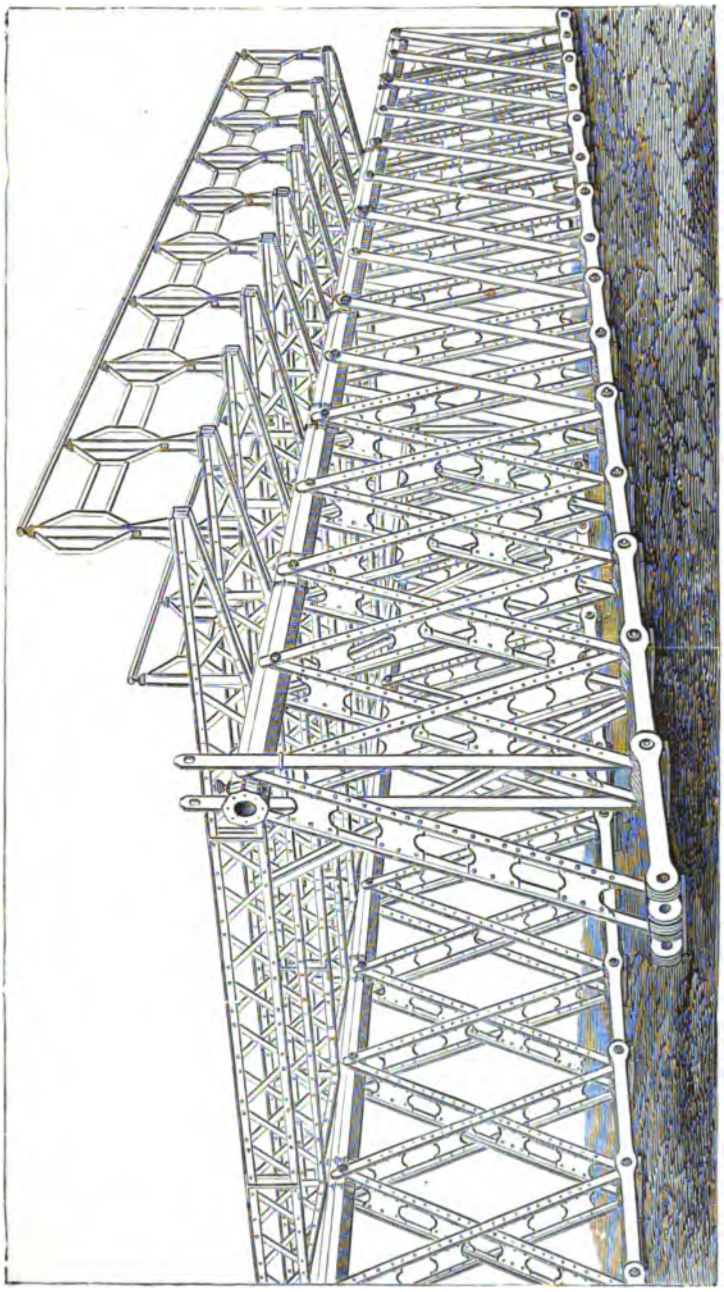
The bridge was not thrown open for public traffic till it had undergone a careful and searching test at the hands of the Government engineer. All the spans were tested individually and collectively; the proof loads, which consisted of bricks, being applied in a variety of ways so as to try the continuous girder system to the utmost in every respect. The test load appointed by the Austrian Government for bridges is 30 cwt. per square fathom, or 96 lb. per square foot, English. This is considerably higher than the proof load used in England, which may be taken at from 70 lb. to 80 lb. per square foot of road surface. On account, however, of the increased weight of timber introduced into the platform during construction, the test load was reduced to 25 cwt. per square fathom, or 80 lb. per square foot. According to the test originally proposed, the load brought upon the ironwork of the structure would have been 6 tons per square inch of sectional area. As it is, however, with the increased weight of the platform, the actual load would appear to be higher. But as in continuous girders the maximum strains do not depend upon the amount of the maximum load alone, but also very considerably upon the difference between the greatest and smallest loads, the proof load really remains within the original test. The highest deflection in any one span was 1 in., and the permanent set varied in the different spans from $\frac{1}{8}$ to $\frac{3}{16}$ in. The weight of the bridge is as follows :—

12 main girders	222 tons	costing about £20 5s. per ton.
139 cross girders	112 ,,	costing about £20 5s. per ton.
Other wrought iron, including handrailing	33 ,,	costing about £20 5s. per ton.
Cast iron	33 ,,	costing about £16 5s. per ton.

Example No. 30.—The engravings on this page and on pages 171 and 173 show a road and railway bridge over the



river Bremer, near the Ipswich terminus of the Queensland Railway, Eastern Australia. This bridge was designed by Sir Charles Fox & Son, the English engineers of the Company, for carrying a single line of railway (3 ft. 6 in. gauge, with locomotives weighing 15 tons), a carriage road, and a footway. There are three spans of 150 ft. each, and the clear width between the parapets is 35 ft., of which 12 feet is allotted to the railway. At the dry season the water is very low, but during floods the stream rises about 40 ft. to the level shown by the dotted line. The abutments are of masonry, and the river piers are each formed of two columns placed 25 ft. apart, as shown in the cross section, Fig. 1, page 173. These columns are composed of cast iron cylinders 6 ft. 6 in. diameter, in lengths of 6 ft., each length being in three segments, and of metal $1\frac{1}{8}$ in. thick. For 21 ft. from the base the cylinders are filled with concrete, so as to form a solid pier independent of



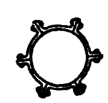
EXAMPLE NO. 30. BRIDGE AT QUEENSLAND.

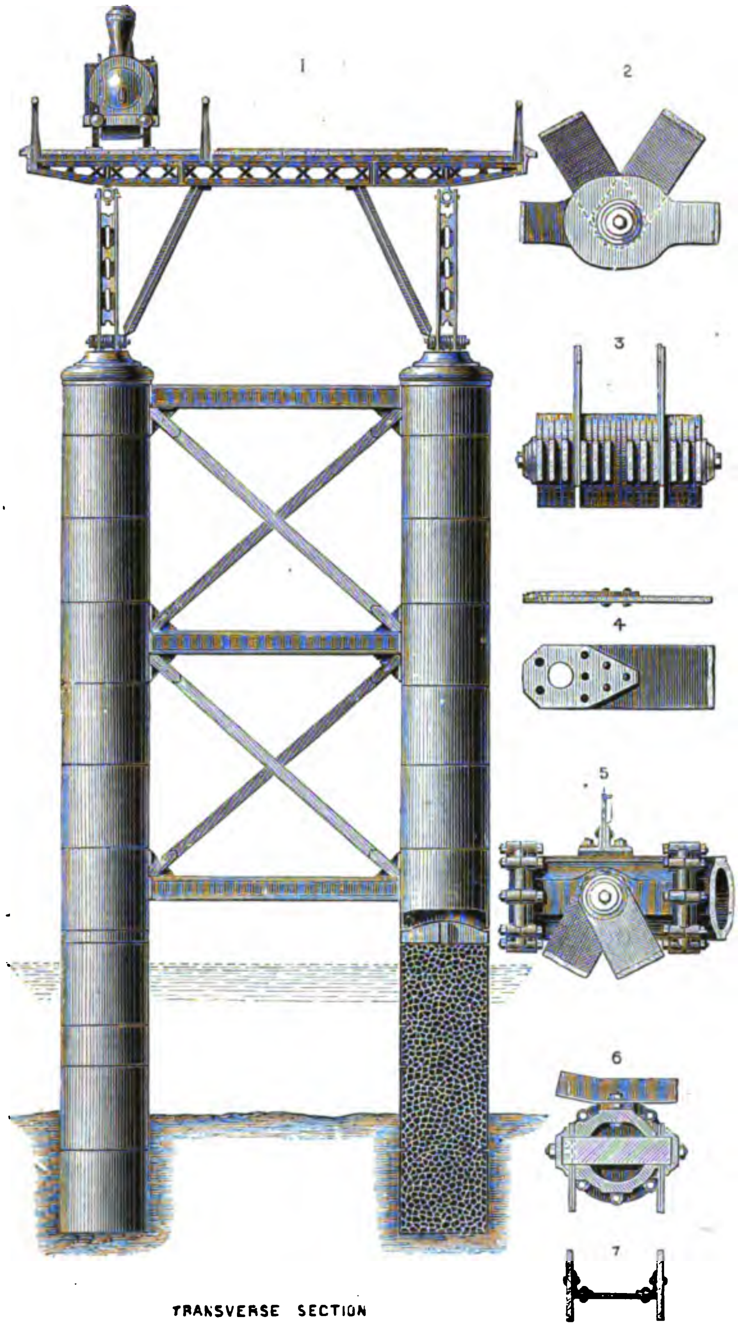
the iron casing; and on the foundation thus constructed stands the remainder of the iron column carrying the superstructure. The two columns of each pier are firmly braced together by plate-girders 18 in. deep, occurring at three places in the pier, and are tied diagonally with flat bars.

The superstructure of each span is formed of two main girders carrying the cross girders and roadway upon their top flanges, as shown in the engraving on page 171, which is a copy from a photograph taken in the factory at Derby. The main girders are 10 ft. 9 in. deep between the centres of flanges, and have the peculiarity of being partly of cast and partly of wrought iron. The top member is formed of octagonal cast iron tubes 12 in. external diameter, made in lengths of about 10 ft., and increasing in thickness from the ends to the centre of the girder.* The ends of the tube are carefully faced in the lathe, and between each of the 10 ft. lengths is a shorter tube or junction piece, as shown in Figs. 5 and 6, page 168, the connection being made by turned pins through drilled holes. The bottom flange of each main girder is formed of parallel links 6 in. wide, varying from four to twelve in number, and capable of taking a heavy tensile strain. (See page 70.) Fig. 3 shows a cross section of the links, and Fig. 2 one of the points of junction with the diagonals. The links are of the shape shown on page 70, and are connected at the ends by turned steel pins, which were made with the greatest accuracy, so as to be interchangeable, and afford facilities for the erection of the bridge.

The diagonal struts are framed of flat bars, placed 12 in. apart, so as to grasp at the upper end the cast iron horizontal tube, and are connected to the bottom flange by the steel pins which unite the links. The struts are strengthened by L irons riveted inside the bars (Fig. 7) and by distance pieces placed at intervals, so as to give sufficient rigidity against the compressive strain. The diagonal ties are 9 in. wide, formed of flat bars thickened at the ends by plates (Fig. 4), so as to give greater bearing surface for the shear of the pins; the section of both struts and ties varying in strength according to their position in the girder. The cross girders are 1 ft. 9 in. deep, diminish-

* In American girder bridges, tubular members are frequently used, but the tubes are of wrought iron segments (see page 155) riveted together.





EXAMPLE NO. 30. DETAILS OF BRIDGE AT QUEENSLAND.

ing in depth where they act as cantilevers outside the main girders, as shown in Fig. 1 and on page 173. There is horizontal bracing between the cross girders. The platform is of timber, with extra wearing planks on the carriage way. The parapet is formed of neat panels of wrought iron bars, with cast iron standards, as shown on page 171.

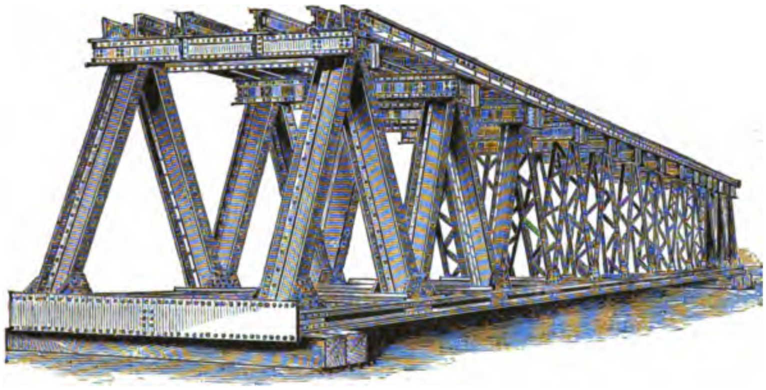
The piers rest upon hard ballast, interspersed with rock, and two months were occupied in sinking them. The main girders were erected upon a pole scaffold, and the whole superstructure was erected in five and a half weeks, including the time for lifting the material from the river banks to the platform. The extra cost per ton of the wrought iron, as compared with ordinary lattice bridges, was amply repaid by the moderate weight and by the extreme facility of erection allowed by the pin system, and by the exact fitting and interchangeability of the various parts.

The weight and cost of the bridge may be divided as follows:—

Cast iron in piers	130	tons,	at about	£12 per ton.
Wrought iron in piers	11	,,	,,	£20 ,,
Cast iron in superstructure ...	91½	,,	,,	} £22 ,,
Wrought iron ,,	277	,,	,,	

Example No. 30a.—A bridge designed by Mr. A. M. Rendel, for carrying a single line, 4ft. 8½in. gauge, of the Holkar Indian State Railway over the Nerbudda River at Khundah, a station 352 miles from Bombay, and about 40 miles from the junction with the G. I. P. Railway. There are fourteen spans of the form shown in the engraving, each of 60 metres, or about 197 ft. The piers and abutments are of brick, with stone landings to carry the bearing plates of the superstructure. The main girders are 14ft. 8in. deep, and, as shown in the engraving, are of the Warren kind with single triangulation, all the parts being riveted. The main booms or flanges are open, of a section something like that shown in Fig. 9, page 56, but with inner L irons also, each boom having eight L irons 5in. × 5in. × ⅝in. the booms measuring 28¾ in. wide inside and 13 in. deep. The five diagonals nearest the ends of the girders are composed of plate and L irons, while the 14 diagonals in the centre of the girder are of open lattice work. In either case these members are 12 in. and 10 in. wide and 19½ in. deep. The railway is carried by cross girders, with solid web plates secured to the top boom of the main girder, and upon the cross girders two longitudinal rail bearers are placed, as shown in the engraving.

One noteworthy feature in the detail construction of the bridge is, that the angle irons forming the booms all break joint. The angle irons are thus, as it were, so bonded that although they are all long enough to cover two bays of triangulations, no waste of sectional area is involved in any bay. The details are simple, best materials and workmanship being used, in accordance with a very stringent specification. The bridge may be taken as the latest type of English construction, the rivet holes fitting very accurately, and the abutting joints being planed with precision. All holes, except those in the cross



girders and longitudinal rail bearers, were drilled by multiple drilling machines through iron templates. Steam riveting was applied to the cross girders and small longitudinal girders.

The testing was carefully and successfully carried out by distributing a dead weight, consisting of rails, over one span, with the following results:—

With 150 tons the deflexion showed $2\frac{1}{16}$ in.
" 300 " " $2\frac{3}{8}$ "

After the load was removed, the permanent set was found to be $1\frac{3}{16}$ in. With regard to this deflexion, it is to be observed that the connexions left to be riveted up in India were only bolted together for the purposes of testing. The deflexion and permanent set would of course have been less if the structure had been riveted up as it was afterwards in India. The average weight of each span is about 133 tons—the exact weight of the fixed and rolling ends differing slightly—the total weight of the ironwork in the entire bridge being about 1,860 tons, the value of which, when iron is selling at the price given on page 135, being about £19 10s. per ton. Messrs. Handyside & Co. erected each span complete before it left their works, the ironwork being painted in parti-colours, so as to facilitate erection in India, adjoining members being thus distinguishable at a glance. The ironwork was delivered at the port of shipment at the rate of one span every three weeks, and this without disturbing the other arrangements at the works.

CHAPTER XVI.

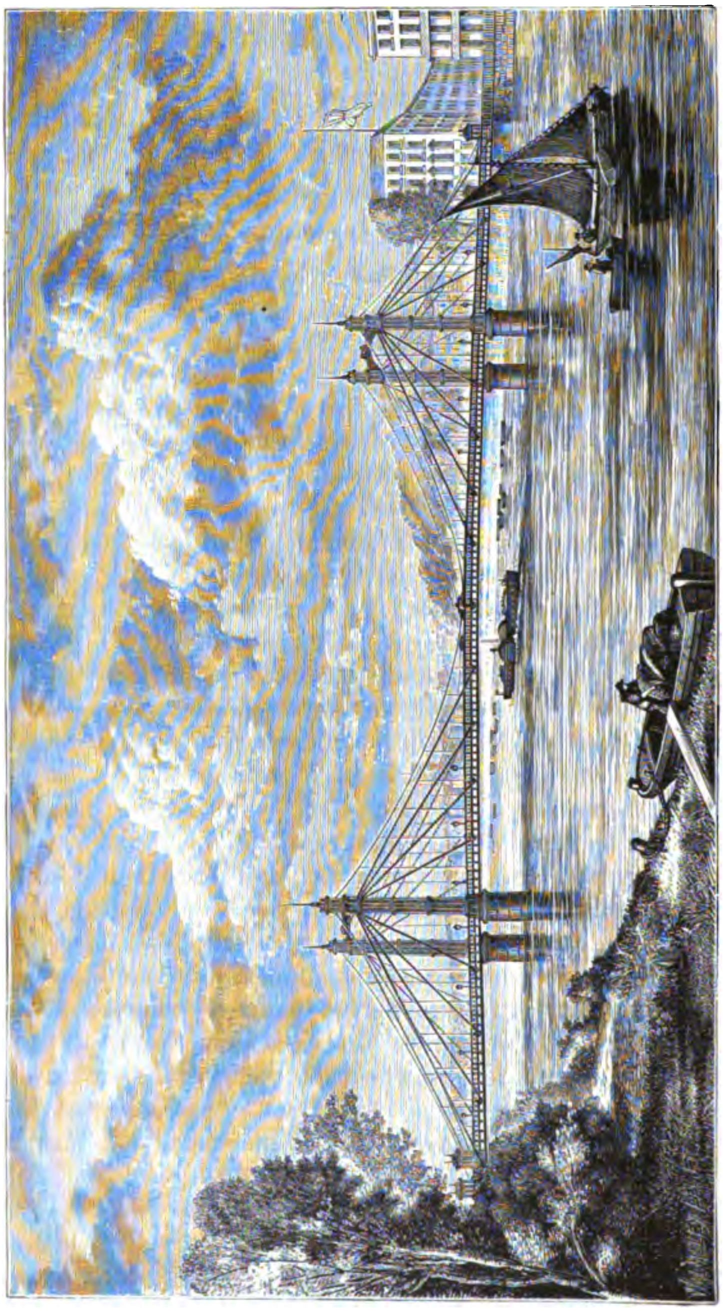
EXAMPLES OF BRIDGES CONTINUED. SUSPENSION BRIDGE. FLOATING BRIDGE.

(For the assumed value of iron in the following Examples, see page 135.)

Example No. 31.—The Albert Suspension Bridge, over the river Thames at Chelsea, London, designed by Mr. R. M. Ordish, and erected in 1872. The bridge is 710 ft. long, with one centre span of 400 ft., and two side spans of 155 ft.; with a roadway 41 ft. wide between the parapets. The general appearance of the structure is seen from the engraving on page 178, and one of the piers, with the tower and a cross section of the roadway, is shown on a larger scale on page 180.

The system of suspension is generally similar to that of the Prague Bridge, described on page 83, with the difference that, in the Albert Bridge, the catenary, besides carrying the weight of the straight inclined bars or chains, also supports a portion of the weight of the platform and the moving load of the bridge at points 20 ft. apart, as well as the whole of the weight and the moving load of the central section of the bridge, which is more or less than 40 ft. in length, according to the arrangement of the moving load. From the fact that the catenary cannot alter its form without affecting the action of the straight chains, there will always be a certain proportion between the weight supported at the apex of the catenary and that supported by it at each of its suspending points, its form also being so calculated as to prevent any change in this proportion.

Each river pier is formed of two concrete columns within cast iron cylinders, placed 53 ft. 6 in. apart from centre to centre, as shown on page 180. At the base the cylinders are 21 ft. diameter, 4 ft. 6 in. deep, and $1\frac{1}{4}$ in. thick. Above the reducing conical pieces A the cylinder is 15 ft. diameter, made in lengths of 6 ft., $1\frac{1}{8}$ in. thick. As the iron cylinders have no permanent load upon them, no exact bearing is required in the joints, which are therefore not faced. A joint, formed of hemp wrapped on hoop iron, was found sufficient to compensate for irregu-



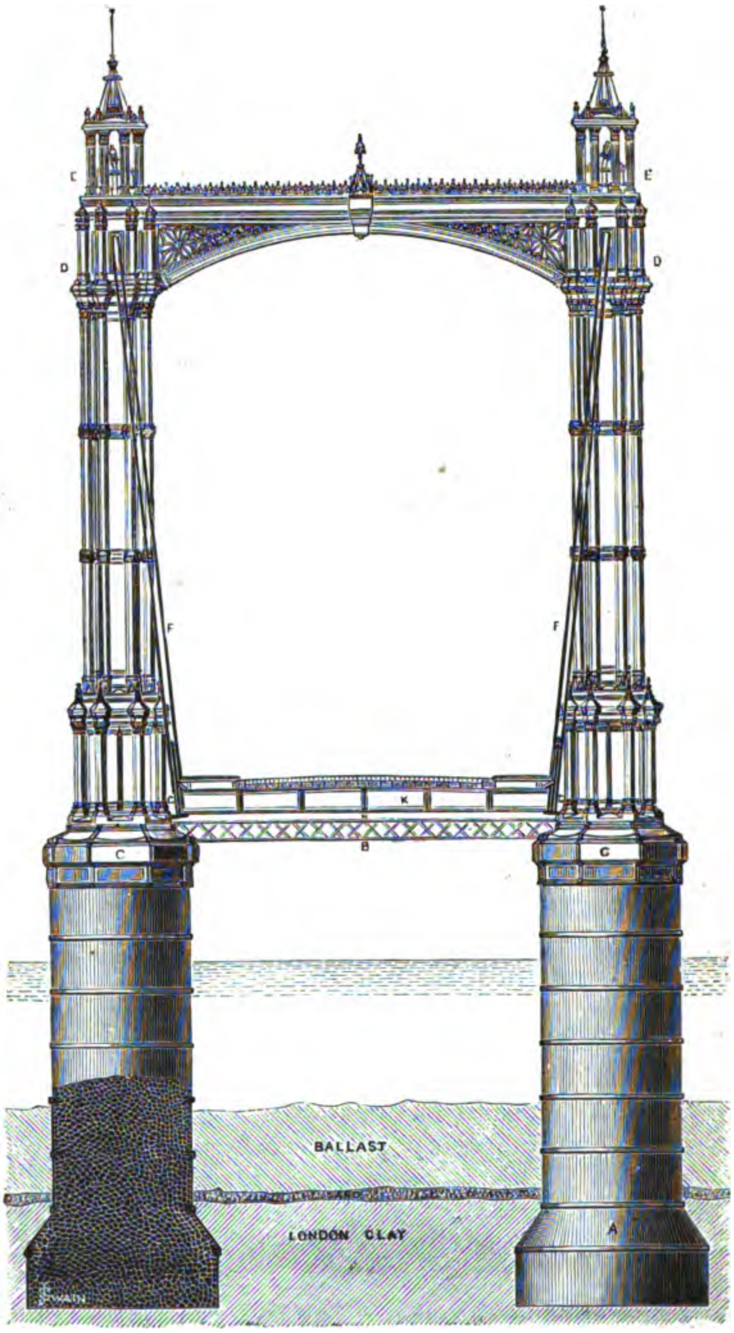
EXAMPLE NO. 31. ALBERT BRIDGE, OVER THE THAMES AT CHELSEA, LONDON.

larities in the castings, and to keep out the water during the process of sinking. The cylinders were forced down by dead weight through 8 ft. of gravel and 1 ft. of sand into the London clay, the excavation being carried on within the cylinders as they sank. The clay, when pierced to a depth of 10 ft., was found sufficiently hard for a foundation, and upon this stratum the concrete was deposited. The concrete is made of shingle, sand, and Portland cement, and at the base of the column the cement forms one-third of the mixture, the proportion being reduced with successive layers of concrete to 1 in 7 at the top. Within a week of the columns being completed the concrete became as hard as stone, affording ample strength for the load of about 7 tons per square foot which comes upon it. The two columns forming each pier are united and stayed by the lattice girder B.

Upon each concrete column an octagonal base plate, C, 11 ft. 6 in. diameter, 2 ft. 2 in. deep, and weighing 10 tons, is placed, the upper surface of the base plate being faced in the lathe to receive the superstructure of the towers. The towers are made entirely of cast iron, successive tiers of columns being united at intervals by large octagonal castings. The castings DD are constructed as saddle plates for the main chains, and smaller saddles EE above receive the catenary wire rope. The height from the bottom of the cylinders to the top of the concrete columns is 50 ft., and from thence to the upper saddle 70 ft. 6 in.

The platform is composed of two lines of plate girders GG, 7 ft. 6 in. deep, with bottom flanges 16 in. wide, and top flanges 9 in. wide. At intervals of 8 ft., cross girders K, 2 ft. 6 in. deep, are riveted to the main girders and stiffened by longitudinal girders or distance-pieces H. The roadway is formed of fir blocks, 4 in. deep, bedded on asphalte, laid on longitudinal fir planks, 7 in. deep.

A staging, supported by piles and forming a temporary bridge across the river, was constructed, and upon this the main girders were erected about 12 in. above their ultimate level. The entire iron platform was riveted together and the permanent roadway completed before the chains from the towers were connected, and this having been done, the bridge was lowered to its proper level and the staging removed. The



EXAMPLE NO. 31. DETAILS OF ALBERT BRIDGE.

inclined chains and the catenary wire rope were erected on a light pole scaffold.

The inclined chains FF which support the main girders, as shown on page 180, are flat wrought iron bars, 10 in. by 2 in. and 6 in. by 1 in., with ends generally similar to that shown on page 70, but of oval shape. The catenary is made of steel wire rope, 6 in. diameter, composed of parallel wires, 0·186 in. diameter, clipped at intervals of about 7 ft.

It will be seen from the cross section of the bridge on page 180 that the plane in which the chains lie is inclined, and that the web of the main girder lies in the same inclined plane. By this arrangement the entire width of the platform is kept within the opening of the towers, and the roadway is not contracted at the towers, as is the case where the attachment of the chains to the platform is perpendicular to the saddle.

The anchorage for the chains and the catenary is formed in a peculiar manner within an iron structure, and is perfectly independent of the great mass of masonry generally employed. It consists of a cast iron cylinder, 20 ft. 6 in. deep and 3 ft. internal diameter, enlarged at the bottom into a chamber, 5 ft. diameter, for anchoring the chains. The cylinder is water-tight and is provided with a man-hole and steps, so that the anchorage can be examined at any time, and cleaned and painted when necessary. This cylinder is set vertically in a surrounding bed of concrete, the bottom being 26 ft. below the roadway level, From this proceeds a vertical anchorage chain, connected to the end of the main girder, to which is also connected the principal back chain and the wire cable. The horizontal strain is thus taken through the main girders and the vertical lift by the mass of concrete in which the cylinder is imbedded, and which is about one-tenth the quantity required in ordinary anchorages.

The bridge is calculated to carry, with a strain of 5 tons per square inch on the chains and 9 tons on the steel wire, a moving load of 70 lbs. per square foot. The headway for vessels below the platform varies from 21 ft. to 38 ft., according to the tide.

The weight of ironwork in the bridge is as follows:—

Cast iron in piers 274 tons,	costing about	£12 per ton.
Ditto in towers, anchorage, toll houses, &c., 547 tons	"	£13 10s. "

Wrought iron in main girders,
472 tons ... ... costing about £20 per ton.
Ditto in platform, inclined chains,
and suspending rods, 147 tons „ £22 „
Steel wire ropes, 56 tons ... „ £50 „
Timber in roadway, 25,000 cubic feet.

The expense of erecting a bridge of this sort would depend chiefly on the depth of the river and the value of the timber at the site. From £2 to £2 10s. per ton, exclusive of staging, and from £1 to £1 10s. for the use and waste of timber, are approximate prices. The cost of concrete, abutments, approaches, and decoration must also be added.

Example No. 32.—The engraving on page 183 shows a floating bridge over the river Hooghly at Calcutta, designed by Mr. Bradford Leslie. The width of the river between the abutment sis 1,528 ft., and a carriage road, 48 ft. wide, with an overhanging footpath on each side of 6 ft., is carried the whole distance on floating pontoons. The roadway is wide enough for six carriages abreast, and in calculating the strength of the platform and the displacement of the pontoons, a maximum moving load of 4 tons per lineal foot is provided for. This assumed load is enough to allow a railway train (without locomotives) to pass over the bridge, in addition to ordinary traffic.

The pontoons are of iron, 160 ft. long, 10 ft. wide, and 8 ft. to 11 ft. deep, with a square section rounded off at the bilge. The pontoons are alike at either end, the bow and stern tapering off (1 in 4) to a point, so as to present as small an obstruction as possible to the stream. Each pontoon will sustain, besides its own weight, 38½ tons for every foot above the bilge it sinks in the water. It is of course important in a floating bridge that the weight of the superstructure and the moving load shall be accurately calculated and maintained. In the Hooghly bridge, the ordinary pontoons sink about 3 ft. 6 in. with the weight of the superstructure only, and this is increased by about 2 ft. during a time of busy traffic.

The engraving on page 183 shows only one-half of the bridge, the arrangement on each side of the dotted centre line being the same. The pontoons are braced together in pairs,

FIG. 1. CROSS SECTION OF RIVER.

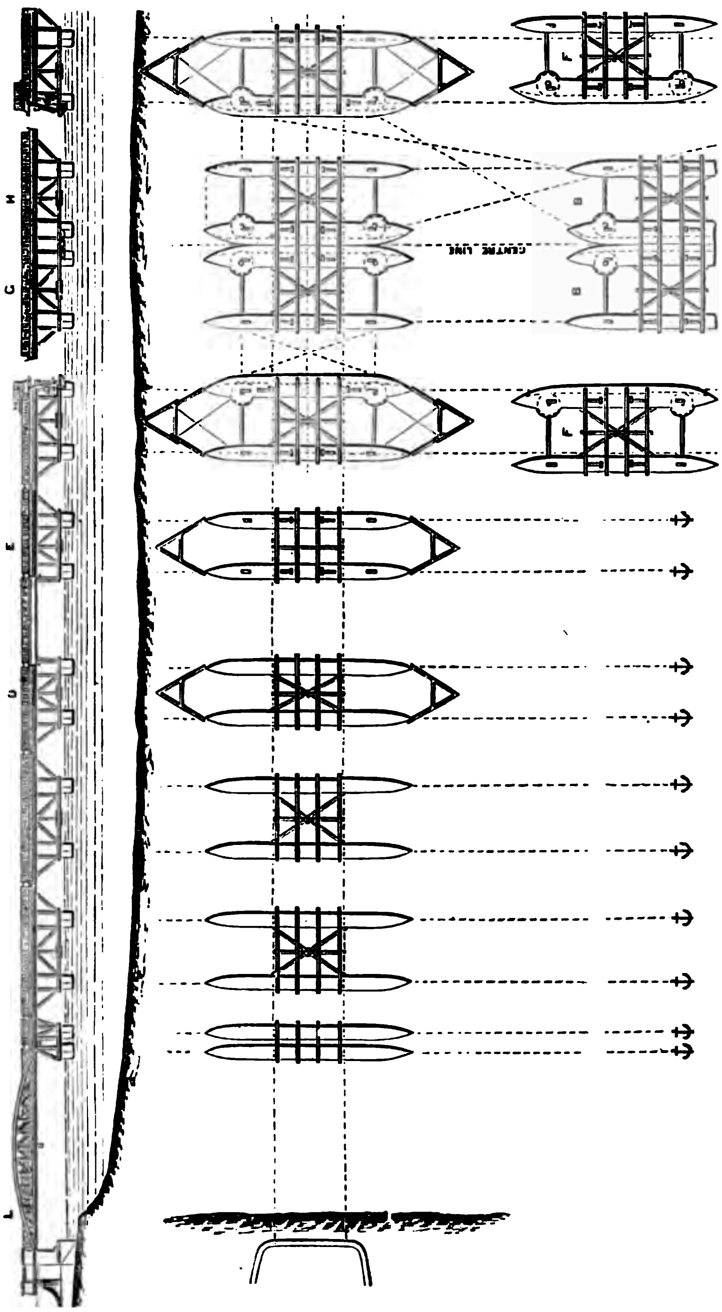


FIG. 2. PLAN.

EXAMPLE NO. 32. FLOATING BRIDGE OVER THE HOOGHLY, AT CALCUTTA.

those at the centre sections being also connected by the sponsons for carrying the moving machinery, and fenders are placed to protect the pontoons from passing vessels.

Each pontoon is anchored fore and aft by ordinary two-fluked anchors sunk into the river bed—here clay and alluvium—and moored by cables of 75 fathoms, the anchors weighing 30 cwt. and 40 cwt., and the cables being of 1¾ in. and 2 in. chain. At the lowest tides the depth of the river at the site of the bridge averages about 33 ft., and the greatest depth is 40 ft. At spring tides the depth is increased by 18 ft.

The superstructure of the bridge is raised to allow headway for the passage of boats, and is supported as follows:—Upon each ordinary pair of pontoons are erected timber framings or trusses, with upper or horizontal members of wrought iron, to carry the platform. The framing is not the same at all the sections, as the opening spans are specially contrived; but the general arrangement is seen in Fig. 2.

The shore sections at either side of the river are 180 ft. long, with a clear opening of 140 ft., the platform being carried on bowstring lattice girders 16 ft. high, two outer and one centre girder, placed 26 ft. apart, making up the total width of roadway. The 60 ft. openings are spanned by plate girders. The flooring of the bridge is composed of 2½ in. timber, with 1½ in. wearing planks. As there is necessarily considerable undulation caused by the tides, the wind, and the variations in the moving load, the spans are connected together by hinged joints.

Provision is made for the passage of vessels under and through the bridge as follows: At each shore span there is a clear opening of 140 ft., with a headway of 18 ft. Between D and E there is an opening of 60 ft., with a headway of 22 ft. when the bridge is loaded. The entire spans G and H are movable, so as to leave a clear opening 200 ft. wide for the passage of large steamers or ships, the opening being effected by warping the pontoons into the positions shown at BB in Fig. 2, then disconnecting them from each other, and allowing the tide to drift them apart into the positions FF.

The hinged platform which connects the bridge to the shore has a gradient, up or down according to the tide, not exceeding 1 in 20.

The weight of ironwork and the quantity of timber in the bridge may be approximately divided as follows:—

28 Pontoons	1,500 tons	£20	per ton.
* 6 Bowstring girders	380 ,,	£20	,,
* Remaining superstructure, including handrailing	500 ,,	£19 10s.	,,
Adjusting gear; drawbridge machinery; miscellaneous ironwork	300 ,,	£40	,,
Chains, anchors, and buoys	330 ,,	£25	,,

Timber in trusses, 19,000 cubic feet.
Ditto in platform 53,000 ,,
Sponsons and wearing planks for roadway in addition.

* In the case of this bridge, only the ironwork marked (*) was made by A. Handyside & Co.

CHAPTER XVII.

LANDING-PIERS AND JETTIES.

THE various systems of construction, the arrangement of details, and the methods of erection, described in the preceding chapters on bridges, apply also to piers, which are properly classed amongst bridge structures. Piers and jetties are used as promenades, for landing and embarking passengers, and for loading and unloading ships.

As, in the great majority of cases, the spans are of moderate size and the loads not excessive, the individual supports are not required to be of great strength. Hence it is that columns and screw piles of small diameter are used more frequently than in bridges. For piers, however, at which vessels are loaded and discharged, on which strong cranes have to be fixed, or railway wagons and locomotives carried, and especially when also it is desirable to have the supports few and far between, large cylinders, columns, or groups of piles are used for the foundations in the same way as has been described under the head of Bridges.

As it is seldom necessary to leave a clear passage for vessels to pass under the roadway, as in a bridge, the supporting piers can not only be placed near together, but strong horizontal and diagonal bracing may occupy the intervening spaces. In exposed situations the real security of the structure depends less on the resistance offered to the waves than on the unrestricted passage left for their movements—that is to say, while a strong wall of unbroken surface could not resist the enormous force of the water, an open network will allow it to pass harmlessly through. Where it is required that the pier shall act as a breakwater, a much stronger structure is needed, and heavy stonework should be placed behind and between the ironwork, to which, if necessary, a smooth surface of iron plates can be attached, to take the first shock of the waves.

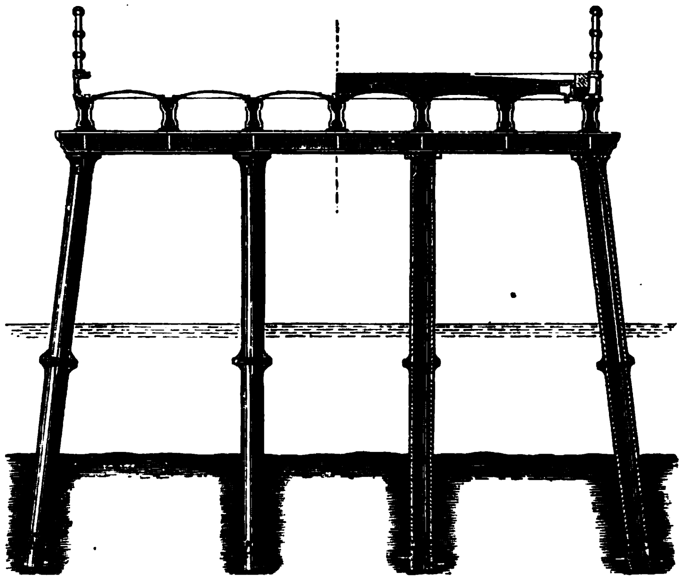
The form of superstructure for a pier depends mainly on the distance between the supports. In ordinary cases a span of from 20 to 40 feet is most convenient, and plate or lattice girders sustain the platform between the columns, the number of girders in each span being regulated by the width of roadway required. Sometimes much longer spans are adopted, and stronger girders are required; these can then be made either parallel or with a flat curve springing from the piers near the water line, or arches of other forms can be employed. Details identical with those of a bridge are then involved, and there may be sufficient head-room for the passage of vessels below.

The flooring may be formed of iron plates attached to longitudinal or cross girders and covered with ballast, or of timber caulked like a ship's deck. It is usual to make the pier-head of greater width than the roadway, and to arrange staircases and landing-floors for the different levels of the tide.

The enlarged head of Margate jetty, constructed by A. Handyside & Co. in 1876, is hexagonal, so as to allow steamers to lie alongside that face of the hexagon which best suits the wind and tide.

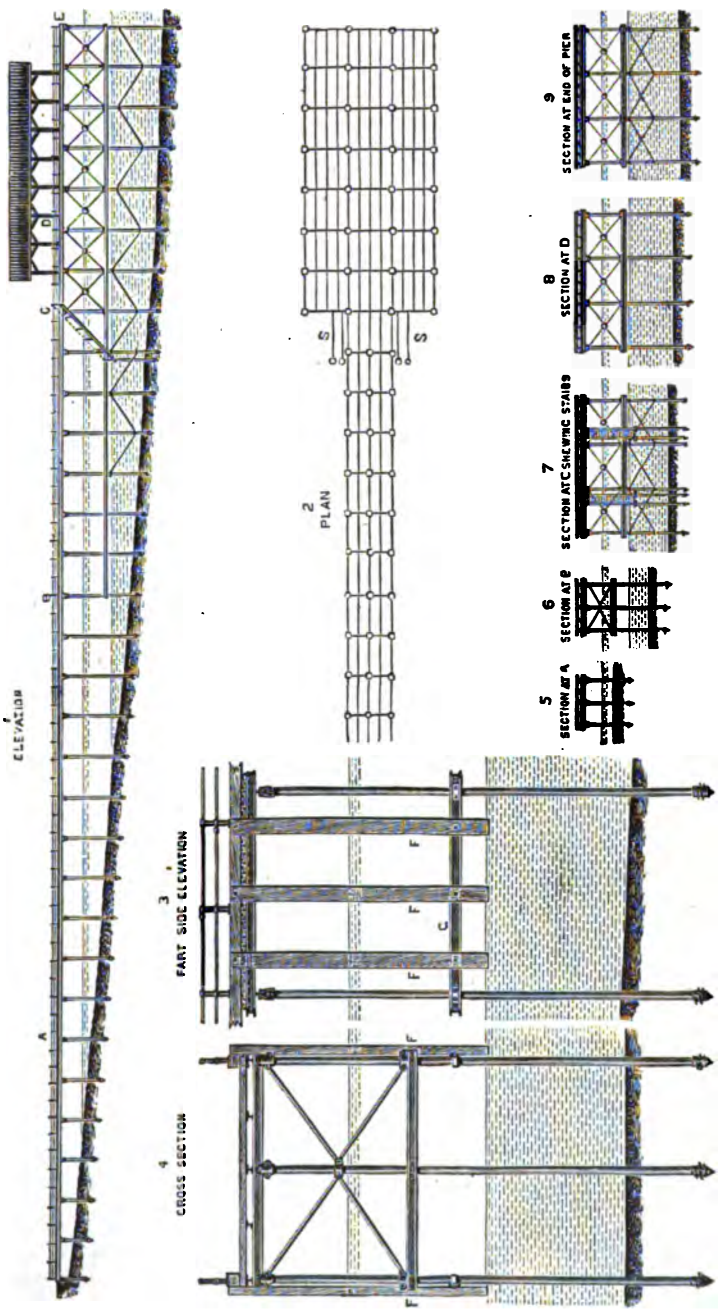
EXAMPLES OF LANDING PIERS.

Example No. 33.—The Mazagon Pier, Bombay, designed by Mr. J. A. M'Connochie, is 336 ft. long and 30 ft. wide, and forms a continuation of a stone pier previously erected. The length is divided into nine bays of 34 ft., at each of which intervals four cast iron columns, 16 in. diameter, are placed, the lower ends forming screw piles, which are screwed down to depths of from 8 to 12 ft. into the bed of the sea. The screw ends fit inside the columns as into a socket, and are attached by rivets inserted from within, with countersunk heads outside, so as to leave a smooth surface. The columns are stiff enough to require no bracing. Resting upon the columns, and uniting them together, are heavy capsills of cast iron, 30 ft. long, forming the breadth of the pier, and carrying the longitudinal girders. The roadway in each bay is sustained by seven of these girders, which are of wrought iron, having a single web 2 ft. deep. Upon the outer girders, and in a line with them, panelled fascia plates, 16 in. deep, of cast iron, are fixed, increasing the apparent depth of the girders to 3 ft. 4 in. The roadway is formed of square "buckled" plates riveted to the girders and stiffened at each seam by strong T irons, and upon these plates the ballast for the road is placed. A simple railing, with strong wrought iron standards, is fixed to the longitudinal fascia plate. The pier is widened out in the last two bays to 60 ft., and iron sheds for protecting goods are erected. Cranes for unloading vessels are fixed under the overhanging eaves of the sheds.

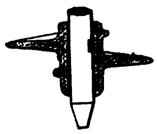


The engraving shows a cross section of the pier. The total weight of the structure, exclusive of the sheds, is 200 tons of cast iron, costing about £12 5s. per ton, and 250 tons of wrought iron, costing about £19 10s. per ton.

Example No. 34.—A landing pier or jetty designed by Mr. B. Keeney, for Punta Arenas, the Pacific port of Costa Rica, Central America. The pier is 434 ft. long, with a width of 15 ft. for the 336 ft. next the shore, and 45 ft. for the remaining part. The bed of the sea slopes considerably, so that while the columns or piles are only 9 ft. long at the shore end, they are 40 ft. long at the sea end. The construction of the pier is extremely simple, and allows considerable repetition in the parts. The columns are all screw piles of solid wrought iron, 5 in. diameter for 140 ft. from the sea end, and 4 in. diameter for the remainder. The screws are of cast iron, 2 ft. 3 in. diameter,



EXAMPLE NO. 34. LANDING PIER AT PUNTA ARENAS, COSTA RICA.



as shown in the engraving, and are so arranged, that they can slip freely on the pile when not held by the key or cottar. This method allows of the removal of the screw in those cases where rocks occur in the sea-bed (which is generally of firm sand), the end of the pile being then merely inserted a few inches in the rock. For the first seven spans from the shore no bracing is required, but for the remaining spans the three columns forming each pier are braced as shown in Figs. 6 to 9, and for the eleven outer spans the columns are braced longitudinally also, as shown in Fig. 1. In the bracing, the tie rods are round, and the struts are rolled joists. At that portion of the pier where vessels lie alongside, vertical timber fenders are fixed to horizontal iron joists, as shown in Figs. 3 and 4. Each of the piles was shipped in a single piece, it being just possible to insert the longer piles of 40 ft. through the hatchways of a vessel of 600 tons register.

The total weight of the pier is 159 tons, costing about £19 10s. per ton, including railing, staircase, and roof.

END OF PART I.

PART II.—ROOFS AND BUILDINGS.

CHAPTER XVIII.

IRON ROOFS AND BUILDINGS. INFORMATION NECESSARY TO THE DESIGN.

THE particulars given in Chapter I. concerning the qualities and prices of iron, together with the succeeding chapters on cast and wrought iron girders, apply to iron structures generally, and may serve as an introduction to iron roofs and buildings as well as to bridges.

The use of iron for buildings and roofs has so many and different advantages, that the demand for structures entirely or partially of this material continually increases. Economy, lightness, portability, facility of erection, are reasons for the use of iron in all countries; but in those where ordinary building materials are scarce, and skilled labour expensive, the fact that complete structures can be imported from countries where iron is abundant is of special importance. Continual improvements are being made in the right application of iron, and these react upon and assist each other. The rapid development of blast-furnaces, rolling mills, and iron-foundries in Great Britain has rendered available for building purposes innumerable new forms, kinds, and qualities of iron, and there are now engineers who, having an intimate knowledge of the materials at their command, make structural ironwork a special study.

Moreover, by the introduction of cast and wrought iron into the number of important building materials, entirely new styles and forms of building have arisen, most notable amongst which are the large iron-glass palaces of modern times.

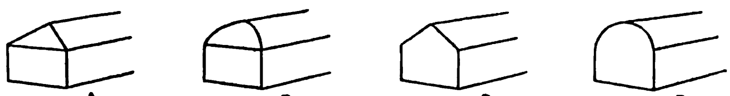
As an introduction to a more detailed description of iron roofs and buildings, a summary of the points to be considered by the designer may be gathered from the following description of the information needed in the case of a building to be designed and manufactured in England from particulars sent from a foreign country. On the completeness of this information depend very largely the cost of the structure, and its suitability for the purpose required. The remarks on page 21, with regard to Bridges, may be referred to as explaining the importance of this more fully. The information required is as follows :—

1. The plan and the height of the building. (In some cases the height is left an open question to be decided by the designer.)

2. The purpose for which the building is intended. Beyond a width of about 40 ft., the question arises whether the roof shall be made in one or more spans, and as the cost may in some cases be considerably diminished by having the roof supported at intervals between the walls, so reducing the width of any one span, it is necessary to know if intermediate columns or walls, so placed, will prove an obstruction.

3. It should be stated whether the iron roof is to be supported on iron columns or on brickwork. If on walls, their strength should be given, so that it may be known whether they will allow of a design (such as an arched roof) involving horizontal thrust.

4. It must be known whether the building is to be open at the sides and ends, or to be enclosed, and if the latter, whether by walls, or by iron screens, or glass.



5. As it is sometimes cheaper and better to a make roof hipped (A or B) than gabled (C or D), any reason or preference for or against either plan should be given.

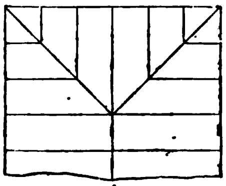
6. The nature of the climate should be stated with reference to the following points: The ventilating arrangements which may be needed; the kind of roof covering most suitable; the strength of the roof for resisting heavy winds or hurricanes; the nature and amount of light required; the gutters and rain pipes

necessary. Any local drains to which the rain-water must be conveyed should be indicated, so that the vertical pipes or water columns may be arranged accordingly.

7. The designer should be informed whether the structure is to have any ornamental character, or whether cheapness is the primary consideration.

8. Local information, as suggested on page 24 with regard to Bridges.

It may be stated as a general rule, that iron roofs and buildings should have their parts equally divided. A hipped roof should consist of regular squares, in accordance with which the columns, principals, and purlines can be arranged. Facilities for repetition and the economical disposition of material are afforded by making the divisions of the sides and ends corresponding. Thus a plan arranged as at A, with the side and end spaces all equal, is better than an irregularly shaped plan.



A

Where an irregular plot of ground has to be covered, it is better to confine the irregularity to as few points as possible, and to let the greater part of the structure be composed of rectangular or other uniform figures, than to provide for the irregularities by altering the dimensions of parts gradually throughout the whole building.

In the following pages, various kinds of roofs are classified, different materials for roof-covering described, and the modes of erection in place explained. The examples that then follow, illustrate the different systems, and give the cost of some roofs and buildings that have been actually made and erected.

CHAPTER XIX.

CLASSIFICATION OF ROOFS. TRUSSED ROOFS. ARCHED ROOFS.

CLASSIFICATION OF ROOFS.

THE endless variety of roof structures—as great as in the case of bridges—renders a precise division into classes difficult; and it is only possible to specify those broad distinctions by which, without question, one kind of roofs may be separated from another.

The chief characteristic in a roof is its "principal," a generic term, which amongst engineers includes every kind of main rib or truss, whatever be its peculiarities. A primary distinction can at once be made into two classes, which will comprise all roof structures—namely, Class A, in which the pressure of the principal upon its supports is in a vertical direction only, and Class B, in which the pressure is at an angle outwards with the vertical. In this latter case the expression is generally used that "the roof has a horizontal thrust." A roof of Class B has in reality an angular thrust, the vertical component of which is directly sustained by the point of support, while its horizontal component is still free, and has to be met by special arrangements, sometimes offering considerable difficulty. Accordingly, principals of Class A., *i.e.* those without a horizontal thrust, are *complete* in themselves or self-contained; and principals of Class B, *i.e.* those with a horizontal thrust, are *incomplete*, and their stability depends on that of the abutments. To these, however, must be added a third class, C, of principals which, taken separately, have a horizontal thrust, but which, by being arranged upon a circular, elliptical, or polygonal base, and inclined towards a common centre, can be made dependent upon each other and independent of abutments, by connecting them at their springing by a tie, which, as it joins all the principals at their springing, is in plan a polygon. Such roofs are called domed or curb roofs.

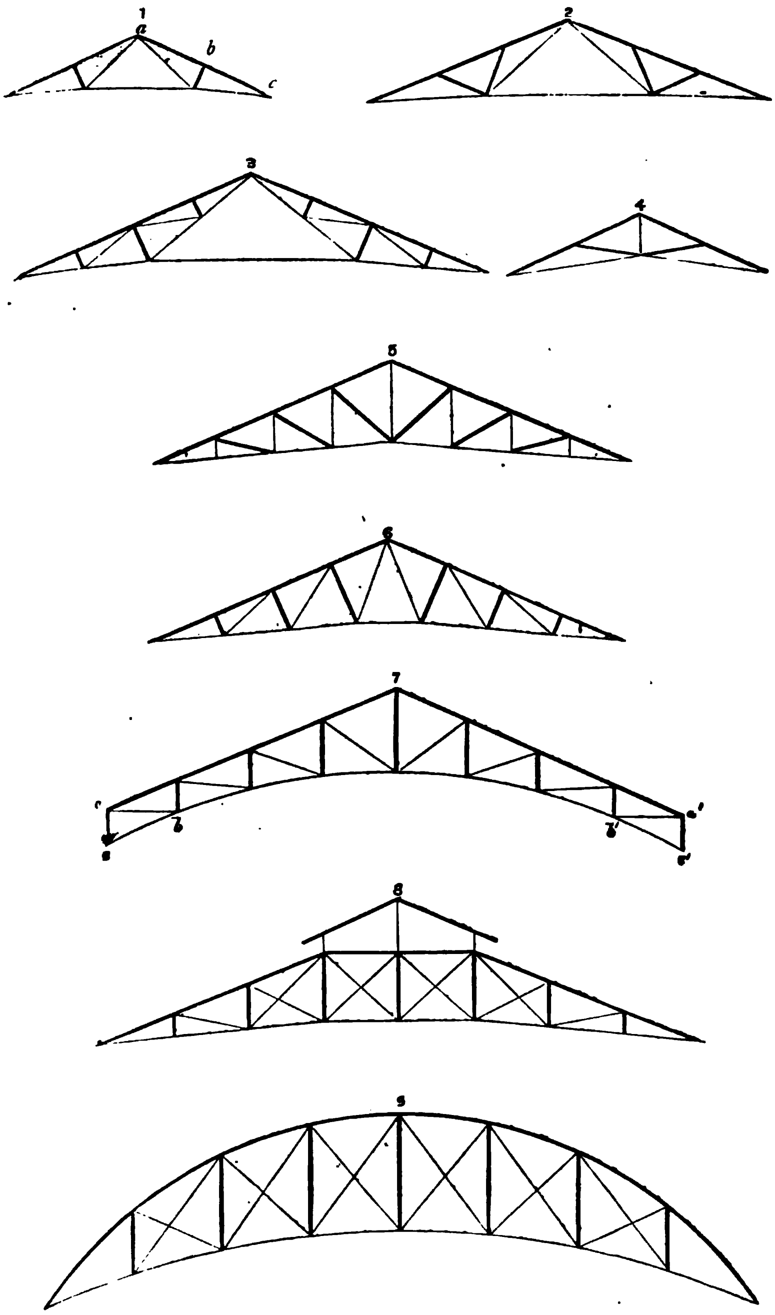
TRUSSED ROOFS.

All principals belonging to Class A are essentially girders or trusses, *i.e.* they consist of a top member which is in compression, a bottom member which is in tension, and various struts and ties arranged within the space between the two, to support the top member and the load at intermediate points, and to transmit the strains produced at these points to the end supports. Instead of attempting to divide into classes, according to their characteristic features, the innumerable forms adopted for trussed principals—a task hardly possible when it is considered how one system is mixed with another—a few forms have been selected which, directly or indirectly, will include most of the varieties which exist. The different kinds are shown in the engraving on page 196, and in each case the thick lines represent compressive members, and the thin lines members exposed to tension.

No. 1 is of the simplest kind, and is equally serviceable for large or small spans. The short struts are often made of cast iron, and, owing to their moderate length, this material can be safely and economically applied without excessive weight. The connections are symmetrical, and have a natural, unconstrained appearance. For the larger spans, *i.e.* those over 40 feet, it becomes necessary to construct the two upper members or rafters as girders to resist considerable transverse strains, because in a roof of such a size there must be purlines between the points *a b*, and *b c*. Roofs with this kind of principal are sometimes called French roofs. No. 2 is of the same kind as No. 1, but with the strut so placed as to support the rafter in two points. No. 3 is also of the same kind as No. 1, but with longer rafters doubly trussed.

The three forms just described are marked by the absence of vertical members, and for this reason the system is not a convenient one for hipped roofs and for those roofs also where a longitudinal bracing between the principals is required in a vertical plane.

No. 4 may be considered as the elementary form of a class in which vertical members are introduced, and in which the struts are not perpendicular to the rafter which they support. The same system is carried out in No. 5, where each rafter is sup-



TRUSSED ROOF PRINCIPALS.

ported at three points. This kind of truss is most commonly used for hipped roofs in which a vertical member is required at the junction of the hipped part. It is applied to spans up to 60 feet. No. 6 resembles 1, 2, and 3, in having the struts perpendicular to the rafters and in having no verticals; but in the general arrangement of the parts, and of the connections, it resembles No. 5.

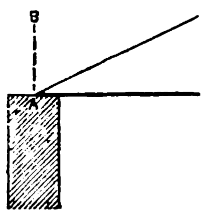
No. 7, which may be said to originate from Nos. 4 and 5, can also be made according to systems 1 or 4. The advantages which this form of truss affords are, the curved shape of the tie and the favourable or large angle of the tie at its start, which is at *a*. The parts *a c* and *c b* do not actually form part of the truss, which is complete without them, *i.e.* between *a b*, *b b'*, *b' a'*, but they are useful as forming bracing with the columns or walls, thus rendering the complete structure of a building more rigid and self-contained than with any of the roof forms 1 to 6. Roof Examples Nos. 48 and 55 give instances of this; and a roof of the same shape, but with the members differently constructed, is described in Example No. 50.

The designation of roof trusses is applied to forms 1 to 8, the term girder being seldom used, although there is no important difference between trusses of this kind and girders. No. 8 is sometimes used when the roof-covering must be interrupted to admit of ventilation. In its construction it resembles even more than do the preceding forms an ordinary girder, and there is nothing special to remark in it. No. 9, which, from its shape, may be called a sickle girder,* has lost almost all traces of a roof truss, and in detail is constructed very much like a bowstring girder with a top member to resist compression, and the bottom member a simple tie. The space between the two members is occupied by bracing, which—as is characteristic of bowstring girders—is of a light nature, and may be either as shown in the engraving, or according to the Warren system (see page 62 and Roof Example No. 58), if there are no hipped ends to render verticals convenient. In all trussed roofs the divisions of the rafter, and the distance apart of the struts, must be arranged to suit the kind of roof covering which is adopted. (See pages 210 to 220.)

Although no reference has been made to the methods used

* In German it is called "Sichel Träger."

for calculating strains on iron structures—all questions based on mathematical formulæ having throughout this book been purposely omitted—there are certain practical considerations in connection with the strains on roof trusses which may here be mentioned. All trusses are composed of triangles, one side of which always forms part of either the top or bottom member, while the two other sides are either diagonal struts or ties. At the springing or point where the truss is supported, the top and bottom member meet at a certain angle. This angle determines the greatest strain in the truss, and it is to it therefore that the attention of the designer is specially directed. But there are other questions which affect and are affected by the choice of this angle, and which also demand special consideration. The



inclination of the roof-covering as considered with reference to wind and rain, the position of the bottom member with reference to the head-room it allows in the centre of the building, the lengths of the diagonal members, the area to be occupied by the entire truss, and in fact almost all points of importance in the roof are, to a large extent, determined by the angle, and by its position in regard to the vertical line *A B*.

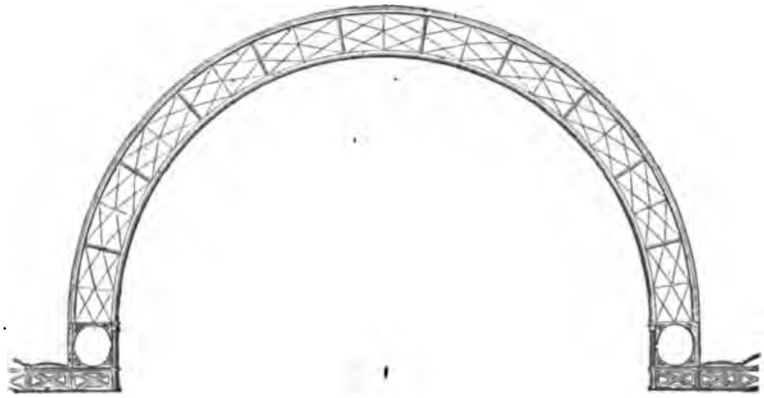
Now, while all these latter questions receive due attention, the first circumstance, *i.e.* the strain resulting from the angle, is sometimes ignored, or sacrificed to the more obvious considerations of convenience. It is evident that a large angle allows favourable or low strains on the top and bottom members of the truss, but at the same time this large angle involves a greater length than would otherwise be the case in the diagonal and vertical members, a high-pitched roof, encroachment on the head-room, and other disadvantages. This will be seen by glancing at some of the sketches on page 196. But while the skill of the designer is taxed to arrive at the best resolution of the different necessities of the case, at any rate he should be aware also of the sacrifice he makes by adopting a very acute angle at the springing point. In all roofs of the kinds 1 to 6 and 8, it is unavoidable that the depth of the truss should increase rapidly towards the centre, more rapidly than the effect of the load increases, and consequently the strains diminish greatly towards the centre. In small roofs this decrease in the strains is met by a varying reduction in the area of the tie; while, for the sake of appearance and convenience, the top member is made of the maximum strength along its whole length. But in large trusses the proper arrangement to meet all the various points which have been described is often inconvenient and difficult, as either the angle *A*, or the height of the truss, becomes almost impracticable. It is here, then, that such trusses as 7 and 9, and sometimes also 8, are applicable, because with them an angle of considerable magnitude may be combined with a moderate depth in the centre of the truss.

ARCHED ROOFS.

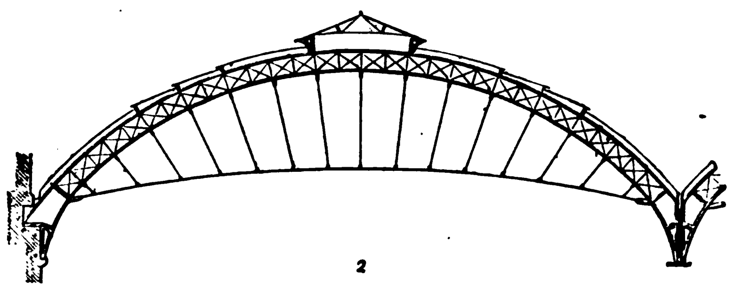
Roof principals having a horizontal thrust (distinguished on page 194 as Class B), must in their construction have such stability at the springing point as will offer to this thrust the necessary resistance. The abutments for arched principals can be obtained in various ways. The most natural method might at first sight appear to be in making the walls on which the arch rests sufficiently strong. In almost all cases, however, this is too expensive, and when it is adopted the wall is only thickened at the points where the principals rest, the part thus thickened forming a buttress or abutment. But for all except very small spans, and in walls of any but moderate height, the abutment would have to extend back a considerable distance to give the necessary width of base; and out of this necessity arises the "flying buttress," which may chiefly be seen in cathedrals and churches having arched roofs of wood or stone. The space thus occupied by the buttress can be, and often is in such edifices, utilised as an aisle within the building itself.

When an arched roof is supported by columns, the latter are frequently placed in pairs with bracing between (Example No. 59), or are strutted by side buildings (Example No. 55*a*). Sometimes in the side building the *roof* (see Example No. 53), and in other cases the *girders* (see Example No. 59), carrying an upper floor or gallery, give the stability which is necessary to the columns for resisting the thrust of the arch. In any case, there must be a continuity of strain from the arch to the ground. Roof example No. 51 shows an arched roof on brick piers with buttresses, and Nos. 56 and 61 structures entirely independent of extraneous support, because the arch is continued to the ground, and is thus in itself complete.

Fig. 1 on this page is taken from the Sydenham Crystal Palace as almost the only example which exists of this form of



roof. Having the shape of an arch with a considerable depth at the crown, it can rest vertically on the supports without abutments, it being, in fact, a girder of a peculiar shape. The depth of the arch at its crown must be considered the depth of the girder in its centre. Fig. 2, which shows the roof principal of the Victoria Station (L. C. & D. Ry.), London,* is properly neither an arch, a truss, nor a girder, but is a tied arch, so called



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because the upper part is in no way different from an arch, the tie acting instead of abutments. If, as in the sketch, the tie is curved, an extra strain determined by the curvature of the tie is applied to the arch. The curvature of the tie, and the tension in the rods which keep it in position, do not however in any way contribute

* Humber's Record of Modern Engineering. London, 1863.

to the bracing of the structure against an unequal load, and this bracing must be effected by the proper construction of the arch itself. (See Example No. 60.)

In the construction of wrought iron arched roof principals, the rules by which stone arches are designed need not be adhered to. A stone arch must be of sufficient thickness to enclose within itself all possible lines of pressure resulting from various loads, because it is assumed that the voussoirs of an arch cannot well resist a transverse strain. In an iron arch, however, a material so specially suited to resist transverse strains is employed, that the outline of the arch may be designed without strict regard to the lines of pressure, if these are duly considered in determining the dimensions of the material.

The sections of arched ribs may, like those of girders, be made in many different ways. For small spans a single web plate is generally used, but where the rib is more than 12 inches deep a lattice or trellis system is preferable as affording the necessary strength with a more elegant appearance. It is seldom, except in large roofs, that the flanges have any but a single T section (see page 56); though in all cases the trough or box section (see Example No. 58), is peculiarly suitable for resisting the strains to which a roof is subjected. If the trellis system with vertical struts (see Example No. 59) be adopted, the diagonals need only be ties as in trellis girders; but if a lattice or other triangulated system be used, all the diagonals should be struts, to meet the various lines of pressure to which the arch is exposed. (Examples Nos. 56 and 60.)

An arched roof generally costs more than a trussed roof, if the expense of abutments be included. But if, by the position or arrangement of the building, abutments already exist, or if for other reasons they have to be provided, then an arched roof may be better and cheaper than a trussed roof.

CHAPTER XX.

ROOF FRAMING BETWEEN PRINCIPALS. PARTS OF ROOFS.

ROOF FRAMING BETWEEN PRINCIPALS.

In a roof which is rectangular in plan, the distance apart of the principals should be from 1/8th to 1/4th of the span, and if these limits are overstepped there will be an unprofitable employment of material. The spaces between the principals are divided into rectangles by longitudinal purlines, and the distance at which these purlines are placed from one another depends chiefly on the kind of roof covering which is to be applied. The rectangles thus formed are in many cases again divided by "intermediate rafters," supported by the purlines, and placed parallel to the main rafter or upper member of the principals.

The different covering materials are described in Chapter XXI., and need only be referred to here so far as they determine the arrangement of the framework. The following five varieties may be noticed:—

(*a*) Corrugated iron, fluted parallel with the slope of the roof.

(*b*) Corrugated iron, fluted horizontally.

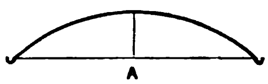
(*c*) Zinc on wooden "rolls." Glass on wood or iron sash bars.

(*d*) Covering on horizontal laths (tiles, slates, lead).

(*e*) Covering on boarding (slate, lead, zinc, felt).

(*f*) Glass, or other covering, on the "ridge and furrow" system.

(*a*) *Corrugated Iron, Fluted Parallel with the Slope of the Roof.*—The framework is always constructed so as to utilise the strength or bearing power of the sheets, which in this case is parallel with the rafters, and the ordinary arrangement is as in Fig. 1, page 204. The sheets rest upon the purlines, and no other supports are required, and the strength of the sheets is altogether so considerable that the purlines may be placed from 8 to 15 ft. apart, depending on the thickness of the iron and on the depth of the flutes. The stiffness and strength given to iron sheets by corrugation allows them to be used as covering for small spans without any ribs or principals, by merely tying the eaves together as at A. A girder or a gutter acting as a

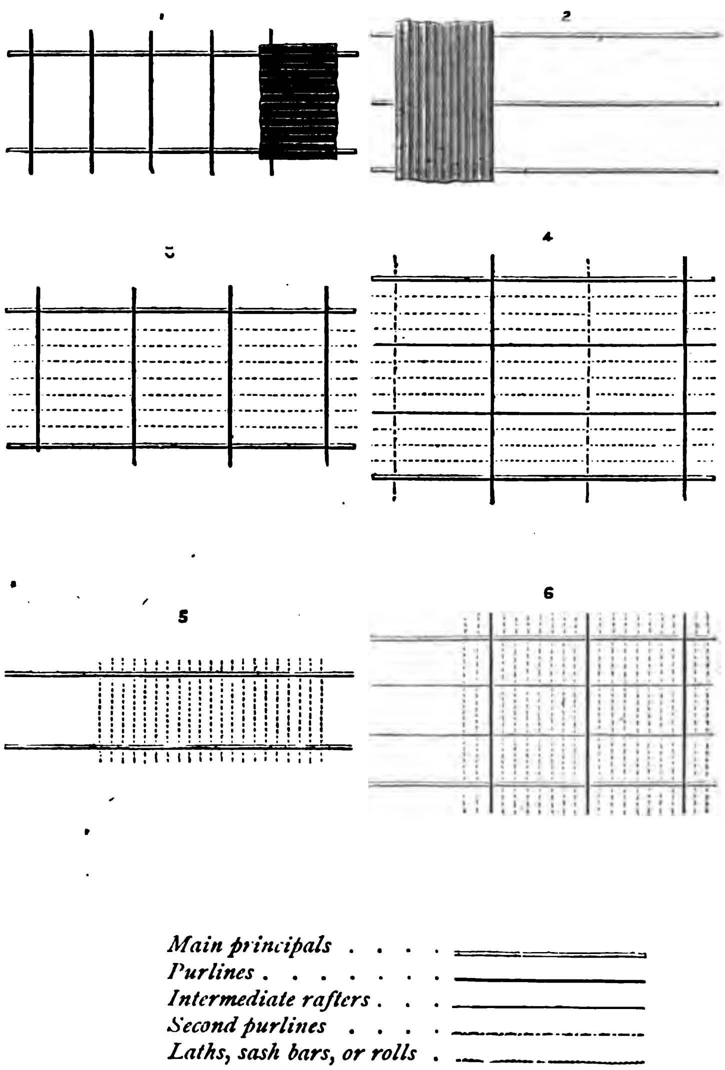


girder, or a longitudinal L iron, must in such cases be attached to the eaves, but no other framing is necessary. Spans as great as 50 ft. have been covered in this way, though, of course, such a roof is neither durable nor strong.

(*b*) *Corrugated Iron Fluted Horizontally.*—(See page 216.) No purlines are required for corrugated iron laid in this way, as the strength of the sheets is at right angles with that of the rafters. But the corrugations of the sheets rendering them so strong horizontally, the supports, *i.e.* the principals, may be at the same distances apart as are the purlines in system *a*. If it is not convenient to place the principals near enough together (Fig. 2), then intermediate rafters must be used, and purlines are necessary to support them.

(*c*) *Zinc on Wooden Rolls. Glass on Wood or Iron Sash Bars.* —With zinc on wooden rolls, according to the Italian system, or with glass on wood or iron sash bars, bearings must be provided at distances of about 7 ft. This limit is not determined by any weakness in the wood rolls or sash bars, for these might be made strong enough to carry more than 7 ft., but indirectly by the limited bearing power of the zinc or glass. The width between the rolls of zinc sheets adopted in this country is 1 ft. 2 in., and glass is seldom laid wider, and the length of 7 ft. gives a rectangle with proportions of 6 to 1, which by experience has been found to be best. This proportion may be modified into 4 to 1, but beyond these limits (as stated with a different ratio, in regard to principals on page 202) the material would not be economically applied. The arrangement, therefore, can be as shown in Fig. 3, with the rolls of sash bars laid upon purlines carried by the roof principals; or as in Fig. 4, where the principals are farther apart, but with intermediate rafters and second as well as main purlines.

(*d*) *Covering on Horizontal Laths* (*Tiles, Slate, Lead*).—The distance apart of the laths depends on the strength and consequent bearing capacity of the tiles or slates, and may be approximately stated as 10 or 12 in. The laths may be sup-

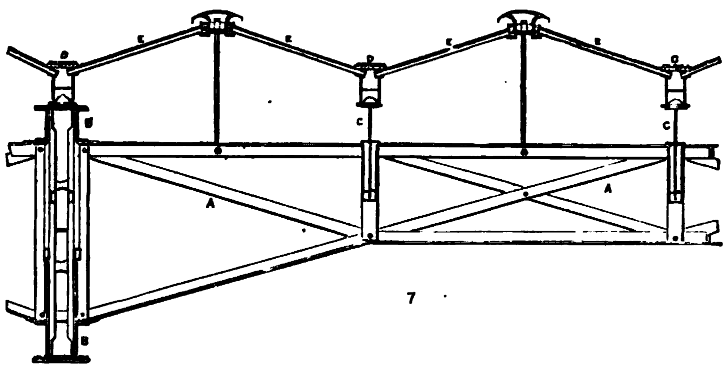


ROOF FRAMING BETWEEN PRINCIPALS.

ported entirely by the principal rafter (Fig. 5); but for any but small spans the principals are generally too far apart to allow the laths to carry their load without intermediate auxiliary supports, and intermediate rafters become necessary (Fig. 6). In this case I shaped rafters are often used, because, without trussing, they may be equally strong at all points to receive a load. Trusses like that shown in Fig. 1, page 196, are often used for slate roofs; because if the rafter can be rendered rigid enough by one strut to carry the equally distributed load, there is no advantage obtained in placing struts at regular intervals, as in the case where purlines have to be supported.

(*e*) *Covering on Boarding* (*Slate, Lead, Zinc, Felt*).—Boarding when used to carry roof covering may be supported by rafters, second purlines, or laths; and if these be not of wood, packings of wood to which the boarding can be nailed down are generally fastened to the ironwork. The boarding is made not more than 1 in. or less than $\frac{5}{8}$ in. in thickness, and is laid on bearings 2 ft. to 4 ft. apart. A framework of this sort therefore resembles that for glass or zinc, the rolls or sash bars for which are represented by larger scantlings, to which the boarding is nailed.

(*f*) *The "Ridge and Furrow" System* of roof covering was introduced, or for the first time made generally known, in the Hyde Park Exhibition building of 1851, and since that time it has been often adopted for railway stations and other buildings. The roof is divided into a series of small roofs, and this plan of



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subdivision allows easy access to the roof for repairs, simplifies the arrangement of gutters and escape of rain-water, and permits in the construction a great repetition of small parts, easily made and fixed. The ridge and furrow are generally made to follow the slope or curve of the roof, and the monotony of a large surface is in this way greatly relieved. In a glass roof the rays of light may by this means be regulated, and on a curved roof the necessity for curved glass is avoided. Fig. 7 shows an example of a ridge and furrow roof with the ridges parallel with the slope, as adopted for the St. Pancras Railway Station, London.* BB is the cross section of an arched rib or principal; AA is a lattice purline; CC are intermediate rafters; EE are the sash bars of the small roofs, the rain-water from which is discharged into the gutters DD. The same principle of ridge and furrow is adopted also in the roofs of the Glasgow and Manchester Railway Stations, erected by A. Handyside and Co. in 1876-7. (See Example No. 61.)

The ridges are sometimes placed at right angles to the slope, but this method is seldom adopted. It is chiefly suitable for a flat roof, or for the upper portion of a curved roof.

In all the systems of framing that have been described, timber may to a large extent be combined with the ironwork; purlines, second rafters, laths, and sash bars being very often made of wood, especially in small roofs, although when a completely fireproof structure is required, the whole is best made of iron.

The necessity for wind-bracing depends on the kind of covering materials which are adopted. Thus, roofs made according to systems *c* and *d* require bracing against wind pressure or other sudden and unequal strains, more than in systems *a, b, e*, where the covering materials by their own continuity act as bracing.

PARTS OF ROOFS.

The economy and fitness of any structure depends as much on the simplicity and symmetry of its parts as on the design; and the remarks on pages 68 to 74, with reference to parts of girders, will, to a considerable extent, apply to roofs also. The practice of engineers differs in regard to the details of their designs, and to some extent this is caused by the facility with

* Mr. W. H. Barlow, Engineer. Minutes of Proceedings of the Institute of Civil Engineers, March, 1870, vol. xxx.

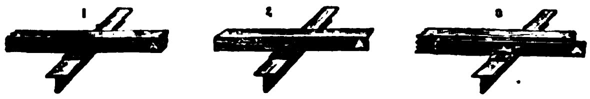
which, in different localities, certain kinds of iron can be procured, or because of preference for certain kinds. Thus, in France or Belgium, where rolled iron joists I (see page 59) are more commonly used, and—as compared with other kinds of iron—more largely made than in England; this form of iron is more frequently than in England employed for the rafters of roof principals. It is not, however, from any scarcity of such iron—which is largely made in England—but the considerations of inconvenience in smithing and making connections (see page 59), which prevent its use in many cases by English engineers.

For trussed roofs, of spans not exceeding 60 feet, the rafters are generally made of T iron, which is a convenient shape for the connections. Above 60 feet, however, where longer and stronger rafters are required, rolled I iron or riveted beams with a plate or lattice web are often employed. As will have been seen from the preceding remarks on the roof-framing between principals, the form of rafter is to some extent determined by whether the roof covering is evenly distributed over the entire length of the rafter—as in the case of a slate roof on laths—or is concentrated at certain points on purlines.

Tension rods are made of flat or round iron, and for small spans generally of the latter. The strength of any tension rod is of course determined by that of its weakest part; and especial care is necessary, both in designing and making the connections, to ensure that the full capacity of the rod itself is transmitted through all its joints and welds.

Although cast iron is most properly used for struts and other parts in compression, it is not advantageous to make long struts of cast iron, if they have to sustain only a small compressive strain; because, for safety in carriage and other secondary reasons, they would have to be made so strong as to involve a waste of metal, which can be avoided in wrought iron. For ordinary principals of the kinds 1 to 6, on page 196, and for spans up to 50 ft., wrought iron struts are made generally of T bars. Their shape is more symmetrical against compressive strains, and is more convenient for connections than L iron. For large roofs, where considerable strains have to be transmitted, struts resembling those of a girder are used, and the sections shown on page 69 are available.

For ordinary roofs of moderate span, where the principals are not far apart, the purlines can be made of wood. Fig. 1 shows a timber purline A, attached to the L cleat on the rafter of a roof principal. Fig. 2 shows an L iron purline A



attached to a rafter in the same way. In Fig. 3 an L iron purline is also shown, but with timber screwed to it to receive a covering such as boarding, which it is convenient to attach by nails or spikes.

Where the principals of a roof are far apart, or where considerable weights have to be sustained by the purlines, the simple kinds just described are not sufficient. In such cases a T bar is sometimes made strong enough by trussing in the manner shown in Figs. 1, 2, and 3, page 65; sometimes I joist iron (see page 58) is used. But in large roofs, and especially where intermediate rafters are employed, the purlines are identical in all respects with girders, and are most generally made of the lattice or trellis kinds. (See pages 60-64.)

Intermediate rafters are generally made to resemble the upper member or rafter of the main principal. Rolled I beams (see Example No. 61) or trussed T bars are also suitable.

In the connections of struts and ties, cast iron shoes are sometimes used, but they should be avoided if any tensile or transverse strains have to be resisted. Malleable cast iron (see page 14), as a tougher material, can be used with advantage for many parts of roofs which are commonly, and not altogether wisely, made of ordinary cast iron.

There is, as a rule, in an iron roof a larger proportion of light pieces and smiths' work than in an iron bridge, and the cost of labour generally in proportion to the cost of material is greater. On the other hand, small and simple sections of bar and L iron are cheaper as material than plates and large sections of T iron (see page 13), such as are more usual in large girders.

Elaborate connections, involving anvil work and welds, are expensive, and multiply the risk of failure; so that it is advantageous both as regards economy and the safety of the structure to make all parts as simple as possible.

Screwed bolts with nuts, when used in roofs, are often placed instead of rivets under shearing strain. In this case their strength should be calculated as under a transverse strain, in which case their diameter is greater than if calculated according to pure shearing. For a tensile strain, on the other hand, it is safest to have bolts instead of rivets, and sometimes, if much depends on their strength, bolts with a nut at each end, so as to avoid the risk of a flaw in the forming of the bolt head. In the main tension rods of a roof, screwed ends at all the points of connection are advantageous; welds are also so avoided, and there is an opportunity for adjustment.

A repetition of parts, which is convenient in all iron structures, is especially so in roofs; and where they have to be put together in a foreign country, the fact that similar parts are interchangeable gives immense facilities for speedy and economical erection on the site. Small differences of dimensions, which though at all times a disadvantage, may be adjusted by skilled workmen, are, abroad, a positive danger; and care in the setting out of templates, precision in workmanship, and proper marking of the ironwork in the factory, are all points which add to the value of the structure. Too often the want of these systematised methods are only discovered when the ironwork arrives at its site, too late for correction.

Undue haste in the manufacture is too often demanded by engineers as well as buyers, and greatly adds to the possibility of errors, as the omission of trying the parts together often renders it impossible to rectify small mistakes, which, when left uncorrected, are the cause of serious delay afterwards. The haste also operates prejudicially in many cases by entailing the employment of inferior workmen.

CHAPTER XXI.

ROOF COVERING. TILES. SLATES. GALVANISED CORRUGATED IRON. ZINC. FELT. LEAD. GLASS.

ROOF COVERING.

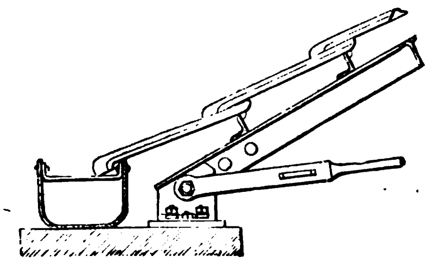
THE materials used for covering roofs differ mainly in the following respects :—*Weight;* this determining to a large extent the strength of the roof framing necessary to sustain them. *Angle* at which they are laid. *Strength* or bearing capability as parts of the roof structure. *Durability,* as shown principally by resistance to rain and atmospheric influences. *Cost.* These points of difference are referred to in detail in the following description.

The measurement, weight, and cost for all kinds of roof covering are stated according to the superficial area occupied, and the unit adopted is the "square" of 100 superficial feet. Thus an area 10 ft. by 10 ft., or any equivalent area, equals one square. The measurement is usually made on the slope of the roof, not on the horizontal area covered.

TILES.

Excepting straw and thatch, tiles have the oldest history as a covering for roofs, and they possess various good qualities. They are cheap, durable, and make a warmer covering than slates. The colour and picturesque effect which their use allows render them still popular among architects, but because of their great weight they have been gradually superseded by slates or zinc. The old-fashioned tiles weighed from 14 to 15 cwt. per square. Pantiles (a lighter and improved form of tile) weigh from 6 to 9 cwt., and cost from 12s. to 20s. per square, according to shape and colour, but exclusive of the cost of laying. Their great weight of course renders a strong roof-framing necessary to support the tiles; but the weight is sometimes considered an advantage in countries where hurricanes occur, as assisting to keep the roof in its place when subject to wind pressure. Tiles are laid or fastened upon wood laths, and may be fixed with or without mortar.

Tiles are very seldom used for iron roofs in England; but in the East and West Indies, South America, and other countries



where roofing materials have to be imported, tiles are largeiy employed, and are often laid directly upon iron roofs without boarding. Tiles are made specially for this purpose, and the engraving shows a peculiar kind made in France. Upon an ordinary T rafter, L iron laths are placed at intervals of 12¾ in., and upon these the tiles are laid. Each tile has a small projecting lip which catches behind the purline, and the weight of the tiles as they overlap keep them in position. But as a precaution against severe wind pressure, each tile can be tied by copper wire to the purline, a small hole being provided on the under side of the tile for the purpose.

The effective width of the tile, exclusive of the lap, is 8 in., and 115 tiles are required per square. Each tile weighs when dry from 5 to 6 lbs., 1,000 tiles weighing about 2¾ tons. As, however, the tiles absorb considerable moisture, 10 per cent. should be added to the weight in calculating the load upon a roof. The tiles cost about £6 5s. per thousand.

SLATES.

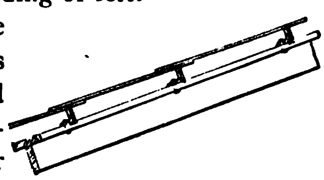
Slates are as durable as tiles with much less weight, and are probably more used in England for roof covering than all other materials put together. Roofing slates vary in size and thickness, and are known commercially as "ladies," "countesses," "duchesses," "queens," "imperials," &c. Imperials (which are now seldom used) have a level sawn edge, the other kinds being merely chipped straight. Slates of large size can be placed on timber battens, and smaller slates on wooden laths, but when so laid they afford little protection against heat or cold; and even when the joints are covered by mortar inside, the wind will often penetrate through the crevices. For these reasons it is best always to lay the slates upon boarding, and, as an additional protection against damp and extreme temperature, to place felt (a non-conductor of heat) between the slates and the wood.

The following is approximately the weight of the different kinds of slating per square:—

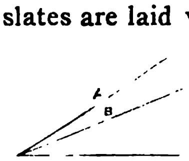
Ladies	16 in. by 8 in. ...	5 cwt. per square.
Countesses ...	20 in. by 10 in. ...	$5\frac{3}{4}$,, ,,
Duchesses ...	24 in. by 12 in. ...	6 ,, ,,
Queens, irregular sizes, about	30 in. by 20 in. ...	8 ,, ,,
Imperials	30 in. by 24 in. ...	10 ,, ,,

The above list is given in the order of expense, the cost in London varying from about £1 5s. per square for the ladies, to £2 for the queens, including copper or zinc nails and the cost of laying, but exclusive of boarding or felt.

In iron roofs the slates can be fixed directly upon L iron laths without the necessity for any wood work, and this plan, which is fire-proof, is often adopted for sheds or warehouses.



It is advantageous to employ heavy slates in exposed situations in preference to the lighter sorts. The angle at which slates are laid varies from 1 in $1\frac{1}{2}$ (A) to 1 in $2\frac{1}{2}$ (B), and if a less inclination is ventured on the most careful workmanship is necessary. Slates are fastened with nails; two to each slate, and iron nails should be avoided as liable to oxidation. For all good work it is usual to specify zinc or copper nails, and for slates on iron laths, lead pegs or copper or zinc clips should be used.



GALVANISED CORRUGATED IRON.

The term " galvanised iron " is that which has for many years been given to articles of iron when coated with zinc ; the object of such coating being to preserve the iron from oxidation by the atmosphere. When iron has been thoroughly cleaned and freed from scale, it will, if dipped in a bath of molten zinc, become perfectly coated. When iron is properly coated with zinc, the atmosphere of course has no direct action on the iron, but a thin film of sub-oxide is formed on the zinc coating, which sub-oxide of zinc is sufficiently hard to resist further oxidation, and to remain sound when subjected to considerable friction.

Galvanised sheet iron is generally " corrugated," the wave-like form being given by rolling between cylinders or pressing in dies.

The great strength and stiffness which the corrugations give to the iron allow it to be used in sheets of considerable size, and for the roofs of buildings of small span almost without framework. (See page 203.)

Great diversity of opinion exists among engineers as to the propriety of using galvanised iron for roofs for railway and other sheds, &c., and many instances have been cited where the process of galvanising seemed to have little or no effect in preserving the iron from oxidation. Under any circumstances the durability of the iron is limited, but the length of time is determined mainly by the quality of the sheets and the atmosphere to which they are exposed. The quality of the sheets depends primarily on the kind and thickness of the iron, and then on the care with which it is coated with the zinc and corrugated. Good galvanised sheets can only be made from a good quality of sheet iron ; for if the iron is not clean, free from cinder, and well rolled, it will not hold the zinc coating properly, and spots of rust appear, which eat into the sheet, make holes on the surface, and so the iron is exposed to oxidation and destruction.

If the iron be not sufficiently tough and ductile it will, when corrugated, crack; and though the openings may be so small as to escape cursory examination, they will, when exposed to the weather, rapidly become rusty, and render the whole sheet worthless.

The sheets are generally galvanised before they are corrugated; but as in the process of corrugation the sheets, especially the thicker ones, will sometimes crack slightly on the surface (unless the iron is of the very highest quality), it is an advantage with all sheets thicker than 20 gauge (see page 215) to galvanise after corrugation, so as to fill up with zinc any cracks that may have occurred. As, moreover, a larger quantity of zinc will adhere to the corrugated than to the flat sheets, they have when so coated a distinctly higher value.

The value of the sheets depends also on the degree of purity possessed by the spelter* or zinc, and on the skill with which it is applied. The competition which in this, as in other trades, has prevailed during the last twenty years, and the tendency to judge everything by the standard of price alone, has resulted in the production of very inferior galvanised sheets; and to this cause, in no small degree, is owing the disfavour with which galvanised iron is regarded by many who have used it. There is no case where cheapness obtained by inferior quality is a falser economy than with galvanised iron, for the deterioration when it commences is so rapid, as to be out of all proportion to the first saving which may have been effected in price.

But while, in pure air, properly prepared sheets last long enough to amply repay their cost, in the vitiated atmosphere of London and other places, the action upon the zinc will in a much shorter time expose the iron to the weather. In gas works, to take an extreme case, galvanised iron is never used. If when the first gloss has left the new zinc coating, the sheets be painted, their durability will be greatly prolonged.

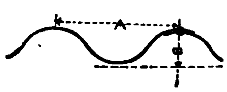
The thickness of galvanised sheets is stated not by fractions of inches, but by the Birmingham Wire Gauge, denoted by the letters B. W. G. Nos. 16 to 22 are the thicknesses generally adopted for roof covering in England, but large quantities of 24 and 26 gauge are exported to the colonies.

No. 16 is only used where great strength is needed, and No. 18 is used for first-class work generally. Anything thinner than No. 22 is used only for temporary roofs. In estimating the comparative advantages and economy of the different thicknesses, it is important to remember that the thicker sheets are not only more durable as against the weather, but allow of

* *Spelter* is the name given in commerce to zinc before it is manufactured into sheets and articles of utility.

B.W.G.	Equiv. in dec. of in.	Approx. weight per square.	Cost per ton.
16 ...	·065...5 in. flutes	...380 lbs...	£23 to £25
17 ...	·056... do.	...320 „ ...	
18 ...	·049... do.	...280 „ ...	
19 ...	·042... do.	...252 „ ..	
20 ...	·035... do.	...224 „ ...	
21 ...	·032...3 in. flutes	...205 „ ...	£27 to £30
22 ...	·028... do.	...185 „ ...	
23 ...	·025... do.	...165 „ ...	
24 ...	·022... do.	...150 „ ...	

the purlines, rafters, and other framework being placed with greater intervals than would be possible with the thinner and weaker sheets. The flutes or corrugations A are made of various widths, those most usual in England being 3 in., 4 in., and 5 in. Sheets with 5 in. flutes are commonly preferred by



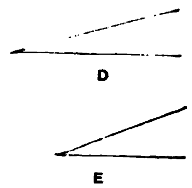
engineers. The depth B is generally one-fourth of the width A, and the proportions can only be modified in the manufacture by making special new dies. Sheets with flutes wider than 5 in. are occasionally used where great strength is required, but in such cases the thinner gauges of iron should not be employed. Sheets of No. 16 gauge, with flutes 10 in. by 2½ in., may be laid on purlines 15 ft. apart (Roof Example No. 58), while sheets of similar thickness, but with 5 in. flutes, require purlines not more than 10 ft. apart. According to the more usual plan of covering a roof with sheets of No. 18 gauge and 5 in. flutes, the purlines are placed from 6 ft. to 8 ft. apart. The exact size of the sheets of course varies according to circumstances, but seldom exceeds 20 square feet, ordinary lengths being 6, 7, and 8 ft. by 2 ft. or 2 ft. 6 in. and sometimes 3 ft. The sheets, when laid, lap over each other about 4 in. in the length and 2½ in. in the flutes; but this depends somewhat on the angle of the roof, the lap being greater if the sheets are laid at a flat angle.

The price of galvanised iron depends mainly on the current rates of iron and zinc. When iron plates cost £12 per ton, as stated on page 13, good black sheets will cost from £13 to £17, and then with spelter at £22 per ton (an average rate*), the

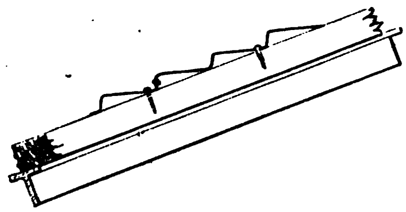
* From 1862 to 1876 the price of spelter varied from £18 to £26 per ton.

prices per ton for the various gauges of galvanised corrugated sheets will be approximately, as stated on page 215. The part of each sheet which is overlapped by the next, and is not seen when laid, is included in the prices and weights given, a square actually containing, therefore, rather more than 100 feet of material.

Fixing the sheets costs from 10s. to 15s. per square. Curving (as for an arched roof) about 3s. per square. Packing for shipment about £1 per ton. The prices given are for plain work, and would not be sufficient for hips or other places involving special trouble and waste in fitting the sheets. The holes through the sheets can be punched by hand, and it is often more convenient to postpone making them till the sheets are about to be fixed. By this plan each sheet can be tried on the roof, and the holes marked with the greatest precision, avoiding the risk of "blind" holes in the lap of the sheet. It is almost impossible to erect a building so accurately that the holes in the covering sheets (even if previously tried on the roof at the manufactory) will exactly coincide with the framing. For buildings sent abroad, where it is desirable to minimise the labour on the site, the holes on one end and one side of each sheet may be punched at the manufactory, and the other holes marked and punched, sheet by sheet, as they overlap during erection. Where corrugated sheets are placed on wooden purlines, they are fixed with spikes or screws 2 in. or 2½ in. long, and when on iron purlines with bolts. Iron purlines have sometimes wood placed upon them (Fig. 3, page 208), to allow the use of spikes. To avoid weakening iron purlines (which are generally of L iron) by holes, and also to avoid a possible non-coincidence of holes with those in the sheets, the latter are sometimes fixed with hook bolts. The bolts, nuts, screws, or spikes should be themselves galvanised. A flatter angle than 1 in 3½ (D) should be avoided if possible, and 1 in 2½ (E) is best.



Corrugated sheets are generally laid with the flutes parallel to the slope of the roof, but as stated at *b*, on page 203, they are also laid with the flutes horizontally. In this case a peculiar kind of corrugation, as shown in the engraving, should be used, as affording a drip for the rain water while maintaining the usual strength of a fluted sheet. When the sheets are laid in this way, purlines may be entirely dispensed with, and intermediate rafters also, if the principals are within a moderate distance of each other.



ZINC.

The tenacity or strength of zinc is much below that of iron, and a closer framework is necessary in the parts of immediate support (the lath or roll), while, on the other hand, as a covering material impervious to rust, it is more to be relied on than the galvanised iron, which has only a coating of zinc. Although sometimes corrugated like the galvanised iron shown on page 213, zinc is more often laid in straight sheets, with corrugations only at the points of connection with the framework. For flat roofs, or for steep or "mansard" roofs, zinc is often used in situations where, formerly, lead was the only available material.

It is of great importance that zinc should be perfectly pure,* for if it contain iron, as is frequently the case, it will not resist the action of the air. The best zinc used in this country is practically pure, as on analysis only the faintest traces of iron are found in it.

Zinc, though subject to oxidise, has this peculiarity (referred to on page 213), that the oxide does not scale off like that of iron, but forms a permanent coating on the metal impervious to the action of the atmosphere, and rendering the use of paint wholly unnecessary. The expansion and contraction of zinc are much greater than those of iron; hence in use proper attention must be paid to the circumstance, and plenty of *play* allowed in the laps, or a substantial and durable covering will not be obtained.

The thickness of zinc sheets is designated by a special gauge, whose divisions approximate to those of the B.W.G. (see page 215), but with the numbers differently arranged, as will be seen by the following table, where both sets of numbers are

* An elaborate description of the nature and qualities of zinc is given in "Gwilt's Encyclopædia of Architecture."

given. The weights per square foot are for perfectly plain sheeting, without corrugations or bends of any kind.*

B.W.G.	Zinc gauge.	Approx. weight per square foot.
22	13	16 oz.
21	14	19 ,,
20	15	22 ,,
19	16	25 ,,

Nos. 14 and 15 are the best for good work. No. 13 should only be used where it is necessary to exercise the greatest possible saving in first cost.

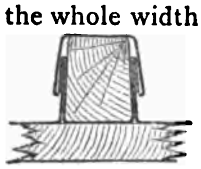
Zinc is generally rolled in sheets 3 ft. wide, by 7 or 8 ft. long, and up to 10 ft. where specially ordered. The exact effective length and width, when applied to roofs, is given in the following description of the various modes of fixing.

The different modes of laying zinc roof covering are known by the following names, and the weights affixed are approximate and *per square*, including the corrugations and laps :—

No. of gauge.*	13	14	15	16
1. Ordinary corrugation	130 lbs.	155 lbs.	175 lbs.	195 lbs.
2. Plain roll cap	130 ,,	150 ,,	170 ,,	190 ,,
3. Drawn roll cap	135 ,,	155 ,,	175 ,,	195 ,,
4. Italian corrugation	130 ,,	155 ,,	175 ,,	195 ,,

1. *Ordinary Corrugation* for zinc is now seldom used, except for side enclosures or for curved roofs, it having been mostly superseded by other methods. The effective width of the 3 ft. sheet, when corrugated, is 2 ft. 6 in. The purlines are generally of light timber or L iron.

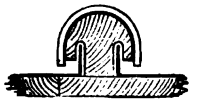
2. *Plain Roll Cap.* (*French plan.*)—This is laid on wood boarding with wood rolls, the ends of the sheets being turned up against the rolls in the width of the sheets and with a cap the whole width of the sheet. The clips are about 1½ in. long, placed at intervals. In the length of the sheet the joints are made with folding laps. By this plan, which is very similar to that in which lead is laid, the sheets are left perfectly free



* The gauges differ from those given in the previous edition of this book. The Vieille Montagne Company, in Belgium, who are the principal makers of zinc sheets in Europe, and from whom roof makers obtain their supplies, altered, in the year 1875, the numbers of the zinc gauge, reducing the thickness by one figure, No. 14 being the same as No. 13 was before 1875, No. 13 as No. 12. and so on.

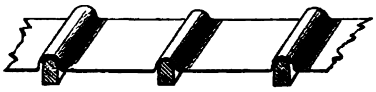
for contraction and expansion. The effective width of the sheets, *i.e.* from centre to centre of the rolls, is 2 ft. 10½ in.

3. *Drawn Roll Cap.*—This is laid similarly to the plain roll cap, but the wood rolls have the zinc drawn over them by machinery, thus dispensing with the loose zinc roll cap. This method is preferred to Method 2 for strength, durability, and

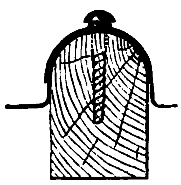


the facility with which it can be laid, as the zinc sheets can be turned up just before they are put on to the roof, and the drawn cap has then only to be dropped over the joint and screwed down. The effective width of the sheets according to this plan is 2 ft. 11 in.

4. *Italian Corrugation.*—This method is under most circumstances the best, and has the advantage that the sheets can be laid without boarding, and if the zinc be prepared in the usual way, it can be laid by



unskilled workmen. The sheets lap over each other on the rolls, and are screwed down as shown in the



engraving. The effective width of the sheets is 2 ft. 6 in. The rolls are generally laid upon purlines placed about every 7 ft., but, if necessary, the distance may be increased by the use of stronger rolls. The usual depth for the rolls is 3 in., but if laid upon boarding, they need only be 2 in. deep. Zinc, on the Italian system, is very effective in relieving the monotonous appearance of a large surface.

The cost of zinc roofing depends upon the current price of spelter, and on the shape and size of the roof.

Zinc being very ductile can be readily bent into shape, and can be cut and adjusted to the exact sizes. There are often special situations where considerable extra labour and cutting to waste are involved. But for plain roofing, the following may be taken as approximate prices per square of the different systems just described, when spelter is at £22 per ton, including fastenings, but no boarding or rolls:—No. 13 gauge, £2 10s.; No. 14, £2 15s.; No. 15, £3; No. 16, £3 5s. Fixing the sheets costs from 10s. to 15s. per square. Packing for shipment about £1 10s. per ton. The extra cost of wood rolls as used for the Italian corrugation, is from 9s. to 11s. per square. For the weight of zinc see page 218.

The demand for zinc is gradually increasing in England, but the quantity used annually is only about one-fifth of that used in France. Between 1860 and 1872 4,000 to 5,000 tons of zinc roofing, chiefly Italian corrugation, were used for station buildings in India alone.

The comparative advantages of corrugated galvanised iron and zinc may be thus summarised. Zinc is not so well adapted as corrugated iron for places where there may be rough usage, and it requires a closer arrangement of the immediate supports. For the latter reason, also, it is more necessary for zinc to be laid on boarding. Rather more skill is necessary for laying zinc and making proper joints, and this of course is sometimes of consequence in roofs erected in foreign countries. Including the wood rolls, the fastenings, the closer framing necessary, and the cost of laying, the first expense of zinc is the greater; but where, other circumstances permitting, zinc can be conveniently fixed, the ultimate cost is generally less than that of galvanised iron, for the reason that under certain conditions of atmosphere, galvanised iron must be periodically painted (say once in four years) to make it last as long as zinc: and when the covering is worn out, the old galvanised iron is absolutely worthless, while the old zinc sheets are worth in England from £14 to £16 per ton.

LEAD.

Lead as used for roofs is first cast into small sheets, and then rolled out to the size and thickness required; it then being called milled lead. The sheets are laid upon rolls somewhat in the same manner as is shown with zinc on page 219, but with close boarding underneath. The necessary strength is stated by the weight of a superficial foot, 6 to 8 lbs. per foot being the strength generally specified for flats, and 5 lbs. or 6 lbs. for flashings.

Lead ⅛ inch thick weighs about 7½ lbs. per foot, and the cost of lead sheeting varies from 25s. to 30s. per cwt., according to the current price of pig-lead. Lead is mostly suited for flat or steep roofs; but for all roofing purposes, and especially on iron roofs, it is now to a large extent superseded by zinc. Although weight for weight it is cheaper than zinc, the greater thickness necessary in lead renders it more expensive, but it will last proportionately longer.

FELT.

Felt, as used for roof covering, is made of hair, wool, or vegetable fibre, these materials, singly or together, being matted and compressed, and saturated with asphalte or bitumen, the cheaper kinds with ordinary tar. The felt is made in lengths of 25 yards by 32 in. wide, and for roofs is about $\frac{1}{8}$ in. thick. Dry felt without tar, as used for lining walls, is made in sheets 34 in. by 20 in., and occasionally in rolls, the thickness varying from $\frac{1}{8}$ to $\frac{1}{2}$ in. Good felt is impervious to rain or snow; is a non-conductor of heat and sound; is elastic, light, economical, and easy of application. For temporary sheds and wooden houses it is used as an outer covering, and will last a considerable time under most conditions of climate. Felt sheeting, made stiff like pasteboard, can be placed directly upon roof framing without any wooden or other lining. But for permanent structures felt is used only as an inner lining, and is applied both to the roofs and sides of buildings. As it serves equally as a protection from heat, cold, and damp, it is serviceable in all climates. For roofs it is generally placed upon wooden boarding, and the outer covering—slates, galvanised iron, or zinc—is bedded upon it. In buildings, bridges, and other structures, felt is often placed as a cushion between iron and iron, iron and stone, iron and wood, to prevent jarring and percussive strains. Good roofing felt, about $\frac{1}{8}$ in. thick, costs about 1d. per square foot, and the dry felt of thicker sizes in proportion.

GLASS.

The kind of glass suitable for iron roofs depends on the purpose for which the building is intended, and the area in the roof available for skylights. If this area be small it is necessary to utilise it to the utmost, and therefore to use clear, transparent glass. Clear sheet glass is used in such cases and also where, for conservatories and other ornamental buildings, the greatest possible light or the best looking material is required. But for ordinary iron roofs, such as are made for railway-stations, store-houses, factories, &c., it is seldom necessary to use clear glass, and a coarser, stronger kind is usually employed. Glass known as "patent rolled rough plate" is most suitable for skylights, and also, if transparent windows are not required, for the sides of such buildings.

The cost of glass depends upon the size of the panes and its thickness, and the latter is determined mainly by the width between the sash bars. Where the width does not exceed 12 in., glass $\frac{1}{8}$ in. thick is quite sufficient to resist ordinary hailstorms, and glass $\frac{3}{16}$ in. to $\frac{1}{4}$ in. for a width of from 12 to 20 in. Where the thickness can be expressed in the ordinary fractions of an inch as above, the rough glass is so described; but for sheet glass thinner than $\frac{1}{8}$ in., the weight in ounces per square foot is specified.

Rough rolled plate may be obtained in sheets from 12 in. to 20 in. wide, and up to 70 in. long, but widths of from 8 in. to 14 in. are most usual, and it is generally found better—and as against fracture safer—not to use sheets longer than four times their width. Panes of ordinary size cost about 5d. per square foot, if $\frac{1}{8}$ in. thick, and 9d. per foot if $\frac{1}{4}$ in. thick.

"Fluted rolled rough plate," of the same kind as that mentioned above, but rolled with small flutes either four or eleven per inch, is stronger, and costs about 1½d. per foot more.

Clear transparent glass is always specified by its weight per foot, and the cost increases with the size of the panes. Moderate sized sheets of 21 oz. glass (an ordinary thickness) cost from 6d. to 8d. per square foot, according to quality.

Glazing costs from 1d. to 2d. per square foot, according to the height from the ground and other circumstances. Wood sash bars cost from 1d. to 3d. per lineal foot, according to the section.

Sash bars, in shape nearly resembling those in wood, are rolled in wrought iron from 1 in. to 3 in. deep. They weigh from $\frac{1}{2}$ lb. to 5 lbs. per foot, and cost from 13s. to 16s. per cwt. Although in iron roofs such sash bars are frequently used, it is difficult with them to keep the roof watertight, owing to the expansion and contraction of the iron and glass not being in the same ratio. For this reason wood sash bars are often employed for iron roofs, but in any case the risk of breakage may be lessened by using putty made in such a way as not to become brittle. Bars of T iron from 1 in. to 1½ in. deep may be used as sash bars. For bars of deep and strong section, cast instead of wrought iron is often used, as more convenient for the connections and as more durable against rust. So also complete sash frames are made of cast iron. (See page 232.)

Glass may be bent to any curve to suit a circular or domed roof; but it is often, especially in foreign countries, difficult to replace glass of this sort when broken. Stained or coloured glass is often employed in conservatories.

In roofs covered with slates or tiles, where it is difficult or undesirable to insert skylights or to use sash bars, glass, shaped as *tiles* and *slates* may be adopted, these being made so that they will work in with ordinary tiles and slates.

CHAPTER XXII.

LOADS AND STRAINS UPON ROOFS.

THE load or pressure which a roof may have to sustain, consists of—1. The weight of the structure itself. 2. The weight of the covering. 3. The weight of snow. 4. The pressure of the wind.

1. The weight of the structure (per foot) increases with the span, but it is only in large spans that this weight forms the principal proportion of the total load that has to be sustained. A weight of about 800 lbs. per square for a span of 60 ft., or 1,000 lbs. for a span of 100 ft., is sufficient for trussed roofs such as are made in England for a covering of slates on boarding. It is evident, therefore, that, as referred to on page 18, there is in moderate sized roofs no advantage to be gained by making the parts of steel.

2. The weights of different covering materials have been fully stated in Chapter XXI., and they vary from 200 lbs. to 1,500 lbs. per square. As these are the weights on the sloping surface of the roof, the load on the horizontal area must be stated at higher figures.

3. The weight of snow is about 1-10th of that of a similar bulk of water. That is to say, while a cubic foot of water weighs 62½lbs., snow lying as it has fallen without compression weighs 6 lbs. In all but the coldest countries, therefore, an assumed maximum load of 15 lbs. per foot, or 1,500 lbs. per square, is considered ample. If the roof be steep, this weight may be reduced, as the total load of snow depends upon the horizontal, not the inclined area.

4. The pressure of wind is determined by its velocity, and by the angle of its incidence upon the roof. In England, the pressure under ordinary circumstances on a surface at right angles to the direction of the wind varies from 1 lb. per square foot (20 ft. per second) in a breeze, to 25 lbs. (103 ft. per second) in a great storm. But in hurricanes, the wind with

a velocity of 150 ft. per second will exert a pressure of 55 lbs. per foot, and even in England a pressure of 35lbs. has been registered. But as the pressure upon a slanting roof is much less than upon a surface at right angles to the wind's course, and as the most violent winds do not occur when there is an excess of snow, a total allowance of from 3,000 to 4,000 lbs. per square for both wind and snow is in Europe considered sufficient. Of course, in countries liable to hurricanes, extra precautions must be taken, and not only should the roof be strongly braced together by wind ties, but the entire structure should be well anchored to the ground. The latter precaution is especially necessary in buildings open at the sides or ends, and liable therefore to severe wind pressure below the roof. In countries where hurricanes occur, stability is sometimes given by using heavy roof covering, or by loading the roof with stones.

It is not only against a severe total load, however, that a roof must be secured, but against unequal pressure. Thus, snow often lies upon one side only of a roof, and one side only may exposed to the greatest violence of the wind. In such cases roof which might sustain a greater load, if more evenly distributed, will fail if it be not properly designed for resisting unequal loads.

In the construction of a roof, it is usual to allow higher strains upon the iron than in structures liable to percussion. Thus, while from 4 to 5 tons per square inch is customary for railway bridges, and 5 to 6 tons for road bridges, strains of from 6 to 7 tons are not uncommon for roofs. These figures are based upon an ordinary quality of iron, such as would break with 21 tons per square inch, but by the use of special iron or steel, higher strains may be permitted. (See pages 10 to 13, and Chapter X.)

In countries liable to earthquakes, or in workshops containing steam hammers, or in any case where the structure is liable to concussion or vibration, extra strength should be given to the parts, and special attention be paid to the tying of the whole structure together.

CHAPTER XXIII.

ORNAMENTAL IRONWORK.

WHILE the use of iron for structural purposes has increased rapidly during the last fifty years, the ornamental forms which are specially suited to the material have been more slowly adopted. At first this was owing to the limited knowledge which existed as to the strength and other characteristics of iron, and mainly for this reason there was a tendency in designing ironwork to adopt too nearly the existing conventional rules for stone or wood. By the increasing knowledge of the capabilities of iron, and especially of cast iron, and by the examples of its use which now abound, a more rational style has been attained in iron construction; but even now some architects seem hardly to be aware how far cast iron may be trusted. There are even some who (for æsthetic reasons) deplore its introduction into architecture at all, and others who will allow ornament to be legitimate only in hammered wrought iron. As a hand-made article may be preferred to one made by machinery, so a legitimate preference may be expressed for wrought iron ornament made by the artist-workman, as compared with the ironwork produced by casting in a mould. But although this kind of wrought ironwork is still occasionally made, and new designs for gates, railings, &c., most beautifully executed, the art-workers in iron—that is to say, the men who being themselves the designers, work at the fire and anvil, as the sculptor at his marble—have almost disappeared, since a similar effect to theirs can be produced in a cheaper way by casting or pressing in a mould.

Most of the ornamental wrought ironwork of the present day for railings, church fittings, chandeliers, &c., is hammered in dies, so that there are in the different pieces a repetition and similarity as great as if they were made of cast iron. Many of the designs usually admired in, and supposed to be peculiar to, hammered wrought iron, are obtainable from iron cast into moulds; and here there is the advantage over wrought iron that the metal may be made to swell with much greater freedom, and indentations or projections of abitrary character may be made with less difficulty. In short, while cast iron may be made to any shape that plastic clay will take, or to any which can be carved in stone, marble, mahogany, or oak, it is nearly equal to hammered iron in giving delicacy of form. Moreover, some designs which are too delicate to be utilised in such materials as clay, stone, and wood, are of sufficient strength if made in cast iron. Herein lies its superiority over all other materials used in architecture; and this advantage is not lessened by the fact, that another material—such as clay or wood—has to be temporarily employed in its production. Indeed, an art-workman has greater scope for design in the earlier stages of cast iron manufacture (*i.e.* in the clay model) than in wrought iron. It would, therefore, be unjust to deny to cast iron the important place in the order of building materials which is now given to it by engineers and builders, notwithstanding the æsthetical objections continually made to it by many architects. But although, as stated above, cast iron can assume any form usual in wood, stone, or clay, its peculiar qualities—hardness, sharpness, strength, and durability—demand a new style of ornamentation. The attempts hitherto made at this, though constantly improving on the past, cannot be said to have perfected such a style; and as cast iron is likely to maintain its position of utility, increasing success may be hoped for in the future.

But while the merits of cast iron are stated as above, it cannot be doubted that the quality and the rude appearance of many of the cheap castings supplied to builders in this country have justified considerable prejudice among architects, and have prevented the use of iron in many kinds of work where artistic ornament is desired, and where, if properly manufactured, cast iron could be adopted to great advantage.

Although it will easily be seen from the examples of bridges and buildings in this book, that for structural purposes cast iron is invaluable, many architects are perhaps unaware how much the mere quality of the iron, apart from the skill in its after treatment, affects the success of an attempt to use it

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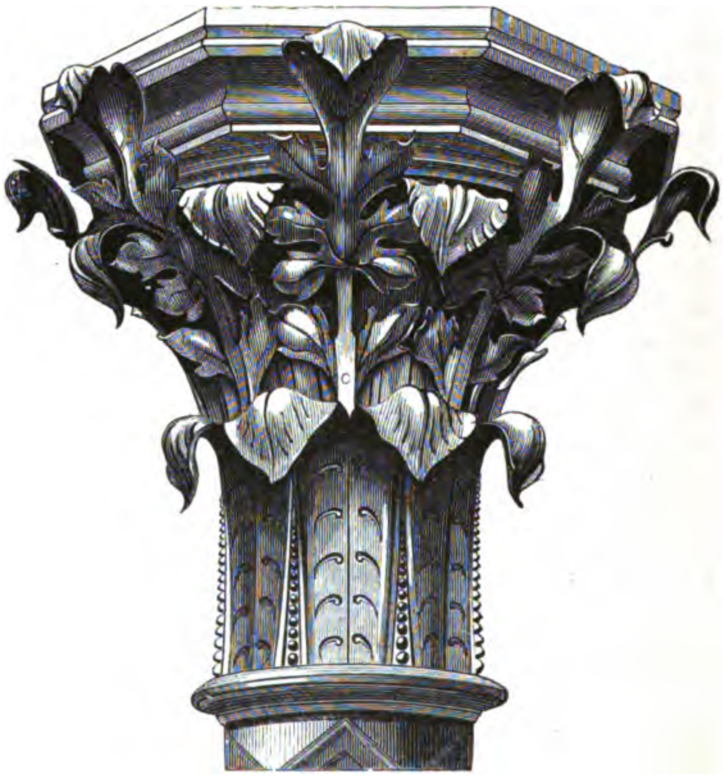


2

CAST IRON COLUMN CAPITALS.

ornamentally. Of the immense differences in point of *strength* enough has been said in Chapter I.; but while the use of good material permits lightness of form to be combined with safety, it also affords a wide scope for artistic treatment. The foliage upon the capitals of columns may be taken as an apt example. Although hammered wrought iron is often used for this purpose, the cost is so great as to preclude its use in most instances, and this form of iron is also ill adapted to resist the action of the weather in a climate such as that of England.* With *good tough* cast iron skilfully treated, ornament may be produced which gives with fidelity the design of the architect at a moderate cost. All the crispness and delicacy of outline, the relief and "undercut," which are essential to effect, can be perfectly secured.

The foliated capitals shown in the engraving on the opposite page are made entirely of cast iron, and are not given as specimens of design, but merely to indicate the kind of forms which may be produced in cast iron. So, also, the sketch on this page illustrates part of a cast iron balcony panel made at Derby, and in this case the metal, although extremely light, is tough enough to endure a fair amount of bending and usage without fracture.

Conservatories, winter-garden houses, and market buildings, are examples of structures in which the advantages afforded by cast iron are most apparent. Considerable impulse was given to the manufacture of buildings of this kind by the successful erection of the large Exhibition Palace of 1851, in Hyde Park; but for some years before that time A. Handyside & Co. had constructed, at Derby, conservatories, mainly of iron and glass.

* For instance, the cast iron gates at the Royal Exchange will long survive the light wrought iron gates at the India and Foreign Offices at Downing-street.

Cast iron is particularly adapted for such work, and the slight columns and elegant arched spandrels obtained in this material afford great scope for ornamental design. The conservatory in the gardens of the Royal Horticultural Society at South Kensington, the winter garden at Leeds, the Indian kiosk, the Madrid markets (Examples Nos. 40, 42, 43, 45, 49), and others which have their place amongst the examples of iron roofs and buildings in the following pages, are specimens of ornamental structures composed principally of cast iron.

Allowing the economical advantage of casting in a sand mould, *malleable cast iron* offers special advantages for light ornamental work. Made from hæmatite iron, and afterwards annealed, these castings possess the qualities of wrought iron to a considerable extent.* They will endure a certain amount of concussion, bending, twisting, and other rough treatment, without fracture, and, though dearer than ordinary castings, are very much cheaper than elaborately forged wrought iron.

* "Malleable cast iron." See page 14.

CHAPTER XXIV.

IRON WINDOWS. VENTILATION OF BUILDINGS.

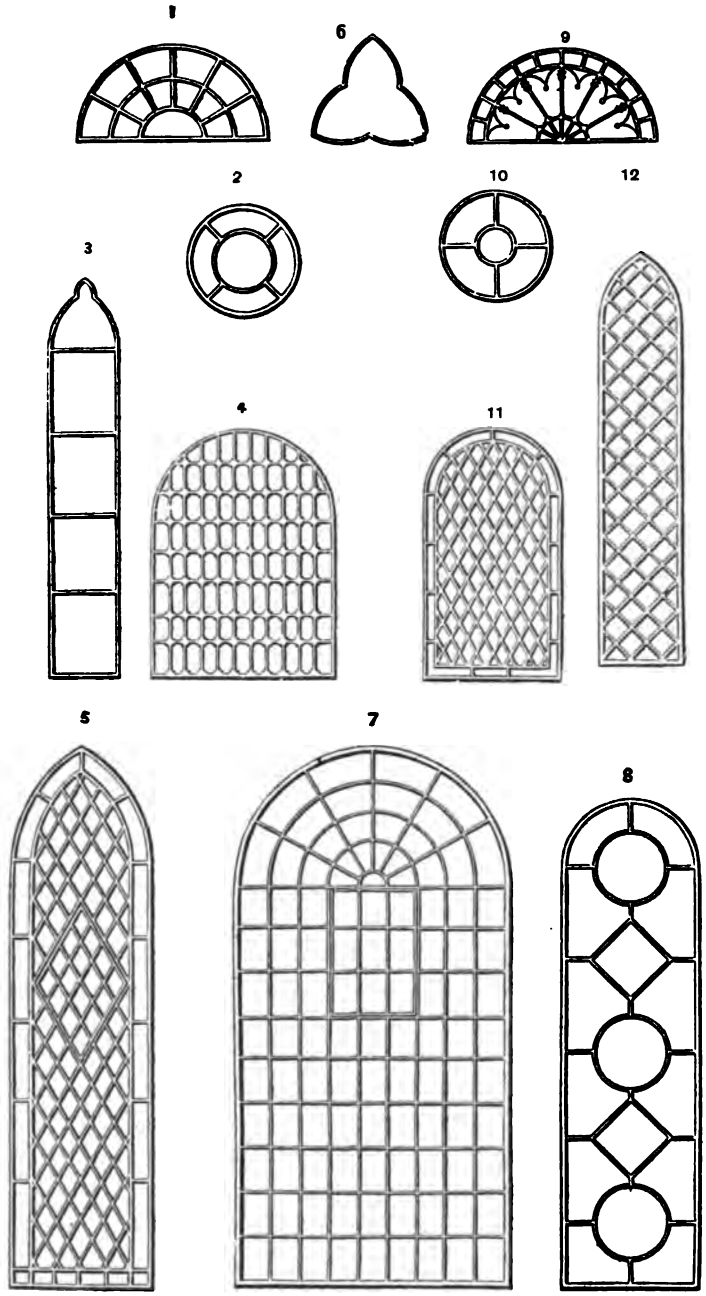
IRON WINDOWS.

WINDOWS and casements are made of bronze and iron, and are chiefly used where small panes are required; that is to say, while the ordinary window frames of a dwelling-house are almost always of wood, the more elaborate patterns of an Elizabethan or Gothic design may be, and are, produced in metal to great advantage. This is especially the case also where there is considerable repetition, as in factories, schools, or large public buildings, as the metal windows can be cheaply made, while against rough usage and exposure to the weather, metal is far more enduring than the wood.

In windows of a close or intricate pattern the sash bars obstruct the light to a more than ordinary degree, but this obstruction is reduced to a minimum by the use of narrow metal bars, which at the same time are much stronger than the wider sections of wood. Small opening casements are much neater and stronger if made in metal.

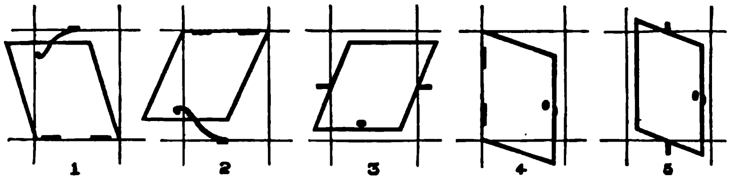
For permanent endurance, the best of all materials is bronze or gun-metal, which, while strong and tough, will endure exposure to the weather without painting. For first-class work, where economy is not an important consideration, the bronze is used, as for example in the Houses of Parliament at Westminster, where all the small windows are so made. The cost is, however, about six times that of cast iron, apart from the expense of fitting the opening casements, which is the same for both. The great majority of metal windows are made of cast iron, and the engraving shows a few of the most ordinary types. The cost varies from 1s. to 1s. 6d. per square foot, or if sold by weight, from 16s. to 20s. per cwt.

Iron windows should be kept well painted, and the hinges and other fittings should be of brass or malleable cast iron.



CAST IRON WINDOWS.

The most usual methods of hanging the opening casements are shown by the diagrams below, and the extra cost of fitting such



casements with hinges, handles, &c., is from 5s. to 10s. each. In a conservatory or other building, any number of casements, by means of a simple apparatus, may be made to open simultaneously, or in such other order as the exigencies of ventilation may require.

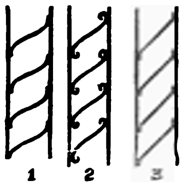
Wrought iron windows are occasionally made, and not being so fragile as cast iron, they can be more easily carried without breakage. They are also better suited for very large panes. But they have little or no other advantage over cast metal, as the superior toughness of wrought iron against rough treatment is a quality not needed in a window, while cast iron is the better suited of the two to endure exposure to the weather.

VENTILATION OF BUILDINGS.

Ventilation may be provided for in many different ways, the methods adopted varying with the nature of the building, its purpose, and the climate.

Where a building is used only for a warehouse, or in any case where but little ventilation is required, it is often sufficient to raise the ridge covering for a width of 12 or 18 in. to allow the passage of air. Where windows with opening casements are provided in the sides of a building, a current of air may be kept up from them to the opening in the roof. Gratings inserted in the walls serve the same purpose as windows, but generally they are placed at a lower level.

The most usual plan of ventilating a large roof is by raising the central portion of it and admitting the air through the vertical sides of the raised part. To prevent the rain beating in, the openings may be fitted with hinged shutters or—as is more frequent—by louvre blades. These louvre blades or



1 2 3

plates may be made of wood, iron, zinc, or glass, and either fixed at an angle which will exclude the rain, or made to work on pivots so as to open and shut at will. Wood or glass louvre blades are made straight; sheet iron (generally galvanised) as in Fig. 1 or 3; zinc blades as in Fig. 2.

In roofs of great span, as for railway stations, it is often desirable to have openings for ventilation besides those at the ridge. In such cases the openings can be made at different places on the slope of the roof, and to effect this, advantage can be taken of the purlines, as in Examples Nos. 55, 58, 60.

For buildings used for trades needing special ventilation, as in certain chemical works, *abattoirs*, &c., the central portion of the roof is raised as before described, but on a more than ordinary scale, so as to allow large volumes of impure vapours to escape.

In conservatories and plant-houses the plan of ventilation most approved of is that by which the admission of cold air by the side windows or by gratings beneath them is in close proximity to the heating pipes, while the egress of the heated air is provided for as near as possible to the ridge. In all cases where warming apparatus is employed, the warming and ventilating arrangements must be considered together.

In very hot countries the roof is often made double, so as to allow an air space of from 6 to 18 in. between the inner and outer covering. This air space acts as a non-conductor, which prevents the extreme heat on the outer covering from penetrating to the interior. (See Example Nos. 35 and 37.)

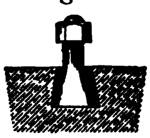
CHAPTER XXV.

ERECTION OF IRON ROOFS AND BUILDINGS.

THE transport of ironwork is described in Chapter XI., as there properly preceding the "Erection of Bridges;" and to a considerable extent the information given on pages 113 to 134 will apply to roofwork also. As compared with bridgework, the parts of iron roofs are less often of a heavy kind, and must be protected suitably for transport. Tie rods, light L and T bars, and similar pieces liable to bend, can be conveniently packed in bundles and tied with rod iron. When there are damageable forgings or fragile castings, they can be protected by wooden packing, and, if their size permits, enclosed in cases. Boxes of open framework (called "skeleton cases") are cheaper than the ordinary kinds, and afford sufficient protection for zinc or galvanised iron roof sheets and other similar pieces. The cost of packing-cases often forms a considerable item in the expense of transport, and the extent to which they will be required is a point for consideration in examining the design and estimating the total cost.

Before proceeding with the erection of an iron building, it is necessary that those dimensions of the plan which have any relation to the superstructure shall be carefully set out. The responsibility for the correctness of the ground-plan dimensions falls necessarily on the builder. In many cases, actual measuring staffs or rods, to indicate the exact dimensions of the ironwork, should be sent to the site in advance.

Iron columns or stancheons are generally fixed on bases of brick or stone, and it is of course necessary that these shall be level. But as a very slight inequality at the base will make a column considerably out of the perpendicular, it is almost impossible to obtain a bearing (contact of surfaces) with sufficient exactitude directly between the iron and the stone. Sometimes an iron bed-plate, having a truly planed upper surface for the column, is fixed on the stone; but in this case there is the same difficulty in placing the bed-plates exactly. There are different methods of adjustment. Sometimes there is placed on the stone a sheet of lead or felt, either of which will yield to some extent to the shape of the column base, and give a proper bearing to it after it is perpendicular. Another plan is to place the column on the stone, but with iron wedges between. When all the columns are erected they are adjusted, and their tops brought into one plane by driving in the wedges. The space between the iron and the stone is then filled with molten lead, or caulked with iron borings (to rust), or filled with liquid Portland cement, the latter, if *of good quality** being in most cases preferable, as its fluidity enables it to occupy the entire space, and it " sets " as hard as stone. Lewis-bolts, or else bolts passing entirely through the stone, are used for holding the column in position.



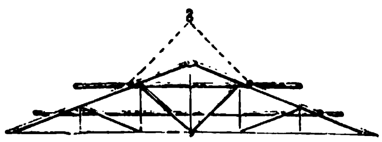
Lewis-bolts are generally fixed in the stone by lead, which is poured into the dovetail space and caulked. Sometimes the bolts are jagged, for the purpose of holding to the lead, but there is the disadvantage in this, that the jagged projections are in the way of the caulking tool. Caulking is necessary because the lead contracts in cooling, and unless compressed would not hold the bolt tightly. But bolts have sometimes to be fixed in places inaccessible to the caulking tool, and in such cases *brimstone*, which expands in cooling, is used instead of lead, and is quite as effective.

The weight of the column and its load in many cases would suffice without bolts; but they are generally provided as an additional safeguard against any lateral push which the column may have to sustain, caused by wind or other pressure on the building. In roofs which are not rigidly connected with the columns, the latter require holding-down bolts, so arranged on the area of the column base as to make the base act as a cantilever. A roof which—like that shown in Fig. 7, page 196—is rigidly connected or braced to the columns, requires no bolts, unless it be feared that the whole structure may be moved.

Roof principals are lifted in different ways, according to their form, size, and weight. For trusses of moderate span, a single derrick (see page 119) is generally used, the chain sling being attached at two points, as shown on the next page. It is obvious, when a trussed principal is suspended in mid air, that

*" Cement." See page 35.

the various parts are subjected for the time to abnormal strains; the tie rods, for instance, being liable to compressive as well as tensile strains. It is necessary, therefore, to temporarily brace the truss, so as to prevent its collapse, and this is generally effected by lashing poles



or light timber to the ironwork. After the truss is lifted, the poles are again useful for supporting scaffold planks. Trusses can be lifted with a single derrick; but it is desirable to have guiding lines hanging from each end of the truss, to hold it steady as it is lifted. Beyond spans of 70 ft, it is advisable to use two derrick poles, the suspending points being thus placed farther apart than is convenient with a single derrick, and the tendency to collapse reduced. The purlines and other intermediate work may be lifted by the same derricks, or by secondary derricks, or by tackle attached to the principals; but, as a rule, a multitude of derricks should be avoided, as causing confusion by their numerous guys.

For arched roofs, various plans of lifting can be adopted. If the arch is small it can be treated in the same way as the small truss just described; and if the rib is of considerable depth, and possesses strength as a girder, it can be lifted by two or more derricks, with perhaps the addition of some temporary timber struts. By means of a travelling stage, higher than the roof, the arched rib can be lifted at so many points as to ensure its safety. (See Example No. 59.)

Methods of lifting an arched principal in two pieces, each having one end hinging upon its abutment, will suggest themselves in practice. Or if the span is too large for this plan, the end or abutment pieces may be so erected, and then securely guyed and strutted to act as overhanging cranes, from which the centre of the arch may be lifted.

For large roofs, the safest and easiest, though not always the cheapest of plans, is to make a staging from the ground and build up the arch in segments upon it. It is not necessary that the staging shall extend the whole length of the building, but it may be made of the width of two bays, and to travel upon rails laid upon the ground. The same staging can be used by the workmen for fixing the purlines, sash-bars, covering, &c., and thus the erection of the intermediate work can follow closely after each principal, and so complete the roof. This plan of having a complete platform has the additional advantage of preventing tools and materials falling to the ground. (See Example No. 61.)

Large domed roofs may be completely put together on the ground, and then lifted entire by screw or hydraulic jacks, the roof being securely packed from below as it ascends, and till the permanent support can be adjusted.

With hipped roofs, the end or complete hip framework should be erected first, so as to obtain a fixed and stable point to start from, and to act as a bracing for the rest of the structure. With a gable roof, the end principal may be first fixed; or to save time, the erection can be commenced from the centre, and worked towards the two ends simultaneously. The first principal that is lifted should be securely strutted to the ground, or to some existing fixed point, before it is released from the derrick; then, as each succeeding principal is hoisted, it should be lashed to the preceding one by scaffold-poles or light timber, until the purlines or other permanent parts can be attached—this being done completely and regularly as the work proceeds. Although as every principal is completely erected, the stability of the roof is increased, it is advisable to fix and adjust the wind-ties as the work proceeds; or if wind-ties are not considered necessary to the design, the addition of the roof-covering (if it include boarding or corrugated iron) will tend greatly to the safety of the structure. Directly the covering is fixed, the roof—if open at the ends or sides—is exposed to wind pressure from below, and the principals should therefore be permanently secured to the columns or walls upon which they rest.

The cost of roof erection depends chiefly on the height from the ground, the value of the scaffold timber, and the amount of care and preparation which the design demands. From £2 to £4 per ton are limits wide enough to cover the great majority of cases. As has been more fully described with reference to bridges, the total cost of the finished structure may, in foreign countries, or in other situations where the circumstances are peculiar, be lessened by facilities obtained in the design—even at some extra expense in the workshop in the first instance.

CHAPTER XXVI.

EXAMPLES OF ROOFS AND BUILDINGS. SPANS UP TO 60 FT.

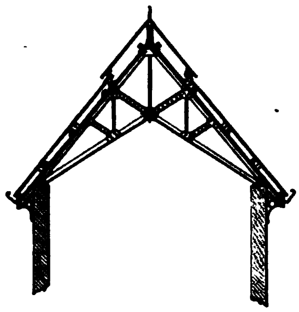
THE iron roofs and buildings enumerated and described in the following pages were all constructed by A. Handyside & Co. at Derby, and in many cases were also erected by them on the sites. As the total cost depended in each case on the current price of iron, the expense of transport, and other varying circumstances, a statement of the actual prices for which the structures were sold would only mislead.* The costs that are given are, therefore, based upon the prices of cast and wrought iron, stated on pages 7 and 13, include only the transport of the structure to an English port, as London, Liverpool, or Hull, and are exclusive of the cost of erection. (See Erection of Roofs and Buildings, Chap. XXV.) The Examples begin with the smallest, and proceed regularly to the larger spans, this being the most convenient order for reference.

The current prices of iron that prevail at any particular time cannot be taken as an absolute guide for determining the cost of finished work. Other causes—especially the price of fuel, the rate of wages, the hours of labour, the repetition of parts and consequent economy—must also be taken into consideration. For fluctuations in the prices of iron during the last twelve years, see page 4, *ante.*

Example No. 35.—The engravings, Figs. 1 and 2, show two iron roofs made in 1865 for the Deccan College, India. The buildings of the college occupy three sides of a quadrangle, and the two wings and all but the centre part of the third side are covered by a roof having principals like that shown in Fig. 1. The clear span between the walls is 20 ft. 6 in., and the principals are placed at intervals of about 10 ft. 6 in. Each truss or principal is composed of T rafters, 4 in. by 3 in., a flat tie bar $2\frac{1}{2}$ in. by $\frac{3}{8}$ in., struts like the tie bars but with flat stiffening pieces $1\frac{1}{2}$ in. by $\frac{1}{4}$ in. riveted

* See foot-note on page 135.

to them; a king rod $\frac{7}{8}$ in. diameter, and queen rods $\frac{3}{4}$ in. diameter.



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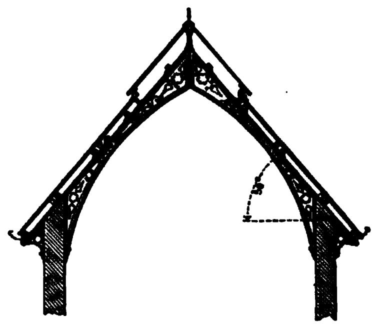


2

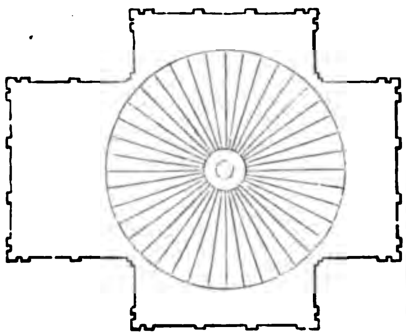
There is a double roof covering. On each side of the principals, five rows of 2½ in. L purlines are laid, and to these are attached longitudinal timbers, 4 in. by 3 in., to receive the inner ceiling of boards. An outer covering of corrugated galvanised iron is also laid upon L purlines, which are carried by small raised brackets, so that there is an air space of 6 in. between the two coverings. On each side of the ridge the roof is raised 14 in. to provide a ventilating space, an aperture for the admission of air being formed by the light perforated girders which carry the raised roof. There is a light cast iron gutter along each of the eaves.

Including the eaves, the area covered is about 100 squares. There are in the roof—

27 tons of wrought and cast iron, costing about £29 per ton.
147 squares of corrugated sheets, 18 gauge.

Example No. 35a.—In the building of the Deccan College, described in the preceding Example, the central hall, measuring 70 ft. by 21 ft., is covered by a roof with arched principals, as shown in Fig. 2, but in all other respects—purlines, ceiling, covering, &c.—similar to that just described. The principals, which are placed 10 ft. apart, are of wrought iron, each composed of a perforated web plate $\frac{3}{8}$ in. thick, 4 ft. deep at the top, and four L irons 2½ in. by 2½ in. The area covered is about 19 squares, and the ironwork weighs 11½ tons, costing about £28 per ton; 31 squares of corrugated sheets as before.

Example No. 36.—A conservatory or winter garden, designed by Messrs. Banks and Barry, for the mansion of Mr. Henry Bessemer, and erected near London in 1868. Fig. 1 shows a ground plan of the conservatory, two sides of which are enclosed by the mansion, and the other two sides by stone walls amply lighted by windows. This is one of the most elaborately ornamental iron buildings yet constructed, and with the exception of the outer walls and the wrought iron ribs in the dome, it is entirely of cast iron. The building is 46 ft. long, and 40 ft. wide, and the general appearance of the interior is seen from the engraving on page 242.



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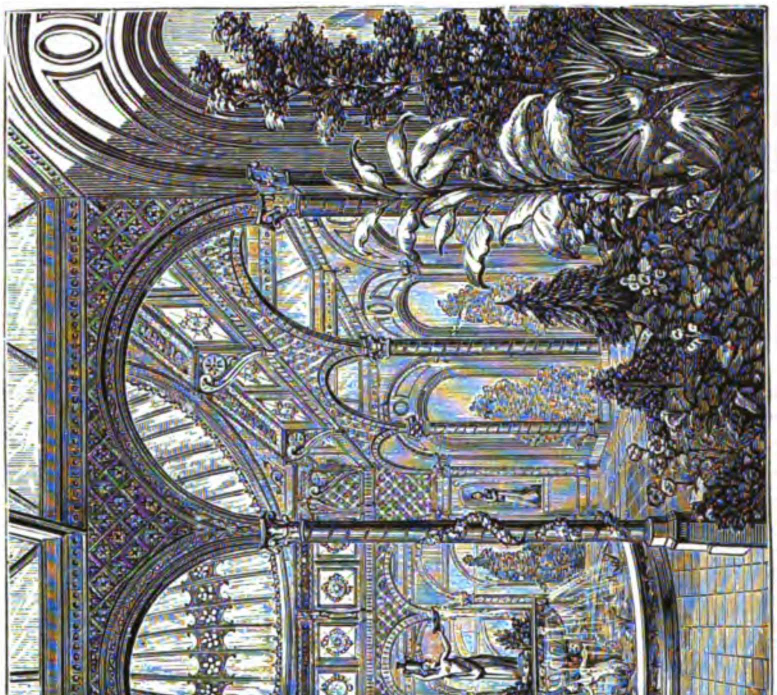
2

There is a domed roof 21 ft. span springing from the rectangle in the centre, as shown in the plan, Fig. 1, the dome having wrought iron ribs made as sash bars for receiving the glass covering. The columns are light and elegant, with enriched capitals, the arches, brackets, and other main parts of the structure, as seen in the engraving, being of the same ornamental character. The roof is entirely covered with glass, and the ironwork is tastefully gilded and painted, the design offering great scope for colour decoration. The roof is formed of ornamental coloured tiles, especially designed.

The mere weight of iron in a building of this sort bears little relation to the total cost, the new patterns, the elaborate workmanship, and the careful fitting, being the chief items of expense. From £2,800 to £3,200 may be taken as the cost of such a structure, and to this must be added from £500 to £1,200 (according to the design) for the glass roof, the floor, and the decoration. The weight of iron would be from 60 to 80 tons.



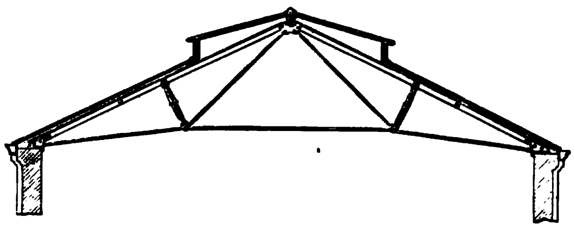
EXAMPLE NO. 36. IRON AND GLASS CONSERVATORY.

Example No. 37.—An iron pavilion 47 ft. 8 in. long, made as a reading-room or divan for the Byculla Club, Bombay. As will be seen from Fig. 1, on page 244, the roof is "hipped" at one end; at the other it is joined to previously existing buildings. The total length is divided into seven bays of 9 ft., and one of 11 ft. 8 in., and the span of the roof, from centre to centre of the columns, is 27 ft. 4 in. The columns are 14 ft. high from the ground to the springing of the roof, and have enriched capitals. The spaces between the columns along the building are filled in by ornamental spandrels and trellis girders. The roof principals are of pierced wrought iron, and are united at the top by a wrought iron ridge 18 in. deep. The purlines are of L iron and wood, like Fig. 3, on page 208. The roof covering is double, thus providing an air space as a non-conductor of heat; the inner lining being of 1 in. boarding, and the outer covering of 15 gauge zinc, on boarding. The eaves of the roof overhang, and with the gutter are supported on brackets, as shown in Fig. 2. There is an ornamental cresting on the ridge of the roof.

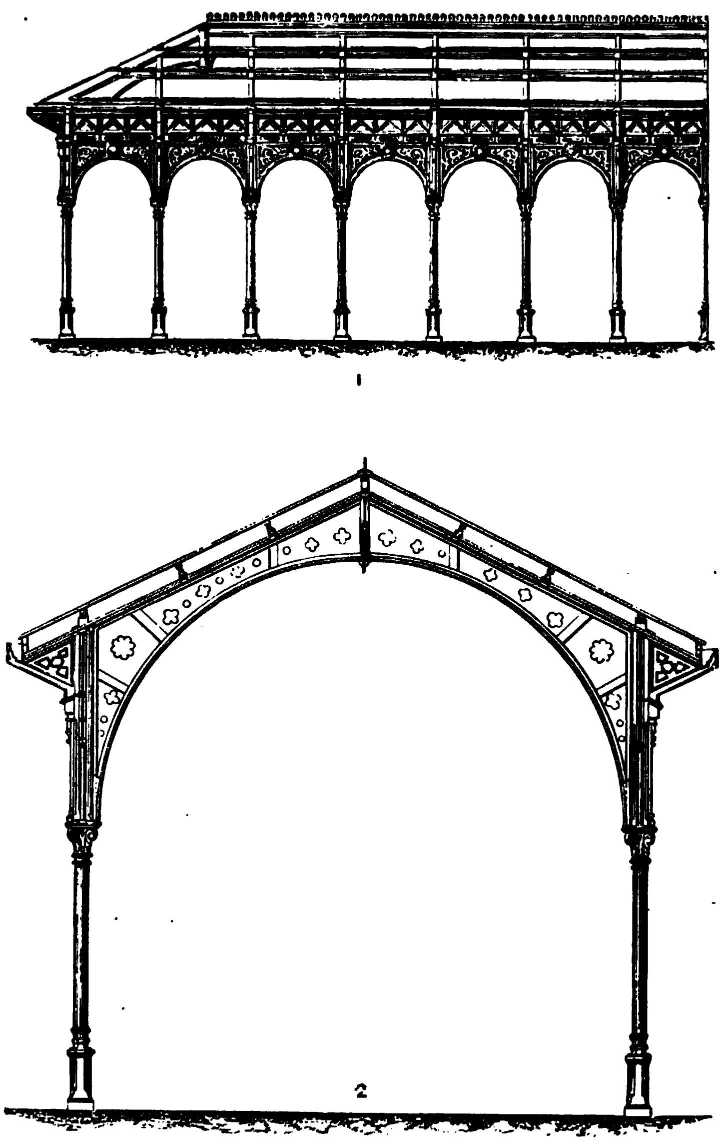
In estimating the cost of a building of this kind, a price per ton may mislead, unless it is remembered that the structure is small, that a considerable number of new and expensive patterns are needed, that the roof has hipped ends, and that all the ironwork is of a light and ornamental kind.

The roof ribs and other wrought iron weigh 8½ tons, the cast iron weighs 37 tons, and the average cost of the whole is about £20 per ton. The zinc roof covering is not included in this cost, and a sum of about £110 would have to be added for it.

Example No. 38.—An iron roof, 60 ft. long and 30 ft. wide, for covering a racquet-court at Elvaston Castle, for the



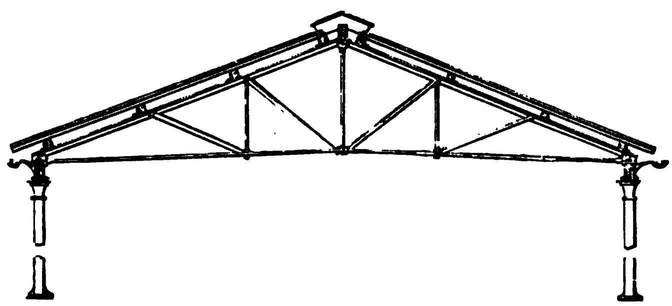
Earl of Harrington. This is a trussed roof of the very simplest description, the principals being of the kind shown by Fig 1,



EXAMPLE NO. 37. PAVILION AT BOMBAY.

page 196. The building is rectangular, and has trussed roof principals at intervals of 7 ft. 5 in., the end trusses being placed just within the gable walls. The rafter of each principal is a T bar 3 in. by 3 in., and the short diagonal struts are of cast iron. The longitudinal purlines are of 2 in. L iron, but the upper row of purlines on each side are of cast iron, arranged to support vertical sash frames and ventilators. At the ridge there is a longitudinal T bar, 3 in. by 3 in. At the eaves on each side is a cast iron gutter 8 in. wide, and there is a down pipe at each of the four corners of the building. The ironwork weighs 5½ tons, and the cost of such a roof would vary from £22 to £25 per ton, according to the size and the amount of repetition allowed. The sash frames (arranged specially with opening machinery) weigh 23 cwt., and are not included in the above cost. The covering is of 16 gauge zinc on boarding, with skylights on the raised part of the roof.

Example No. 39.—A shed of 268 ft. long and 30 ft. wide, open at the sides and with a roof hipped at the ends. The shed is divided into 27 bays by cast iron columns supporting the roof principals. The columns are 16 ft. high, including 2 ft. below the ground; they taper from 7 in. to 6 in. diameter, are of metal ¾ in. thick, and are of the simplest form. Each line of columns is connected longitudinally by wooden beams 12 in. by 6 in., and to the sides of the beams light brackets are bolted to support the gutter Down pipes for the rain-water are placed against six columns on each side of the shed.



The roof principals are of the ordinary trussed kind, as shown in the engraving above. The rafters are of T iron, 3 in. by 3 in.; the diagonal struts are of T iron, 2½ in. by 2½ in., the horizontal tie is of round iron $1\frac{1}{4}$ in. diameter, the central vertical or king rod is 1 in. in diameter, and the queen rods are $\frac{3}{4}$ in. diameter. At the ridge, a horizontal T bar, 4 in. by 3 in., runs from end to end of the roof, connecting the principals together; and upon this T bar a timber ridge-piece 9 in. by $4\frac{1}{2}$ in. is bolted. There is a longitudinal tie connecting the lower ends of the king rods, and there are diagonal wind ties under the roof covering from the ridge of one principal to the wall shoe of the next. On each side of the roof there are four lines of timber purlines resting upon the rafters and bolted to L iron "cleats." For a width of 3ft. 6 in. at the ridge the roof covering is raised to allow of ventilation. The covering is of zinc, of the Italian pattern, laid on wood rolls.

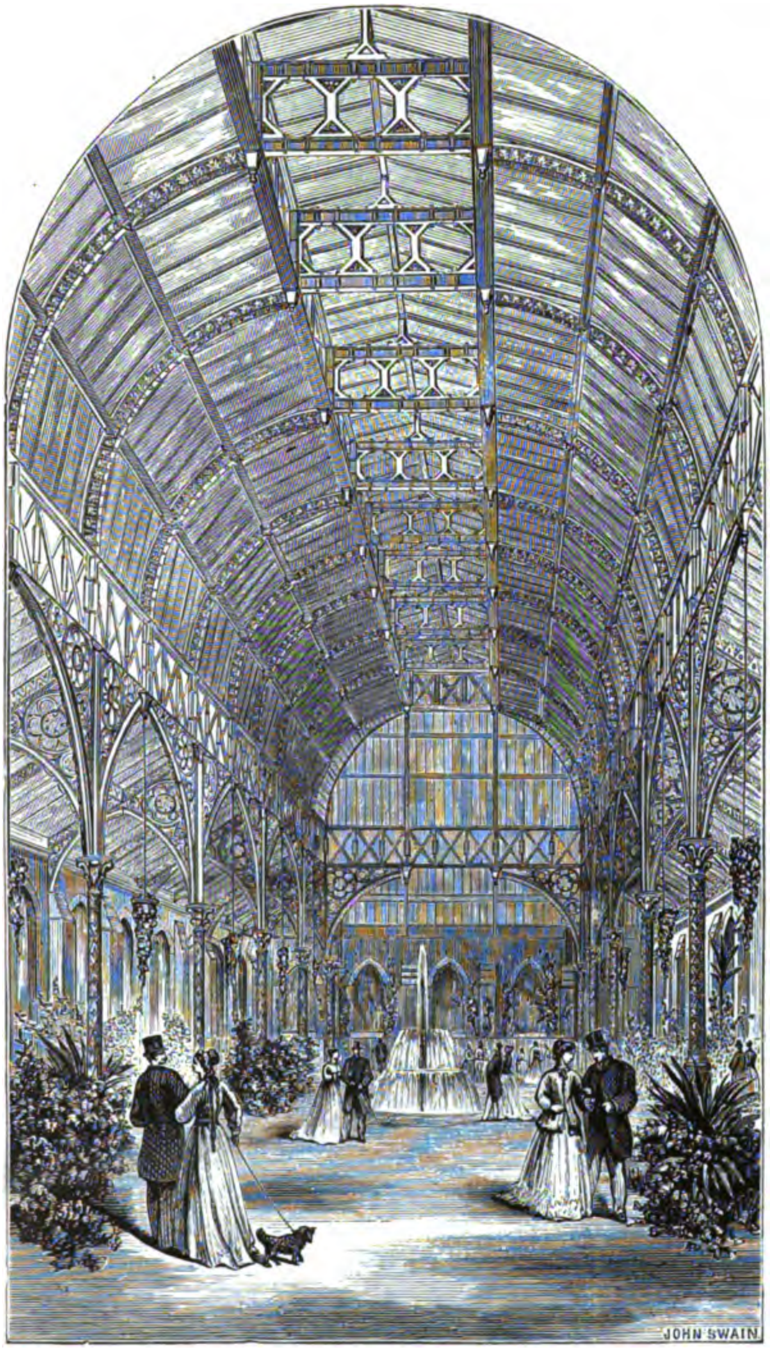
The weight and cost of the shed may be divided as follows:—

60 columns	$18\frac{1}{2}$ tons, costing about	£10 per ton.
26 roof principals, hips, &c.	$12\frac{3}{4}$,, ,,	£23 ,,

97 squares of zinc, 14 gauge. (See page 218.)

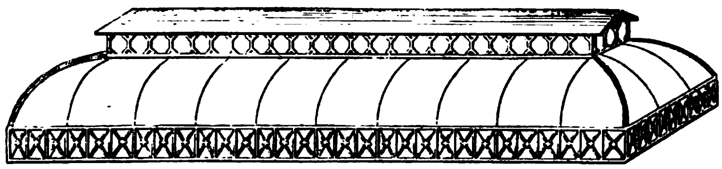
Example No. 40.—The engraving on page 246 shows an iron and glass building, designed by Sir George Gilbert Scott, R.A., as a winter garden for the Infirmary at Leeds, where it was erected in 1868. The engineering construction was entrusted by Sir G. Scott to Mr. R. M. Ordish. The building is 151 ft. long, 63 ft. wide, 60 ft. high, and, with the exception of the lattice girders over the columns and in the clerestory, is entirely of cast iron. The columns, 12 in number, placed 30 ft. apart, are 10 in. diameter and 32 ft. high, with enriched capitals, at a height of 18 ft. from the ground, of the kind shown in Fig. 2 on page 228. Between the columns, and springing from them, are light ornamental spandrels, made in halves, and at right angles to the spandrels are perforated cast iron arches for carrying the side roof.

The construction of the main roof is novel and peculiar, the parts being so arranged that there shall be no outward thrust on the end and side walls of the building. The 12 columns before mentioned stand in two rows down the building; the distance between the rows being 37 ft. 3 in., and the aisle space on each side is about 13 ft. Immediately above the columns is a frame of lattice girders connecting them together, the



EXAMPLE NO. 40. WINTER GARDEN AT LEEDS.

frame forming on plan a rectangle 124 ft. 2 in. by 37 ft. 3 in. From the four corners of the frame spring strong cast iron arched ribs, which are connected at the top to the four corners of an upper frame or rectangle, composed of wrought iron lattice girders so framed and braced together as to form really one strong box girder.

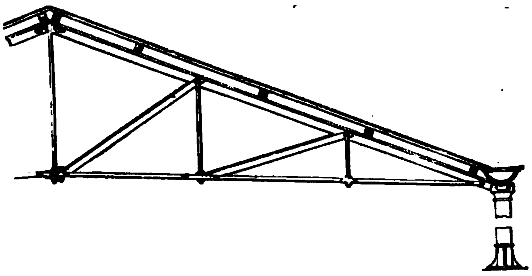


This upper frame, therefore, may be considered as a rigid structure, its weight and the weight of the roof coming upon the corner ribs, which transmit a horizontal thrust upon the upper frame. On the other hand, the horizontal strain is received by the lower frame on the bottom of the ribs, which acts as a tie.

A complete "self-contained" structure having been formed as above described, the intermediate ribs serve only as local supports for the roof covering, their weight being taken by the upper and lower frames, the corner ribs, and the columns; no horizontal thrust whatever being produced. This principle of dealing with the horizontal strains is very similar to the mode of construction adopted in domes; and although neither round nor polygonal in plan, the present structure may with justice be termed a domed or curb roof.

The total weight of cast iron in the building is 108 tons and of wrought iron 30 tons, the whole costing on an average about £17 per ton.

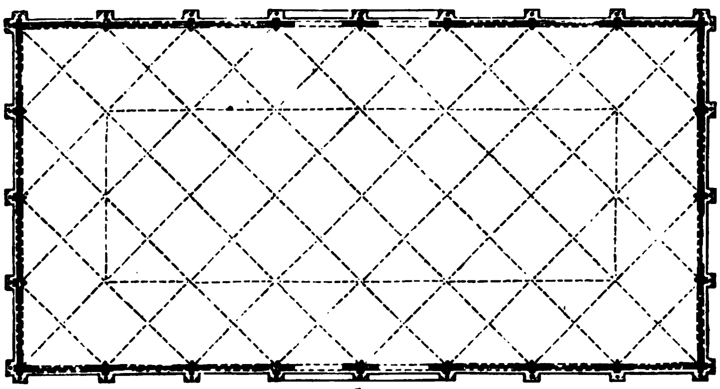
Example No. 41.—An iron workshop, 180 ft. long, 42 ft. wide, and open at the ends, made as a boat-building shed for the Royal Dockyard, Kidderpore, India, 1861. At intervals of 10 ft. along each side of the building, plain cast iron columns 12 ft. long and 8 in. diameter are placed to receive the roof principals. The principals are ordinary trusses, 40 ft. span, of the kind shown in Fig. 5, page 196, the rafters being T bars. 3½ in. by ½ in.; the diagonal struts, L bars; and the tension rods, round iron. The purlines are of timber, 5 in. by 3 in.,



supporting corrugated galvanised sheets, No. 18 gauge. Along the eaves are iron gutters 18 in. wide, made of sheet iron, and these gutters discharge the water into the columns.

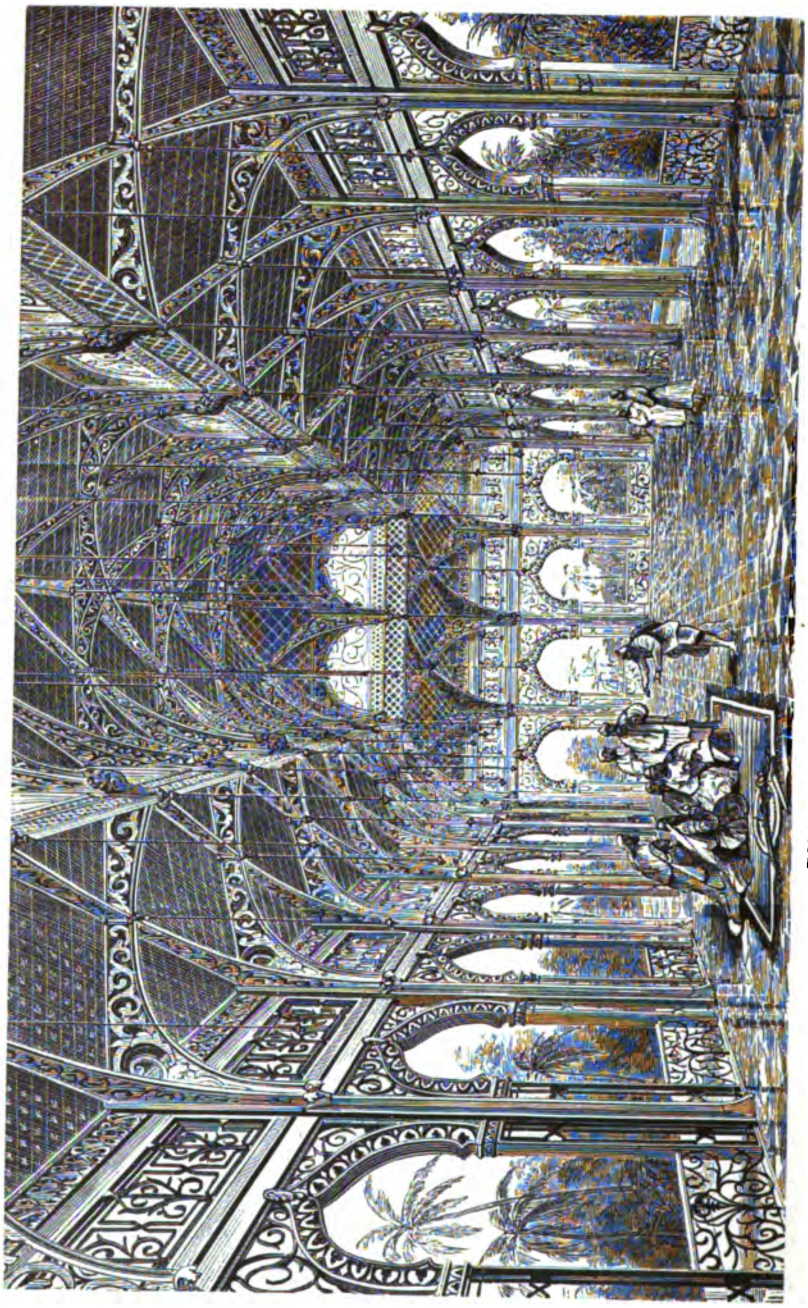
The building contains 15½ tons of cast iron, costing about £10 per ton; 10½ tons of wrought iron in the roof (exclusive of the covering), costing about £21 per ton; and 1½ tons in the gutters.

Example No. 42.—A kiosk for India, made entirely of cast iron, from the design of Mr. Owen Jones and Mr. R. M. Ordish. This building is 80 ft. long, 40 feet wide, 42 ft. high in the centre, and, as will be seen from the engraving on the next page and from the following description, is rather a remarkable



1

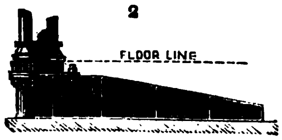
specimen of iron construction. Fig. 1 on this page shows a plan of the building, which, both in its length and width, is divided into equal bays of 10 ft., double columns standing at these intervals to support the roof. The roof ribs spring diagonally from each column, and by their intersection divide the entire roof into equal squares, thus making the hipped



EXAMPLE NO. 42. KIOSK FOR INDIA.

ends of the building the same as the rest of the roof, whereas generally the hips of a roof are of irregular construction.

The load on the roof, acting on the structure as if it were concentrated at the springing of the upper ribs, would tend to bend this point inwards, raising the crown at the same time under the influence of transverse strain, and turning the column round its base. To prevent this, and at the same time to maintain the light appearance of the visible parts of the structure, the base of the column beneath the floor level is rendered immovable by being secured by means of a number of $1\frac{1}{4}$ in. bolts to a girder of 10 ft. in length, which forms at the same time a foundation plate running inwards from the base of the column.



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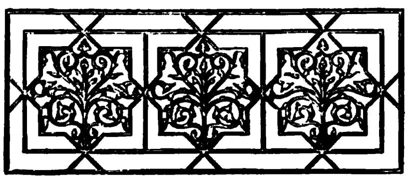
In consequence of this arrangement, the springing of the upper ribs and the crown cannot give way in the manner described; and, while the ribs can be regarded as being rigid near the eaves, the only strain acting on any part of the structure of the roof will be shearing strain; transverse strain being only applied to the girders. There is an almost entire absence of bolts in the roof, the intersecting ribs being dovetailed in an ingenious manner.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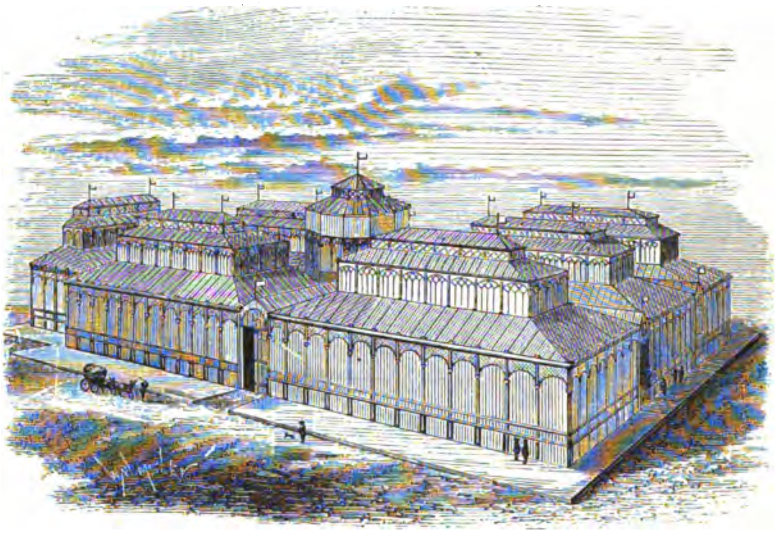
4

The ornamental detail has somewhat of a Moorish character, as will be seen from the engraving on page 250, and from the arabesque panels at the side of the building, shown in Figs. 3 and 4 above.

£550—a considerable part of the total cost—was expended on the patterns, which, owing to the peculiar nature of the design are applicable to a building of any greater length advancing by 10 feet. There are 202 tons of ironwork in the structure, costing, exclusive of patterns, about £13 10s. per ton. This does not include the floor nor the roof covering; the latter, if made of corrugated iron or zinc, being worth about £200.

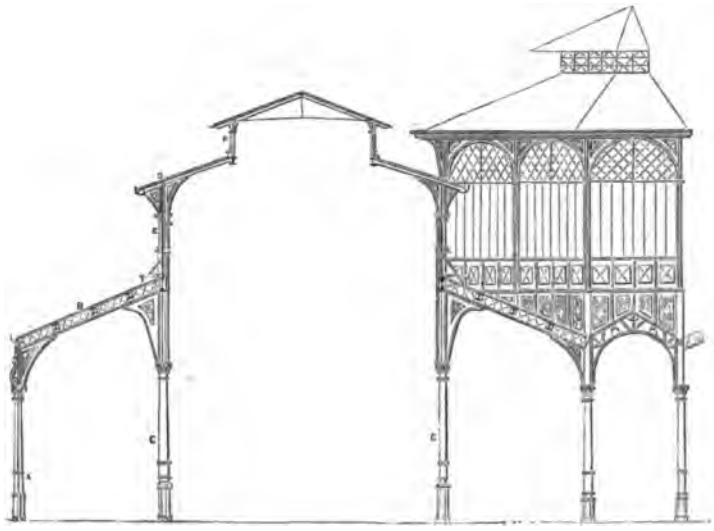
Example No. 43.—An iron market, designed by Mr. E. Mathieu for Madrid, and erected in the Place de la Cebada, in that city, in 1872-3. The market covers an irregularly shaped area of 66,000 square feet, and this space is occupied by four similar rectangular pavilions, three irregular pavilions, and one central dome. The pavilions are divided from each other by covered ways, 13 ft. wide.



Each of the four principal pavilions is 119 ft. long and 79 ft. wide, the irregular blocks having an outline somewhat similar, but modified so as to suit the shape of the area covered. The mode of construction is indicated by the engraving on the next page, which shows a cross section of one of the pavilions adjoining the dome. The roof is in three sections or stories, the uppermost story forming a lantern, the top of which is 60 ft. from the floor.

The exterior columns A are 35 ft. high, and are placed 9 ft. 10 in. apart. For 4 ft. from the ground the space between the columns is occupied by a stone wall, and for 18 ft. above the wall by cast iron sash-frames with glass louvres, the sashes being surmounted by an ornamental arched panel. Lattice girders B, acting as rafters, rest at the lower ends on the exterior framework, and at the upper ends upon the inner framework of columns and girders. Upon the rafters are longitudinal lattice purlines, stiffened at intervals by intermediate rafters.

The inner columns C are made in two lengths, the total height to point D being 47 ft. The clear span between the interior columns C C is 40 ft. The outer sides E of the second story consist of cast iron panels fitted in between the columns and filled with glass louvres, as described for the lower story. The sides F of the third story are filled in with light cast iron panels of simple design.



The whole of the pavilions, the covered ways, and the dome are covered with galvanised corrugated iron, except the roof of the third story, which is covered with glass.

The weight in each rectangular pavilion is approximately as follows :—

Cast iron	170 tons, costing about ...	£14 10s.	per ton
Wrought iron ...	70 ,, ,, ...	£21	,,

95 squares of corrugated iron, 25 squares of glass, in the lantern on the third story.

To this must be added the cost of erecting and painting the ironwork, the cost of glass louvres, glazing, fittings for stalls, &c.

All the ironwork is light, and the cast iron work is, besides, specially ornamental. The columns are fluted, and have elaborate and highly-finished capitals. The panels and other castings are of the same character, so that the expense of patterns and of fitting bears a considerable proportion to the total cost of the ironwork.

There are 94 squares in each rectangular pavilion, and it will be seen from the foregoing figures that the cost of the ironwork is about £40 per square, exclusive of corrugated iron. For the area covered by the irregular pavilions and the domes, a considerably larger sum per square would be needed.

Below the market, the entire area is utilised for cellars, and the cost of these is entirely distinct from that of the superstructure. The ground is excavated to a depth of 15 ft., and the market floor is composed of brick arches on iron girders. Cast iron octagonal columns, 10 in. diameter, and 13 ft. 6 in. long, are placed at intervals of 19 ft. 8 in., and are connected at the tops by plate girders 16 in. deep, running the whole length of the building. These lines of columns and girders are about 20 ft. apart, and this distance is spanned by rolled iron joists, placed 3 ft. 3 in. apart on the girders; and on the joists the brick arches are built.

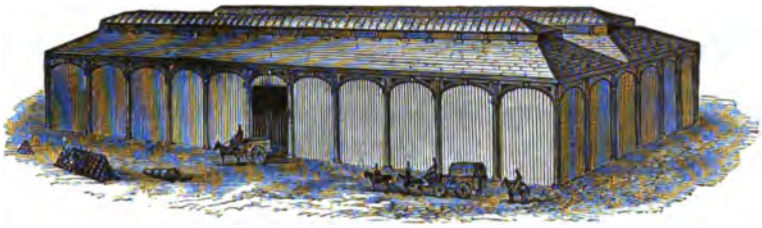
In the total area of the cellars (66,000 square feet) the weight of ironwork, including three staircases, is as under:—

Cast iron	226 tons,	costing about ...	£11 per ton.
Wrought iron...	460 „	„ ...	£19 „

In the cast iron is included the weight of light springers placed on the joists to act as skewbacks for the brick arches.

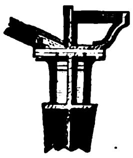
Example No. 43A.—An iron building at the Shell Foundry, Woolwich Arsenal, designed by the officers of the Royal Engineers. This building is 158 ft. long and 86 ft. wide, and, with the exception of a wall at one end, is entirely of iron. In length and breadth the plan is divided into bays of 14 ft. 4 in., and down the centre of the building a row of columns divides the total width of the roof into two spans of 43 ft. The columns are octagonal, as shown in the section, Fig. 4, and are 19 ft.

high, including 3 ft. above the capital, with an outside diameter of 9½ in. at the base. To the upper portion is attached the ends of the cast iron spandrel girder.



1

The roof principals, as shown in Fig. 3 below, are 7 ft. 2 in. apart, and occur alternately over a column and over the centre of a girder, in the latter case being attached as in Fig. 2. The principals are of the ordinary kind, shown in the diagram No. 5, on page 196; the rafters and diagonals being of T iron, and the verticals of round bars. The end principals, to which the hip rafters are attached, are stronger than the others. The purlines are of timber, and are fastened on each rafter by small L brackets, or cleats, as shown in Fig. 1, page 208. Diagonal wind ties are placed across the building at various points. The covering is of slates, on boarding 1½ in. thick.



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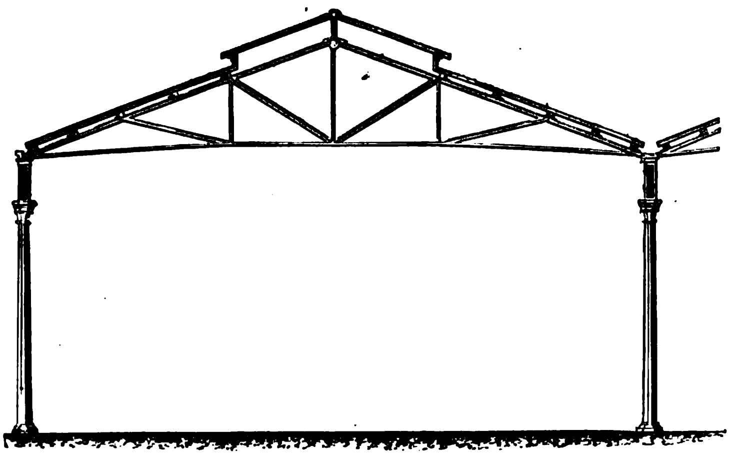

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At the top of each principal, a cast iron standard carries a longitudinal ridge purline, to which are attached wooden glazing bars. The lower ends of the glazing bars are carried by timber, supported by the purline below.

4

The two sides and one end of the building are enclosed by corrugated iron (not galvanised but painted), the sheets of which are attached to the side flanges of the columns, as shown in the section Fig. 4. At two points in the height of the column, namely at 8 ft. and 13 ft. from the ground, strong L bars are fixed horizontally from column to column to stiffen the corrugated sheets. Doors replace the screens in some of the bays, and some have the upper portion of glass.

Cast iron gutters rest on the girders along the sides and ends of the building, and a valley gutter similarly between the spans. Three columns at each side, and one at the end, serve as down pipes for the rain-water to the drains in the ground below.

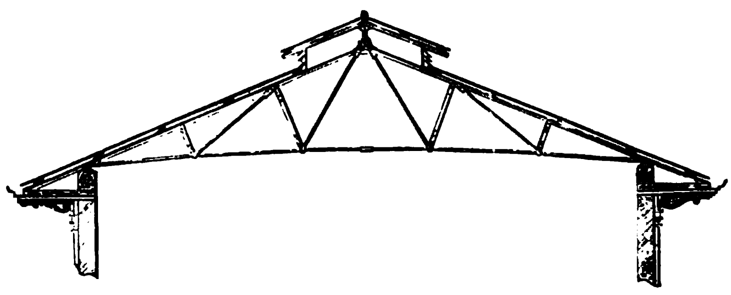
The weight and cost of the ironwork may be divided as follows :—

37 columns	36 tons,	costing about	£11 per ton.
Girders, gutters, and other cast iron	31 „	„	£12 „
Roof principals, and other wrought iron	28 „	„	£23 „

Corrugated iron (in roof alone), 16 gauge, 100 squares.

The building as here described is a type of a great number erected for the Government in the Woolwich Arsenal for storehouses, workshops, &c.

Example No. 44.—An iron roof, made in 1870, for covering the Wilberforce Memorial Hall at Sierra Leone. This building is 69 ft. long, and 44 ft. 6 in. wide within the walls, but the



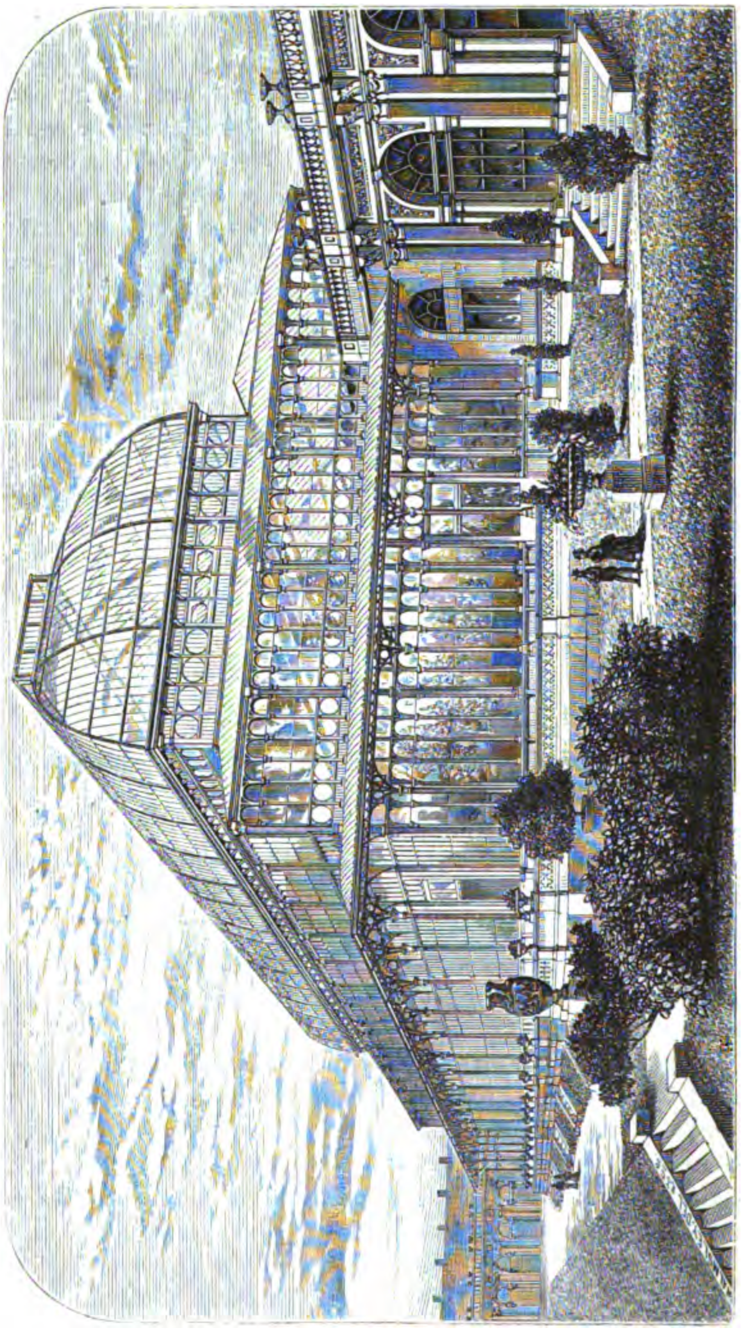
roof projects both at the sides and ends, and forms a covering 79 ft. by 66 ft. 6 in. There are eleven principals of the form shown in the engraving, placed about six feet apart, one principal being fixed just inside each end wall, and the walls themselves built up as gables. In each tension rod is a screw coupling for adjustment, and the truss is altogether a good specimen of design, with details neatly formed. The main rafters are of T iron, 4 in. by 4 in., and the diagonal struts are of L iron, 3 in. by 3 in. On each side of the roof there are five rows of purlines formed of L irons, fastened to L cleats on the rafters, as at Fig. 2 on page 208, and at the ridge there is a T purline. At the top of the roof there is a ventilating space, with side louvres, supported on cast iron brackets fixed to the rafters. At the side and end eaves, where the roof projects, ornamental cast iron brackets support the overhanging rafters and purlines. The roof is covered with galvanised corrugated iron, 16 gauge, and along each side there is a cast iron gutter 15 in. wide, with four down pipes, the water being conducted to them along the top member of the brackets. The weight is as under:—

10¾ tons of cast iron, costing about £14 5s. per ton.
10¼ „ wrought iron, „ £22 10s. „

Of the galvanised iron there are about 7½ tons, which, with the louvre blades of the same material, cost about £240.

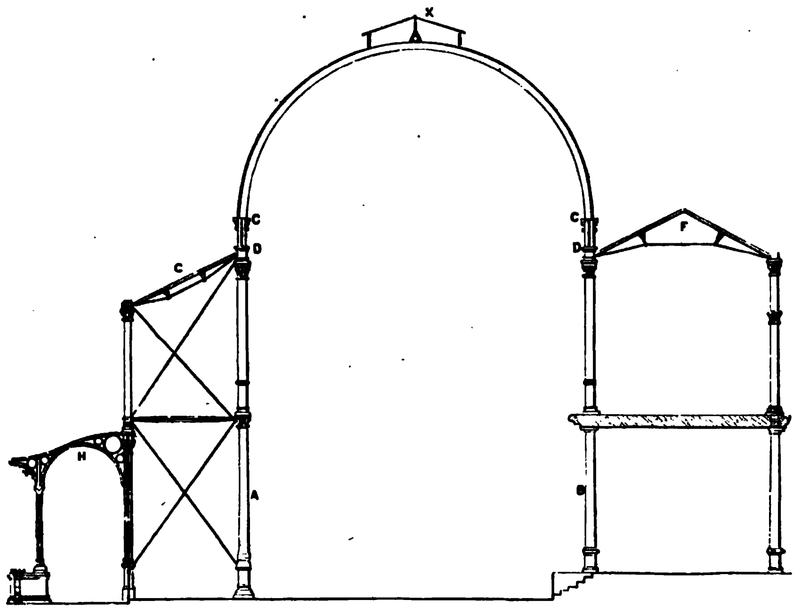
Example No. 45.—A conservatory or winter garden, of iron and glass, designed by Captain Fowke, R.E., for the gardens of the Royal Horticultural Society, London, and erected in 1860. The general appearance of the building will be seen from the engraving on the next page, which is copied from a photograph.

The conservatory is 210 ft. long, with a central aisle of 45 ft., covered by an arched roof, as shown on the cross section on page 259. The columns A and B are each made in two lengths, with an average diameter of 8 in. and are 49 ft. high to the springing of the roof. The crown of the arch is 71 ft. from the ground; the main ribs or principals are placed 15 ft. apart, and the roof is hipped at the ends. The ribs are 14 in. deep, and are each composed of a web plate ½ in. thick (pierced to an ornamental pattern) and four L irons, 2½ in. by 2½ in. A large



EXAMPLE NO. 45. CONSERVATORY IN THE ROYAL HORTICULTURAL GARDENS, LONDON.

cast iron gutter girder runs round the building on the outside at the foot of the arched ribs to which it forms a curb. At the top of the arched ribs a portion K of the roof, 15 ft. wide, is raised 5 ft. for ventilation. The purlines are of T iron, 6 in. by 4 in., and upon them rest glazing bars of cast iron arranged for panes of glass 14 in. wide. A space 7 ft. 6 in. deep (C to D) between the columns, below the springing of the arched ribs, is filled in with a framework of cast iron and wood, and fitted with circular opening casements.



On the north side of the building (on the right of the engraving on page 258), a space 240 ft. by 24 ft., forming the entrance corridor, is covered by an ordinary trussed roof F, carried on each side by cast iron girders on columns. The principals for this roof are placed 7 ft. 6 in. apart, and are made with 3 in. T rafters and cast iron struts. The roof is covered by glass in cast iron sash bars, carried on light T purlines.

On the south side of the central span is a small lean-to roof with principals of 3 in. T rafters G trussed, and light T purlines glazed in the same way as on the 24 ft. roof described above.

On the east, west, and south sides of the main building is a verandah 11 ft. 6 in. wide, covered with galvanised corrugated iron. The principals H are placed 7 ft. 6 in. apart, and are each made of two 3 in. T bars back to back with wrought iron rings between. The verandah is supported on the outside by light cast iron octagonal columns, 13 ft. high and 4 in. diameter.

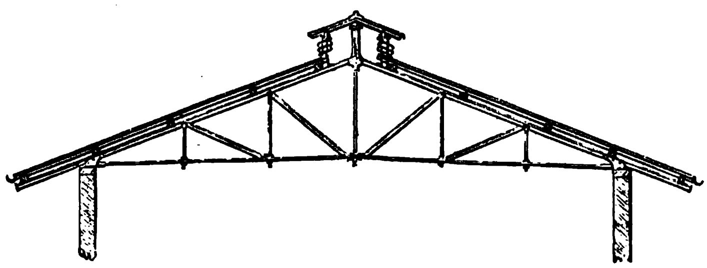
The sides of the conservatory between the columns are filled in with neat wooden frames with arched panels, the whole being glazed with clear glass.

The total area covered by the main and side roofs as here described is 271 squares, and the wood and glass form a considerable proportion of the total cost. But the weight and cost of the ironwork may be stated as follows:—

Cast iron,	157 tons,	...	costing about £14	per ton.
Wrought iron,	70 ,,	...	,, £26	,,

The chief characteristic of the conservatory above described is the extreme lightness of its parts. The design, both as a whole and in its details, is elegant and symmetrical, but the lightness of the castings is carried to a point which is perhaps excessive. In the construction of a similar building, the same general appearance might be maintained, but greater strength given, without increasing the cost, by a slight addition to the weight of the ironwork, and by a better arrangement for receiving the thrust of the arched roof.

Example No. 46.—A workshop, 200 ft. long and 46 ft. wide (measured inside the walls), with an overhanging roof hipped at the ends. The roof rests upon brick walls 18 in. thick and



21 ft. 6 in. high, the principals being placed about 8 ft. apart. The principals are of the ordinary trussed kind, 8 ft. 6 in. high in the centre, the tie rod being raised 12 in. above the horizontal

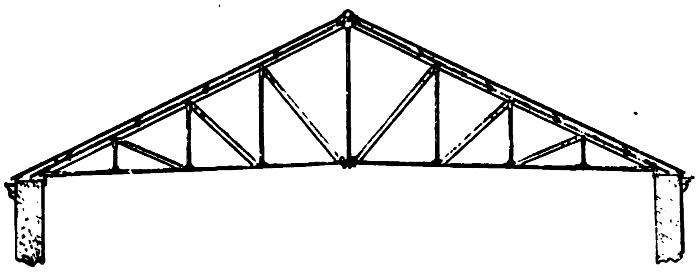
line. The rafters are T bars 4½ in. by 3½ in., projecting 5 ft. 6 in. beyond the wall to carry the overhanging eaves, thus making the total width of the roof 60 ft. The diagonal struts are T bars, 3 in. by 2½ in., the tension rod is 1¼ in. in diameter and the vertical rods are ¾ in., ⅞ in., and 1⅛ in. diameter respectively. The hipped ends of the roof are divided into equal spaces, as shown on page 193.

The roof is raised at the centre for a width of 8 ft. to provide ventilation. Louvre standards support the roof covering above, and the standards are fitted with curved louvre blades of zinc. (See page 234.)

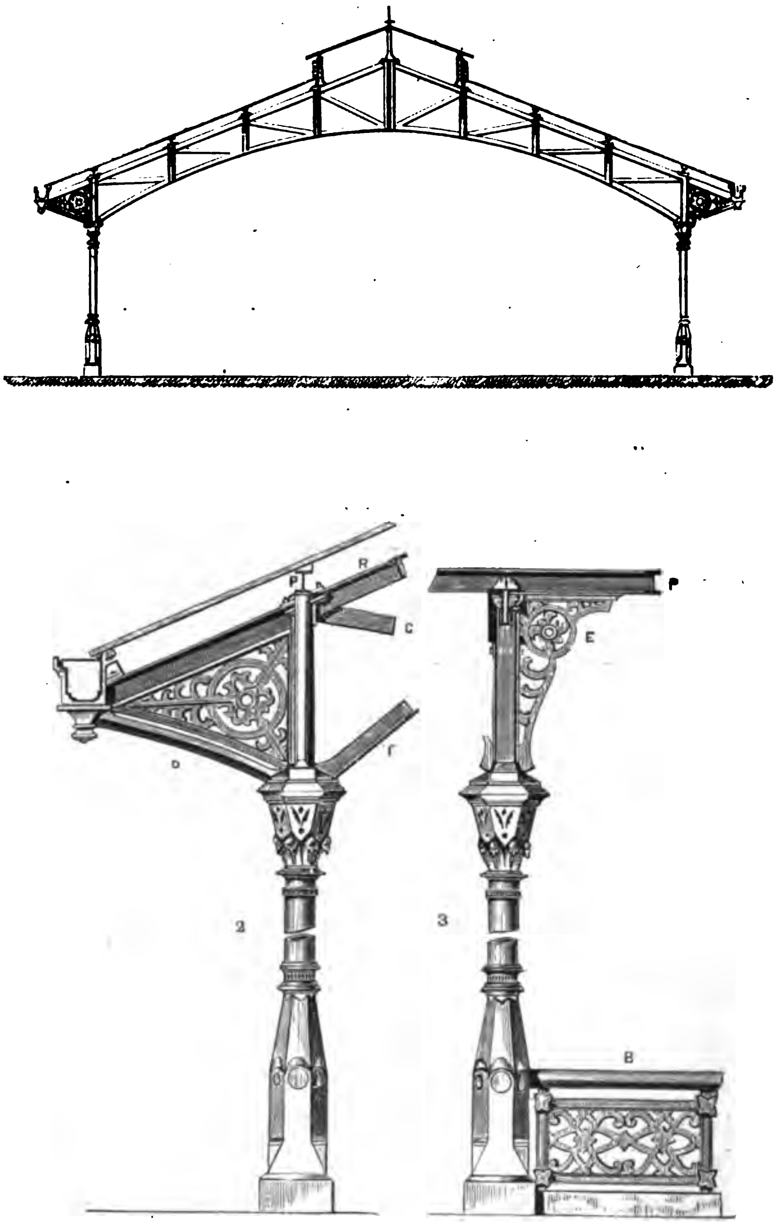
Upon each side of the roof, five lines of timber purlines, 7 in. by 4½ in., are carried by the rafters, and a timber purline, 6 in. by 4 in., is also carried on each of the three louvre standards. The purlines on the rafters rest against and are bolted to L iron "cleats," as shown in Fig. 2, page 208. The roof is stayed by wrought iron wind ties.

The ironwork in the roof weighs 23½ tons, costing about £22 5s. per ton, and there are 130 squares of zinc, laid in the Italian manner.

Example No. 47.—An iron roof over a warehouse, 70 ft. long by 50 ft. wide (measured inside the walls), with gable ends. The walls are 2 ft. 3 in. thick, and there are eleven roof principals at intervals of 6 ft. 11 in., one being placed directly inside each gable wall.



The roof trusses or principals are 11 ft. 6 in. high, the tension rod being at the centre 12 in. above the horizontal line. The rafters are T bars, 4 in. by 4½ in., the diagonal struts are T bars, 2½ in. by 3 in., the tension rod is 1½ in. diameter at the ends and 1¼ in. diameter in the middle, and the vertical



EXAMPLE NO. 48. IRON BUILDING AT NICTHEROY, BRAZIL.

rods are $\frac{3}{4}$ in., $\frac{7}{8}$ in., 1 in., and $1\frac{1}{4}$ in. diameter respectively. The junction points of the central vertical king rods, with the tension rods in each principal, are connected by a tie rod $1\frac{1}{4}$ in. diameter, running longitudinally from end to end of the building. At the top of the roof a longitudinal ridge piece of wood, 5 in. by 4 in., is carried by a T bar 3 in. by 3 in., which acts as a stay between the top of each principal.

Upon each side of the roof, six lines of T iron purlines, $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in., rest against L iron cleats upon the rafters. Upon the purlines is laid a covering of corrugated iron (painted and not galvanised), 16 B.W.G.

A cast iron gutter, 10 in. wide, is placed along each of the eaves, and there are two down pipes on each side for the rain-water.

The iron roof weighs 17 tons, and costs about £20 per ton. This is exclusive of the covering, of which there are 41 squares.

Example No. 48.—An iron building, 162 ft. 6 in, long, and 50 ft. wide, made in 1869 for the Nictheroy Gas Works, Rio de Janeiro. The dimensions given are those between the centres of the columns, but the eaves overhanging 5 ft. increase the total space covered by the roof to 172 ft. 6 in. by 60 ft. The building has a hipped roof, and is divided both at the sides and ends into bays of 12 ft. 6 in., the columns and roof principals being placed at those intervals. The columns are fixed on base plates below the ground, and are 13 ft. 6 in. high to the springing of the roof. The building is open at the sides, but an ornamental railing of cast iron, 3 ft. high, as shown at B, Fig. 3, is fixed between the columns; three panels of railing filling each bay.

The roof principals are of the kind shown in Fig. 7, page 196, and are 6 ft. high in the centre, the curved tension member having a rise of 7 ft. 6 in. The rafters are each composed of two L bars, 4 in. by 3 in., and the tension members are similarly constructed. The central vertical or king post consists of four 3 in. L bars, back to back, and the other verticals of two 3 in. ⊔ bars, back to back. The two diagonals (almost horizontal) on each side nearest the eaves are each made of one 4 in. flat bar; the four diagonals in the centre of the roof each of one 3 in. bar. The rafter projects at the eaves and is supported by the cast iron bracket D, which by its connection to the rafter, to the vertical channel iron, and to the column, renders the whole framework rigid and complete. The bottom member of the bracket is hollow, and conducts the rain-water from the eaves gutter to the column, which acts as a down pipe.

The purlines P are rolled I joists, fixed at intervals of 6 ft. 6 in. in small cast iron shoes on the rafters, and braced to the vertical members of the principals by cast iron brackets E, as shown in Fig. 3.

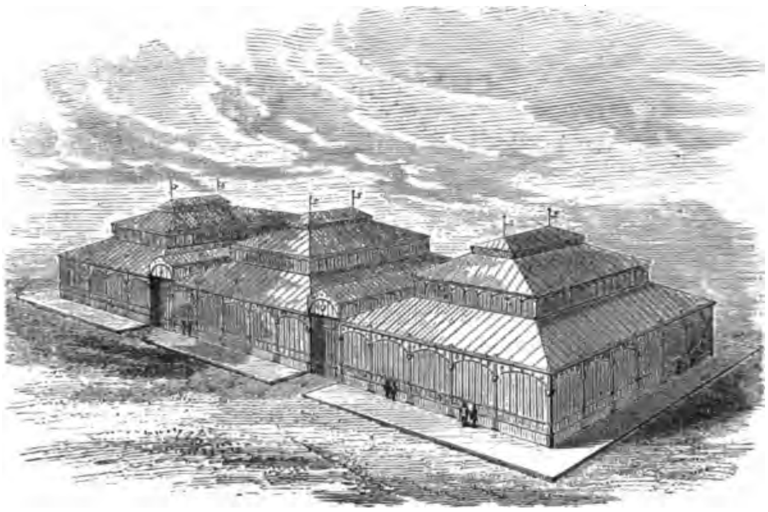
The central portion of the roof for a width of 12 ft. is raised 2 ft. for ventilation, louvre blades being fixed upon cast iron standards, as shown in Fig. 1. The ridge of the roof is surmounted along its whole length by an ornamental cast iron cresting.

Light timber rafters are placed on the purlines in the manner represented by the dotted lines in Fig. 3, page 208, and boards are nailed to these rafters to receive the outer covering of slates. The timber and slates were sent with the ironwork from England to Nictheroy.

The weight and cost of the ironwork may be divided as follows:—

34 columns and base plates,	22 tons,	costing about	£12 10s. per ton.
Railing panels and handrail,	7¼ "	"	£13 10s. "
Cast and wrought iron in roof; bolts, &c. ...	55 "	"	£21 "

Example No. 49.—An iron market, designed by Mr. E. Mathieu, for Madrid, and erected in the Placa de los Mostenses, in that city, at the same time as that in the Placa de la Cebada, described in Example No. 43. Though similar to the latter in structural arrangement, the present Example is more simple, both as regards the shape of the area to be covered and the ornamentation of the ironwork. The market occupies an area of 38,500 square feet, and consists of three rectangular pavilions, each 127 ft. long and 90 ft. wide, separated by covered ways 16 ft. 6 in. wide. The clear span within the interior columns is 54 ft. The roof is in three stories, as in the Cebada market, and the cellars underneath are precisely similar.



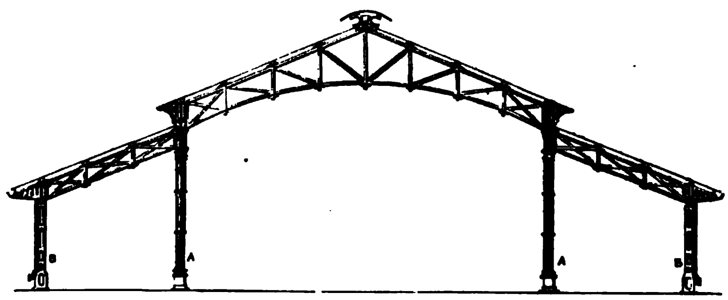
The weight and cost per square of the cellar ironwork is about the same as for the Cebada market; but for the superstructure, although the weight per square is approximately the same, the cost per ton is rather less, because of the greater simplicity in regard to the ornament and details generally.

CHAPTER XXVII.

EXAMPLES OF ROOFS AND BUILDINGS CONTINUED. SPANS UP TO 100 FEET.

(For the assumed value of iron in the following Examples, see page 239.)

Example No. 50. — A sugar factory, 276 ft. long and 125 ft. wide, made for Trinidad in 1871. The entire framework of the building is of iron, the roof being supported on columns which are independent of the walls. As will be seen from the engraving below, which shows a cross section of the building, the roof is divided into three spans. The centre span



is 65 ft., the side spans each 25 ft., and with the addition of eaves overhanging 5 ft. on each side, the total width covered is 125 ft. The roof is divided into bays of 15 ft. 4 in., the inner rows of columns A and the outer stancheons B being placed at these intervals. The building is enclosed at the sides and ends by walls, into which the stancheons are built, but the walls act merely as screens, and do not carry any of the weight of the roof.

The centre or main principals are trusses of the form shown in the engraving, firmly attached to the columns. The rafters are each composed of two L bars, 4 in. by 3 in., and the curved tension member below is made in the same way. The diagonal members are struts formed of two T bars, 4 in. by 2 in., placed back to back, as in Fig. 2, page 69. The verticals are each formed of two flat bars 3½ in. wide. The connections with the rafter and with the lower member of the truss are each made by a single turned pin.

The side principals are light lattice girders, this form being adopted for the headroom they afford below. The stancheons are united by upper and lower cast-iron wall-plates, the space between the two being filled in with light gratings, and these latter serve as glazing frames or for ventilation. In the same way the inner columns A are united at the top by wrought iron lattice girders, the upper parts of which are open for ventilation, and the lower parts glazed in cast-iron frames. Purlines of trussed T iron are placed every 9 ft. above the vertical members on the side and main principals. The walls at the end of the building are built up as gables, but the roof framing is independent of these. The roof is entirely covered by galvanised corrugated sheeting, 18 gauge, spiked down to wood fixed on the top of the purlines.

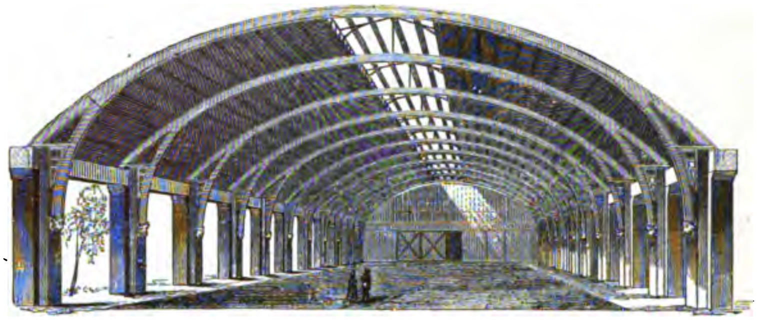
The weight of the ironwork is as follows, exclusive of doors and windows:—

38 columns	67 tons	costing about £13 per ton.
38 stancheons	22 „	
Other cast iron	78 „	
Wrought iron in principals, purlines, wind ties, &c.	124 „	„ „ £21 „
Bolts and nuts	6¼ „	„ „ £34 „

Galvanised roofing sheets, 415 squares.

Example No. 51.—An iron roof 120 ft. long and 66 ft. span, made for a saw mill at Bombay. The main principals of this roof are arched wrought iron ribs, each composed of a web plate 12 in. deep and four L irons 2½ in. by 2 in. The ends of the arched ribs are forked, as shown in the engraving, one member resting on the top of the wall, and the other being carried down to a stone corbel built into the wall.

The principals are placed 10 ft. 10 in. apart, and on the top of each are three cast-iron standards supporting a secondary roof of 12 ft. span, the sides of which are closed with hinged cast iron frames fitted with wooden shutters, which can be opened for the purpose of ventilation. The purlines are composed of timbers 4½ in. by 3 in., secured at each principal by L iron cleats.

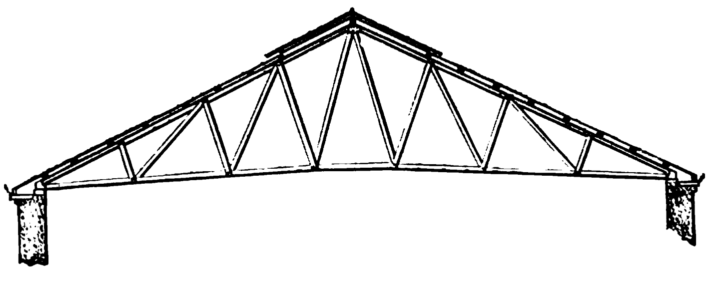


The wind bracing is made of ⅝ in. round iron. With the exception of the raised skylight the roof is all covered with zinc.

The total weight of ironwork is :—

Cast iron...	3¼ tons, costing about	£18 per ton.
Wrought iron	21¼ „ „	£24 „
Zinc	79 squares	(See page 217.)

Example No. 52.—An iron roof 156 ft. long and 66 ft. span, erected over the goods station of the Midland Railway at Bath, in 1869. The building is of brick, with gable ends, the walls being 2 ft. 3 in. thick. The principals, which are trussed and of the form shown in the engraving, are placed at intervals of 6 ft. The rafters are T bars 4 in. by 4½ in., and the struts

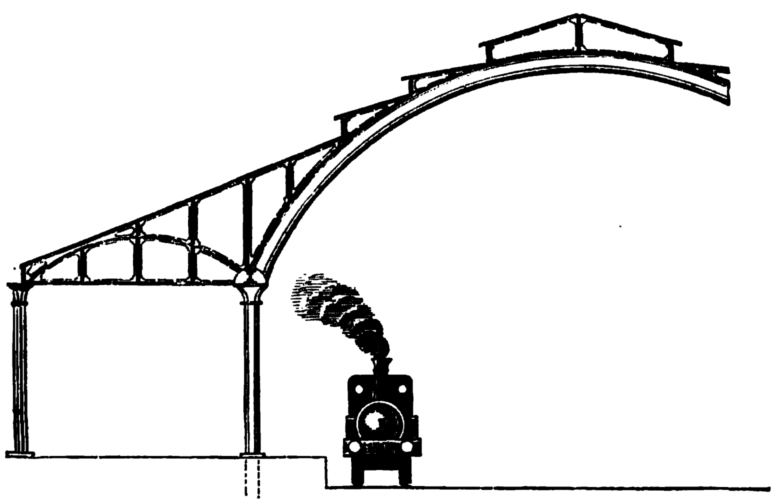


are made of two flat bars, 3 in. by 3⅛ in., with cast iron distance pieces between them. The tension member is also composed of two flat bars ⅝ in. thick, and from 2 in. to 2¾ in. wide; it is raised in the centre 18 in., the height of the principal at this point being 13 ft. 6 in. At the top of the principal a small cast-iron standard is placed to raise the roof covering 7½ in., and this raised portion of the roof is glazed on iron sash bars.

On either side of each principal there are seven purlines composed of L bars, 3½ in. by 2½ in., and timbers 3 in. by 2 in., upon which boards are nailed to receive the slate covering. Cast-iron gutters, 8¾ in. wide, are placed at the eaves, and there are four down pipes on each side of the building. Each roof principal weighs 25½ cwts., and the total weight of iron-work, including the gutters, is 55 tons, costing about £19 per ton.

There are 88 squares of slating on boards, and nine squares of glass ⅜ in. thick.

Example No. 53.—The engraving on this page shows a cross section of the Midland Railway passenger station at Bath, designed by Mr. J. S. Crossley, and erected by A. Handyside and Co. in 1869. The building is 300 ft. long, with a centre span of 66 ft., and two side spans of 23 ft., but for a length



of 146 ft. on one side of the station, another span of 23 ft. is added to cover a cab-stand, making the total width along this portion of the building 135 ft. The roof is divided into 14 bays, of about 20 ft. 9 in., and at these intervals octagonal cast iron columns, 16 ft. high above the level of the passenger platform, are placed to carry the roof principals. The arched ribs of the centre span are of wrought iron, in section like plate girders, 1 ft. 9 in. deep, and 1 ft. 2 in. wide. The ribs are united by wrought iron purlines, made as lattice girders, and from the ridge to the lowest of these purlines the roof is glazed on wrought iron sash bars, which rest upon the purlines, as shown in the engraving.

The side spans are made with cast-iron principals, framed to the centre roof, and adding to its stability. The purlines are of wrought iron, and the roof is covered by slates on boarding.

For a length of 125 ft. on each side of the station, the outer ends of the small principals are carried on a stone wall; at all other points iron columns serve this purpose.

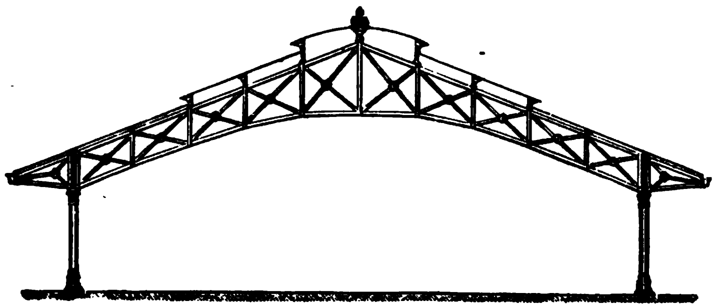
The inner end of the roof is closed by the station buildings, the outer end by a gable screen of glass and iron.

The ironwork may be divided as follows:—

54 cast iron columns,	87 tons	costing about £11 per ton.
Other cast iron ...	102 ,,	
15 wrought iron arched principals	77 ,,	,, £19 10s. ,,
Other wrought iron, including side roof	134 ,,	
Wrought iron in screen	9 ,,	,, £26 10s. ,,

Example No. 55.—An iron building, erected on the Wellington Pier, Bombay, as a shelter for carriages or for merchandise. The shed is 96 ft. long and 86 ft. wide, but the span between the columns is only 70 ft., the overhanging eaves of the roof making up the difference. The columns are 1 ft. diameter, and 12 ft. 9 in. high to the springing of the roof, but they are continued 4 ft. 6 in. higher, so as to unite firmly to and form part of the roof truss, which is somewhat similar in kind to that shown in Fig. 7, page 196.

As will be seen from the engraving, the principals are each divided into ten bays, having cross bracings between the verticals, and these being made alike in section (each vertical is composed of two ⊔ bars 4½ in. wide) and in their connections, act either as struts or ties, and serve equally to resist the load or pressure from above, or the wind pressure from below.



The trussed principals are of wrought iron, the rafter being made of 2 L bars, between which the diagonals—each a flat bar 4 in. wide—enter and are fixed. The principals are placed 14 ft. apart; they are each 9 ft. deep in the centre, and the total height from the ground to the ridge is 31 ft. The purlines are of wrought iron; there is a longitudinal bracing in the centre of the roof between each span, and there are diagonal wind ties close underneath the covering. Ventilation is provided near the ridge, and also on each side, half-way between the ridge and the gutter.

Rain-water is carried from wrought iron gutters by wrought iron pipes to the columns, through which it passes to the ground. The covering is of corrugated galvanised iron sheets, 18 gauge.

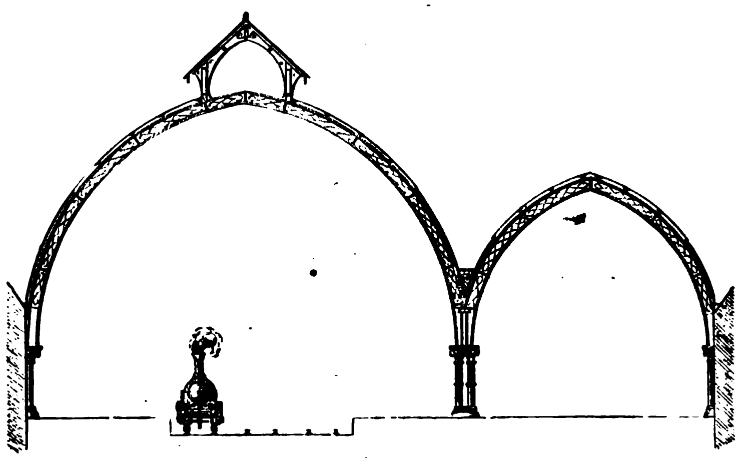
The building was designed with a specially ornamental character, the columns being octagonal, with enriched capitals, and all the details neatly finished.

The weight and cost of the ironwork may be divided as follows:—

12 columns ... ... 15½ tons, } costing about £15 per ton.
Other cast iron ... ... 3¾ „ }
Wrought iron in principals, purlines, &c. ... 31 „ „ £25 10s. „
Galvanised corrugated iron covering No. 18 gauge, 10 tons.

Though the above prices are apparently high, the total cost of the building or the cost per square is not great.

Example No. 55^A.—A roof over the railway station at Middlesboro', for the North Eastern Railway Station, *Works in Iron.*



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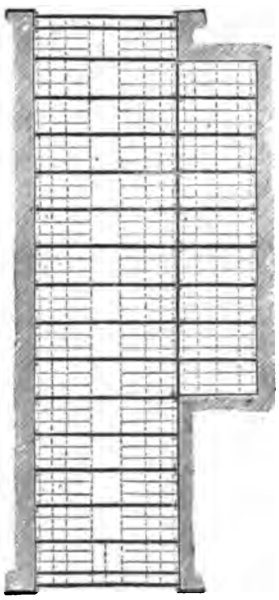

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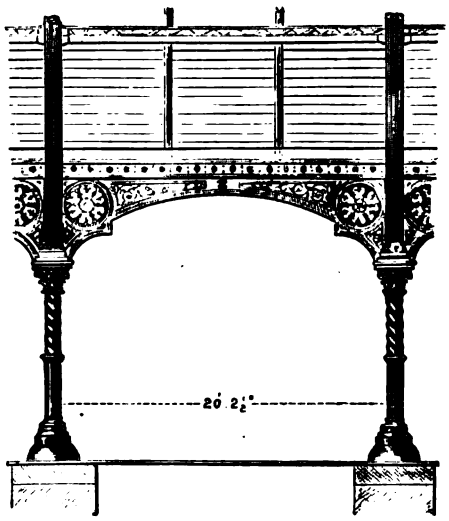


3

EXAMPLE NO. 55^A^.

designed by Mr. W. Peachy, Architect of the Company, and erected by Andrew Handyside & Co., 1876. The station is 309 ft. long, covered for 180 ft. of that length by two spans, one of 74 ft. (in the clear), and one of 43 ft. 2 in., and for the remainder by the larger span only, this arrangement being shown in the plan Fig. 2. The arches are pointed in a somewhat gothic style, and are not tied or trussed, the thrust outwards being taken by the walls, which are sufficiently buttressed by outer buildings not shown in the engraving. In the plan, Fig. 2, the thick lines show main ribs, the thin lines intermediate rafters, and the dotted lines purlines. The main ribs are placed 20 ft. 2 in. apart, and spring from stone columns or pilasters attached to the walls, and from pairs of iron columns where the two spans meet. The pairs of iron columns are connected longitudinally by wrought iron box girders pierced and ornamented with pateræ, and with ornamental cast iron spandrils, filled in as shown in Fig. 3. The ribs for the 76 ft. span are formed as triangulated ribs 2 ft. deep, with flanges 12 in. wide, the upper flange being composed of two plates $\frac{3}{8}$ in. thick, riveted to a T iron 5 in. × 4 in. × $\frac{1}{2}$ in., and the lower flange of one plate $\frac{3}{8}$ in. thick attached to a similar T iron. The diagonals are channel bars $2\frac{1}{2}$ in. × $1\frac{1}{2}$ in. × $\frac{1}{4}$ in. There are eight lines of purlines in the large span, each made as a lattice girder 1 ft. 6 in. deep, widened out at the ends to the width of the arched ribs which it intersects. Upon the purlines are placed intermediate rafters, which are single T bars 4 in. × 4 in. × $\frac{1}{2}$ in., the feet of these rafters resting at one side on the wall, and on the other upon the girders between columns. At the crown of the arch is a raised ventilating roof, as shown in Fig. 1, formed of cast iron spandrils placed on the main ribs, having wood louvres at the sides, and covered by slate on timber rafters. From the springing to the second line of purlines the roof is covered with slates on boarding, and from these upwards to the sides of the ventilating roof by glass in iron sash bars. The glass covering terminates at the distance of one bay from each end, the portions thus left being covered with zinc upon boarding. The main ribs for the 43 ft. span are similar to the large ribs but smaller, the rib being 18 in. deep, and the flange plates 9 in. wide. There are six lines of purlines, but these are only 1 ft. 2 in. deep, the intermediate rafters being

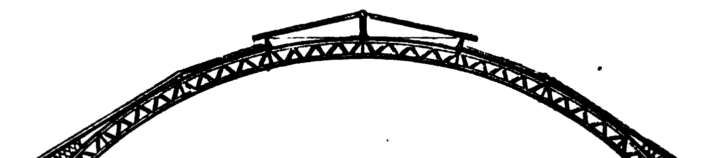
T

similar to those in the larger span. At each end of the station two main ribs are placed close together to carry the screen. These screens are formed of wrought iron framing glazed in wooden sashes, and reaching to within 15 ft. 3 in. of the rail level. There are some small side roofs, and other minor structures, but exclusive of these, the weight and value (exclusive of fixing) of the ironwork described above is as follows:—

In Main ribs for large span	155 tons.	About £20 15s. per ton.
„ Purlines do.	55 „	
„ Intermediate rafters do.	20 „	
„ Ventilator and other ironwork	26 „	
„ Main ribs for small span	30 „	
„ Purlines do	20 „	
„ Intermediate rafters do.	9 „	
„ Box girders between columns	10 „	
„ Other ironwork	5 „	
Eight pairs of cast iron columns	20 „	£14 5s.
Cast iron spandrils between columns and longitudinal stays between principals	52 „	

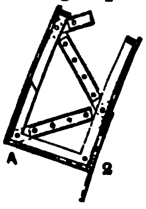
The gutters are of lead.

Example No. 56.—A Drill Hall, 150 ft. long and 75 ft. wide, erected at Derby, in 1870, for the 1st Derbyshire Rifle Volunteers. The construction of this building, as an example of an iron roof complete in itself and independent of the side



walls, is somewhat peculiar. There are nine main ribs of wrought iron, placed at intervals of 15 ft. These ribs are 2 ft.

deep, of an open triangulated girder section, the flanges each being formed of two L irons 3½ in. by 3½ in. (the bottom flange having a plate 9 in. wide besides), and the diagonals each of a



flat bar 3 in. by ½ in., stiffened with two bars 2 in. by ¾ in., one riveted on each side. It will be seen from the engraving on page 274, that the ribs spring from the ground, the crown of the arch being 30 ft. from the ground, the lowest part (from A downwards in Fig. 2) being of cast iron. There are seven lines of purlines, made as light wrought iron triangulated girders, of the same depth as the main ribs which they intersect. From the crown of each alternate arch, T bars, fixed as wind ties, descend diagonally under the roof covering to the springing of the rib three bays distant, crossing the intermediate ribs at the points where the purlines intersect. For a width of 21 ft. at the upper and raised portion of the roof, the covering is of glass, the sides of the framing above the purlines at these points being arranged for ventilation by means of wooden hinged shutters. The rest of the roof is covered with slates on wood boarding.

This building has served its purpose admirably, the open space unobstructed by columns allowing the whole area to be utilised. Although the building is enclosed by walls, the latter serve only as screens, and do not in any way support the roof.

The weight and value of the ironwork may be divided as follows:—

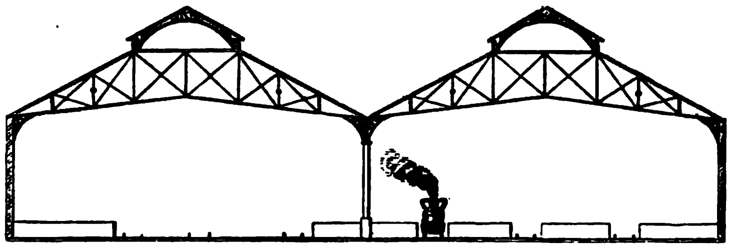
	Tons.		per ton.
Wrought iron in 9 arched principals, 70 lattice purlines, wind ties, bolts, &c.	46,	costing about	£20 10s.
Cast iron in standards, spandrils, and louvre standards	26	,,	£14 10s.

The cast iron gutters are not included above.

In 1876-7 A. Handyside & Co. constructed a roof of the same character and the same span (75 ft.) but 257 ft. long, for the terminal railway-station at Cape Town, South Africa.

The design of the Derby building was also adopted by the Admiralty for the Gymnasium of the New Naval College at Greenwich.

Example No. 57.—The terminal station of the London and North-Western and the North London Railways at Broad Street, London, designed by the engineer of the L. & N. W. Railway, and erected in 1865. The part of the station from



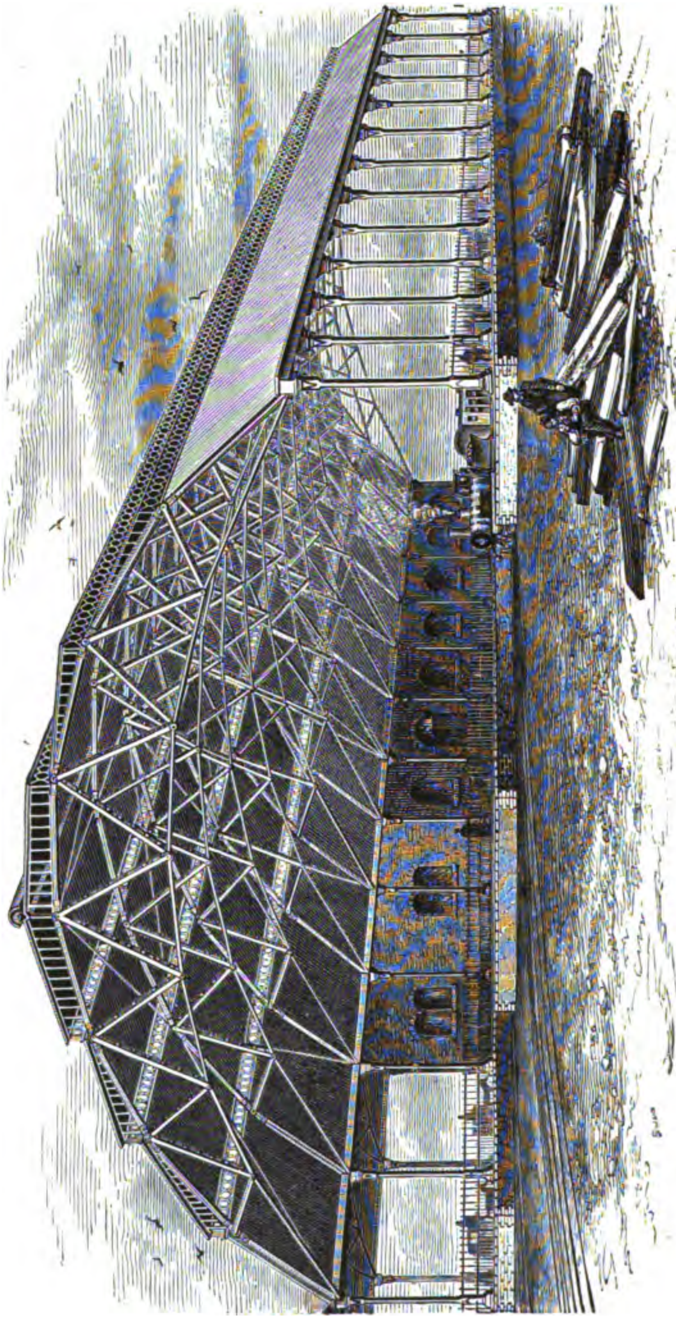
which the trains depart is 484 ft. long and 190 ft. wide. The roof is divided into two spans of 95 ft., which spring from the outer walls and meet in a line of centre columns, as shown in the illustration above. The columns are handsome and well proportioned; they measure 20 ft. in height with an average diameter of 15½ in., and the bases and capitals are enriched with loose foliage. The columns are placed 36 ft. 10 in. apart, and the roof is divided into similar spaces.

The roof principals are of the shape shown in Fig. 8, page 196, but without the struts there shown. The rafter or upper member is a riveted plate girder 9 in. deep, trussed by one vertical cast iron strut and tension rods. With this exception the principal is not a truss proper, the diagonal rafters and the horizontal upper member being in other respects constructed as a tied arch. Longitudinally in the building, the columns are connected by wrought iron lattice spandril girders, 9 ft. 2 in. deep at their springing from the column capitals, and 1 ft. 8 in. deep at the centre. On each side of each span, at the vertical member nearest the eaves, the principal is intersected by longitudinal lattice girders or purlines, 3 ft. 3 in. deep, and upon the rafters at the points where they become horizontal, there are purline girders 3 ft. 9 in. deep. Two intermediate rafters, made like the main rafters, but without the horizontal top member, occur between each main principal, thus dividing the space of 36 ft. 10 in. into three smaller bays. The intermediate rafters on the outer sides of the building spring from the walls, and at the centre of the building from the spandril girders, their upper ends being attached to the bottom flanges of the upper purlines. Cast iron arched spandrils spring from the upper purlines, which are fitted with open louvre blades for ventilation. Two rolled **I** iron purlines 6 in. deep, and five **T** purlines on each side rafter, receive the covering. The raised part of the roof, and also a space 11 ft. wide on each side of each span, are covered with glass on wooden sash bars, and the remainder by slates on boarding. The whole roof is strongly braced by wind-ties, which, in this design, are specially necessary for the security of the structure.

The weight of the ironwork in the roof is as follows:—

14 ornamental columns	60 tons,	£13 10s.
Other cast iron, principally light and ornamental	210 "	£14
Wrought iron	510 "	£23 10s.

This weight is for the main roof only, and is exclusive of other roofwork on the end of the platform, that over the offices, and the carriage portico in front of the station, all of which were erected by A. Handyside & Co. at the same time.



EXAMPLE NO. 58. THE AMSTERDAM STATION OF THE DUTCH-RHENISH RAILWAY.

CHAPTER XXVIII.

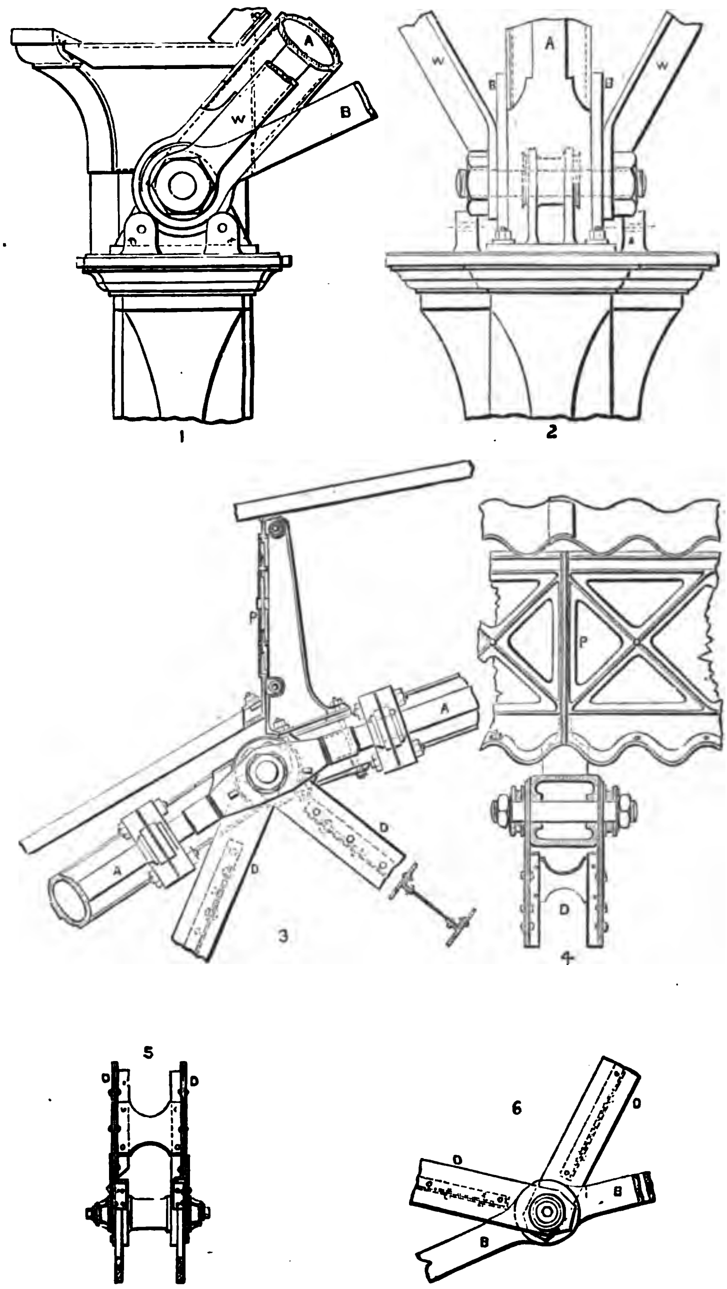
EXAMPLES OF ROOFS AND BUILDINGS CONTINUED. SPANS UP TO 200 FEET.

(For the assumed value of iron in the following Examples, see page 239.)

Example No. 58.—The Amsterdam Station of the Dutch-Rhenish Railway was designed by Mr. R. M. Ordish, and made at Derby, in 1863. The station is 300 ft. long, divided into twelve bays of 25 ft. by the cast iron columns supporting the roof. These columns are octagonal, and as the building is in a situation exposed to violent winds, they are very firmly secured to the stone foundation-piers on which they rest. The principals—which may be termed bowstring trusses (the arch or main-compression member is of cast iron)—are each 120 ft. span, from centre to centre of the shoes. The rise of the cast iron arch is 30 ft., and the rise of the tie-bars 17 ft., giving a depth of 13 ft. in the centre. The word arch is used in describing the compression member of the principals, but it is in fact polygonal, being composed of straight lengths of cast iron tubes, 8 in. diameter, turned truly at their abutting ends.

The tie-bars consist of two flat links, 4 in. by $\frac{7}{8}$ in., the holes for the connecting pins being bored, and the whole of the links proved with a strain of 12 tons per inch, without any *permanent set.* The breaking strain for the links is 24 tons, the actual strain they may have to bear being about six tons. The diagonals each consist of two flat bars, 6 in. by $\frac{5}{16}$ in., the pins and bolts for these and other principal connections being turned and the holes through which they pass being accurately bored to fit. The purlines P, Figs. 3 and 4, are of cast iron, partly glazed with sheet glass and partly left open for ventilation. The gutters are in one length between the columns, and act as purlines for supporting the roof covering, the rain-water escaping down the columns. The wind ties are bars, 4 in. by $\frac{3}{8}$ in., and form an important feature in the design.

Ventilation is provided at the top of the roof by means of cast



EXAMPLE NO. 58. DETAILS OF ROOF.

iron open work ridge purlines, with a covering of galvanised iron, No. 16 gauge, having corrugations 10 in. wide.

Some of the more important details are given in the engraving on page 280. Figs. 1 and 2 show the springing of the roof truss from the column, A being the cast iron upper member of the truss, B the lower or tension member, and W the wind tie. Figs. 3 and 4 show the connection of the diagonals D to the upper member A of the truss, and also the connection of the cast iron purline P with the roof covering above. Figs. 5 and 6 show the connection of the diagonals D to the tension member B.

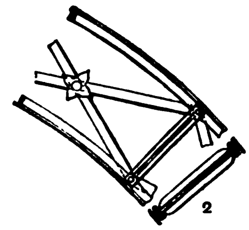
It will be seen that the principals for this roof are constructed on the same system and with a similar use of cast and wrought iron as the girders in Bridge Example No. 30, although there the triangulation is double. The same exact method of construction in the parts rendered the roof, like the bridge, one extremely easy to erect, and great economy in material was allowed by the design.

Including those for the side roof there are 30 columns, weighing 25 cwt. each, costing about £11 per ton. The rest of the ironwork weighs 150 tons, costing about £16 per ton, and the total cost per square, including columns and holding-down bolts, but exclusive of foundations, covering and erection, would be only about £8 5s. per square.

Three years after the station was built the gable ends of the roof were enclosed by wood and iron, involving an additional principal as well as an extra weight of 3½ tons of cast and wrought iron.

Example No. 59.—The Agricultural Hall, London, designed by Mr. F. Peck for the cattle shows of the Smithfield Club, and erected in 1862. The building is 384 ft. long by 217 ft. wide, and, with the exception of the outer walls, is constructed entirely of iron. The centre roof has a clear span of 125 ft., with the crown of the arch 70 ft. from the ground; and the side roofs have each a span of 36 ft.

The general construction of the building will be seen from the engraving on page 283, which is taken from a photograph of the interior. The main ribs or principals are placed 24 ft. apart, and made in the form shown by Fig. 2 on page 282, in detail resembling wrought iron trellis girders, with vertical cast iron struts. The thrust of the arch is taken by a double row of columns, as shown on page 283, the stability of the columns being increased by the floor-girders of the side galleries. There are six lines of purlines, of the same depth as the main ribs which they intersect. In shape the purlines are also trellis girders, with cast iron verticals, but are altogether lighter than the arch ribs. The roof is well secured with wind-ties.



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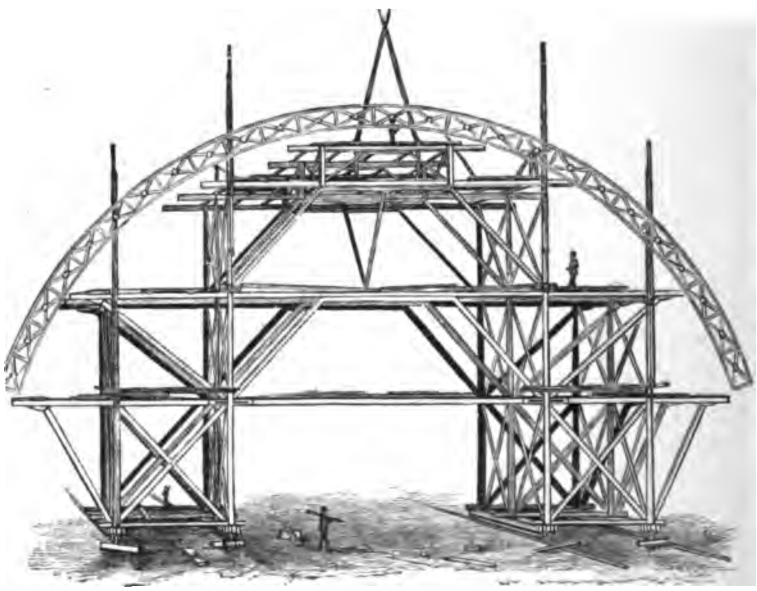
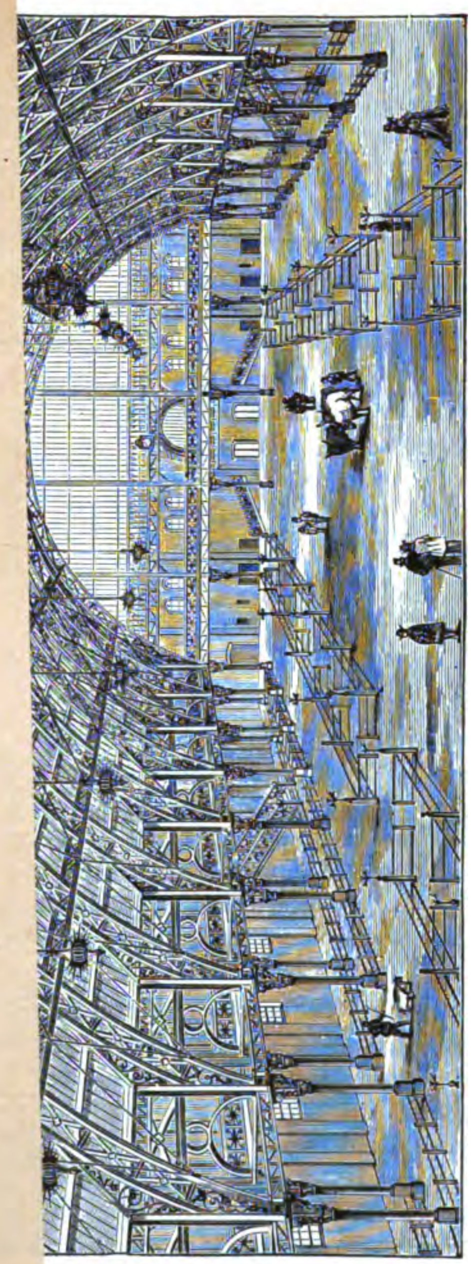
The side roofs over the galleries are composed of ordinary trussed principals, 36 ft. span.

With the exception of the upper part of the centre span, which is of glass, the whole roof is covered with slates on boarding. In the process of building the ironwork in place, the main ribs were completely framed together on the ground, and then lifted, each at one operation, by means of a travelling stage, which travelled upon four lines of rails laid upon the



floor of the building, as illustrated above. At four points on the framing, corresponding with the rails below and with the purlines above, ordinary timber derricks were fixed, so



EXAMPLE NO. 59. THE AGRICULTURAL HALL, ISLINGTON, LONDON.

that the main ribs could be seized at four points; and by means of the same derricks, the purlines could also be lifted. In the centre of the stage at the top, shear legs were placed for lifting the material of the ventilating louvres above the main ribs.

The weight and cost of the ironwork may be divided as follows:—

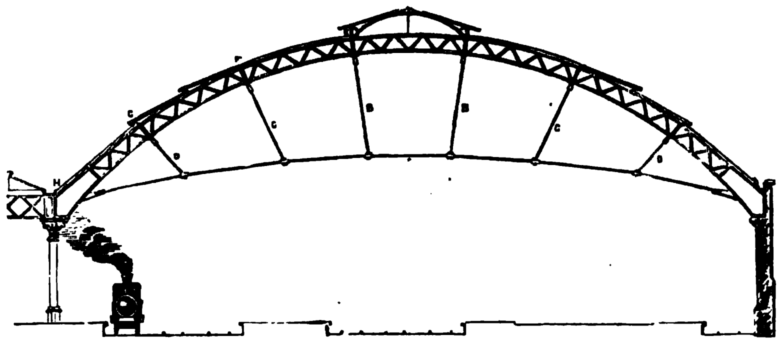
Wrought iron in main roof,	256	tons,	costing about	£19 per ton.
„ in side roofs (hipped)...	61	„	„	£23 10s. „
„ in girders for galleries...	163	„	„	£18 „
„ gable iron-work & bolts	10	„	„	£30 „
Cast iron in columns ...	221	„	„	£10 10s. „
„ bracing frames, spandrils, brackets, gutters	102	„	„	£11 10s. „
„ staircases, light spandrils, &c.	45	„	„	£14 10s. „
	858			

A roof of this span is not the cheapest for covering a large space; but for the special purpose of giving an area uninterrupted by intermediate supports, it affords all that can be desired. From the figures given above, the cost per square can be calculated; and to this must be added the cost of glass, slates, and boarding. Taking an average on both cast and wrought iron, the extra expense for erection would be from £3 to £4 per ton, including staging. Some years after the building was erected the galleries were widened.

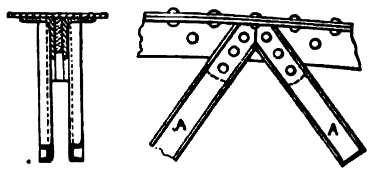
Example No. 60.—A roof 160 ft. span, for the terminal railway-station at Liverpool; designed by Mr. John Fowler, and built in 1872-3, for the joint use of the Midland, Great Northern, and the Manchester, Sheffield and Lincolnshire Railway Companies.

This roof is of the kind described on page 200 as a *tied arch*, and has some peculiar features. Owing to alterations in the arrangement of the walls and adjoining buildings, supports for the roof could only be formed at a considerable distance apart, and hence the roof principals occur at unusually great intervals.

The roof spans the running shed of the passenger station, and is 495 ft. long, divided into nine bays. The main ribs or principals are placed 55 ft. apart, and have a clear span of



160 ft. from the springing, and a rise in the centre of 40 ft., the tie also having a rise of 14 ft. The main arched rib is 3 ft. 9 in. deep, with flanges as shown in Fig. 2, 12 in. wide, and L bars 5 in. by 4 in. The diagonal members AA are ⊔ irons $3\frac{1}{2}$ in. by $1\frac{1}{2}$ in. At the points E F G purlines intersect and stiffen the main rib. The tension rod T, by which the arch is tied, is of steel, 3 in. diameter, equal to a breaking strain of 46 tons per square inch. The suspending rods B are of iron $1\frac{1}{8}$ in. diameter; the rods C of steel $1\frac{1}{8}$ in. diameter, and the rods D of steel $1\frac{3}{4}$ in. diameter. In testing the steel, it was found that *permanent set* commenced at about 22 tons, and that the reduction of area at the point of fracture was about 15 per cent. The main rib at one end of the building supports a hanging gable screen, which is trussed against the action of the wind. The other end of the roof is closed by the station buildings.



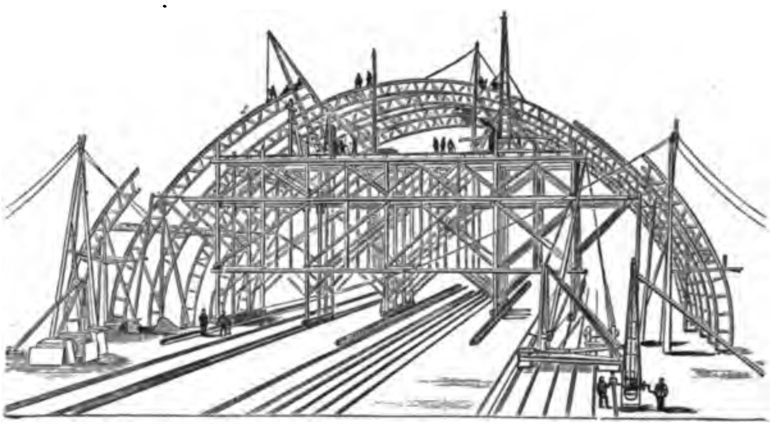
The purlines are lattice girders, and in the distance of 55 ft. between each principal, support five intermediate rafters, the centre one being of the same depth as, and acting as bracing to, the purlines. The intermediate rafters support light secondary purlines for carrying the roof covering. From E to F and G to H, the roof is covered with slates on boarding, but from F to G with glass on iron sash bars. Under the eaves or drip of the glass there are openings for ventilation. At E light spandrils above the purlines carry a raised skylight, the spandrils being open for ventilation.

It will be seen from the foregoing description that an unusually great weight is concentrated on each main rib or principal. At one side the principal is supported by a wall (acting also as a retaining wall) and on the other by a massive column 2 ft. 3 in. diameter at the base, and 1 ft. 6 in. at the top; the columns being connected by the longitudinal girders which they carry and on which the ends of the intermediate rafters are fixed. The height from the rail level to the springing of the rib is 27 ft.

Each main rib weighs $21\frac{1}{2}$ tons, of which the steel forms 2 tons 8 cwt. There are nine main ribs or principals, including the one which supports the gable screen, and which differs from the others. The total weight of the roof is as follows:—

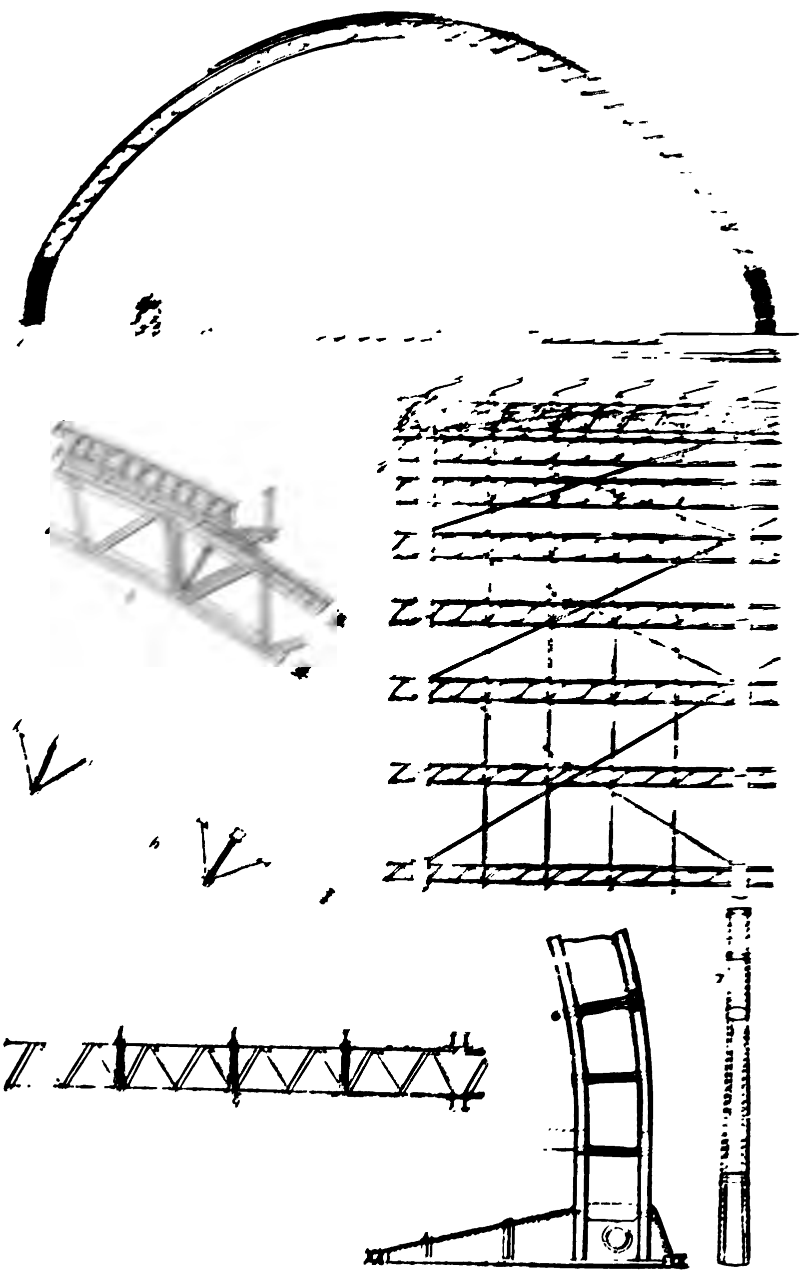
Wrought iron in main ribs, purlines, rafters, &c., sash bars and gable, cast iron in washers, &c.	495 tons, costing about £20 per ton.
Steel	20 tons ,, ,, £60 ,,

Example No. 61.—Roof over the railway-station at St. Enoch-square, Glasgow, erected in 1876 for the Union Railway Company, to be occupied by the Glasgow and South Western and Midland Railways, Mr. Blair being the engineer. The station is 518 ft. 3 in. long, divided into bays, *i.e.* thirteen of 36 ft. 10 in., one of 24 ft. 9 in., and one of 14 ft. 8 in. The main ribs, which are placed at these intervals, are curved, as shown in the engraving, are 5 ft. 1 in. deep, and in detail are constructed as triangulated girders, as shown in Fig. 3. The flanges are each formed of two ⊔ irons $9\frac{1}{4}$ in. × $3\frac{1}{2}$ inch, and one plate 1 ft. 4 in. × $\frac{1}{2}$ in. widening out towards the bottom to 2 ft. 6 in. The diagonals are formed of T irons in pairs, braced together by plates ornamentally cut. The web of the main ribs is made solid for 19 ft. above the floor. The ribs terminate at the bases in a foot 20 ft. long, as shown in Fig. 6, held down on the masonry foundations by four anchor bolts $2\frac{1}{4}$ in. in diameter. The purlines, Fig 5, are constructed as warren girders 3 ft. 4½ in. deep, with upper and lower flanges, each made of two L irons 4½ in. × 3½ in., and the diagonals are of T irons 3 in. × 3 in. of varying thicknesses. The purlines pass through the space between the ⊔ irons of the main ribs—as shown on Figs. 1 and 3—to which they are riveted. Intermediate ribs or rafters of 10 in. × 5 in. **I** irons are placed at intervals of 7 ft. 4 in., this being the distance spanned by the "ridge and furrow" roofs (resembling those described at page 205) which cover the upper part of the roof. The lower part below the gangway is covered by slates on boarding. The intermediate rafters, which are of **I** iron



10 in. × 5, in. rest upon the purlines, as in Fig. 5, the purline and the rafter being braced together as indicated on Fig. 4. The roof is tied together by diagonal wind bracing, formed of T bars on the part above the gangway, and of flat bars below.

The station is at each end enclosed by a screen, that at the open end terminating in a flat arch 16 ft. from the ground at the springing, and 34 ft. at the centre. At the inner end of the station, closed by an hotel building, the screen is at a distance of 20 ft. 9 in. from the hotel, and terminates in a horizontal line 36 ft. above the ground. Between this horizontal line and the hotel there is a sloping roof, thus sheltering the upper floors of the hotel from the vitiated atmosphere of the station. The screens are constructed in a somewhat novel manner, for instead of the girder across the span, which is usually placed to take a horizontal thrust, and which gener-



EXAMPLE NO. 61.

ally rests either on the side walls or supports of the building, the screen is suspended from the roof, and is bracketed firmly to the purlines, to which the wind pressure is therefore directly transmitted. The screens are formed of wrought iron framework, glazed in wooden sash bars.

The roof was erected on a strong timber stage, which travelled on eight rails along the station, the stage being long enough to support two bays of the roof. The pieces of ironwork were lifted by two steam hoisting engines placed upon the stage, as shown on page 287.

The total weight of the roof and the screens is 1,460 tons, the average value appended is exclusive of erection, and is based upon an assumed value of iron as described on page 239.

No.		Tons.	
15	Main ribs	557	Average value about £19 per ton.
55	Intermediate ribs	243	
221	Purlines	288	
30	Foundation shoes	110	
2	Screens	40	
	Wind bracing	52	
	Other ironwork	170	

As the Glasgow roof is to some extent a repetition of the well-known roof over St. Pancras Station of the Midland Railway, London, it may be interesting to state the points of difference. The Glasgow roof has a span of 198 ft., and a clear length of 518 ft. 3 in., as compared with a span of 240 ft., and length of 689 ft. at St. Pancras. The ribs are rounded at the top, while those of the London roof are slightly pointed, and the triangulation of the ribs is single instead of double. Instead of being tied across the station by wrought iron girders, as at St. Pancras, the Glasgow roof is merely anchored to the masonry. The roof ribs are further apart at Glasgow than in London, the purlines are therefore stronger, and are also of a different shape.

Before the Glasgow roof was completed, another of similar kind was undertaken by A. Handyside & Co. for the joint station of the Great Northern, Midland, and M.S. and L. Railways in Manchester. In this case the span is 210 ft., the length 550 ft., and the total weight of ironwork is about 2,400 tons.

CHAPTER XXIX.

PAINTING IRONWORK. PAINTING CAST IRON. PAINTING WROUGHT IRON. PAINT. DECORATIVE PAINTING. GILDING.

THE durability of ironwork depends so much on the efficiency with which it is painted, and the deterioration is so rapid when the proper painting is neglected, that the subject is of great importance in connection with the various structures described in the preceding chapters.

On page 58, reference was made to certain kinds of girders which were in some parts inaccessible to the painter's brush. As there stated, the importance of regular painting is often not sufficiently appreciated, and in many existing structures the elements of decay are actively at work. The flakes or scales of rust which fall from wrought iron of course weaken the structure in the proportion which they bear to the entire thickness of the iron, and this proportion is considerable in the case of plates ½ in. to 1 in. thick. Of course the most rapid decay takes place in structures exposed to the weather, such as bridges where the painting is neglected, and especially so in railway bridges, where the constant vibration shakes loose the paint. But ironwork in buildings protected from wet weather is also liable to rust in those cases where, while exposed to the air, it is from its position inaccessible to the painter. With wrought iron girders and joists sustaining, as they often do in warehouses, immense loads, the risk of ultimate disaster through this cause is considerable. If box girders be so well riveted, caulked and painted, as to be air-tight, the inner surface will be permanently preserved. An example of this was afforded by the bridge of the Blackwall Railway, over the Commercial Road at Stepney, which was removed by A. Handyside & Co., in 1875, after it had been erected twenty years. The inner surfaces of the iron in the box booms of the main girders were found perfectly good, and untouched by rust.

Iron completely embedded in brickwork or masonry is preserved from rust, but it is a good plan to give a thick coating of bituminous paint to the iron before it is so built in. The lime in the mortar is the preservative, and in cathedrals and other ancient buildings ironwork has been found which has been kept in good condition for 600 years.

As cast iron and wrought iron are different substances, and require different kinds of treatment, they are referred to separately.

PAINTING CAST IRON.

In the process of casting iron, the molten metal fuses the sand upon the surface of the mould, and produces on the casting a skin, which has almost the appearance of a silicate, and which is much harder than the purer iron within. This skin is of value in giving a hard, smooth continuity of surface to the iron, and as it would, if allowed to rust, soon be destroyed, it is desirable to protect it by paint. A casting therefore should have a coat of oil or paint given to it as soon as possible after it leaves the foundry, and before any oxidation has commenced. If this be done, and a second coat of paint be added, the original surface of the iron may be permanently preserved by occasionally painting afterwards as required. Whether one year or five years elapse before fresh paint is wanted, depends upon the weather and climate to which the iron is exposed, and the kind and quality of the paint. If rust does appear on a casting, it should be carefully scraped off before the paint is applied.

PAINTING WROUGHT IRON.

Upon the surface of wrought iron a skin is formed during the passage of the heated bars or plates through the rolling mill. This skin, unlike that upon cast iron, is not inseparable from the solid metal, but in fact forms a scale which can be detached. It is a chemical combination of iron with oxygen, the proportion of the latter increasing as the iron is exposed to the air, until it produces peroxide or rust. But the elements of rust are on the iron from the commencement. The scales must fall off sooner or later, and in a manner entirely unlike the granular rust of cast iron. It is sometimes the case that engineers endeavour to prevent oxidation by specifying that the iron, while yet hot from the rolls, shall be dipped in oil. This plan is for a time very effectual, but there are three objections to it. 1. After the iron has been coated, the cutting, punching, and other treatment to which it is subjected is sure to leave many places exposed. 2. However well the iron may be oiled and coated with the paint, it is impossible to preserve for any considerable time the original surface. 3. It is so inconvenient to the iron-makers that they are most unwilling to undertake it, except at a considerable charge.

It cannot be too well understood, that the thin skin or scale which forms on new wrought iron is of no value, and that it must fall off or be removed before the real iron is reached. When the iron is galvanised (the technical term for iron coated with zinc*), it is necessary to remove the scale before the zinc will adhere to the iron. This removal is effected by a process of "pickling," the iron being first dipped in dilute acid to remove the scale and then washed in pure water. If the trouble and expense were not a bar to its general adoption, this is the proper process for preparing wrought iron for paint, and it is exacted occasionally in very strict specifications. But somewhat the same results may be obtained by allowing the ironwork to rust, and then scraping the scale off preparatory to painting. If some rust remains upon the iron, the paint should not be applied lightly to it, but by means of a hard brush should be mixed with the rust. But according to the ordinary plan of applying the paint on the original surface of the iron, the outer skin is only preserved for a time, and will become loose at about the period when the paint needs renewal, and will fall off in scales; when the surface must be rubbed preparatory to painting. Or, if the old paint peel off, it will be found that the black scale adheres to the paint, and comes off with it. It is therefore important that care should be used to thoroughly clean the iron from rust when this second period of painting has arrived; for it is then that the real iron is reached, and permanent protection by paint may be effected.

PAINT.

The paints used for ironwork may be divided into four classes, as—1. *Lead paints;* 2. *Iron oxide paints;* 3. *Bituminous paints;* 4. *Silicate paints.*

* See page 213.

1. *Lead Paints.*—Paint made of red or white lead was formerly used for iron boilers, girders, &c., almost to the exclusion of every otner kind, and it is still employed to a considerable extent. For some 20 years past, however, it has been thought by many engineers that the chemical action of lead upon iron renders such paint unsuitable; and other kinds, especially iron oxide paints, are now generally preferred. Owing to the high price of lead paint (30s. to 46s. per cwt.) and its great weight, there are considerable inducements to adulteration by the mixture of coloured earths and other substances. Very cheap lead paints should always be suspected, as it is impossible to produce them in a genuine state below a certain price.

2. *Iron Oxide Paints.*—The manufacture and sale of "Torbay paint," made from the iron oxide earth found at Brixham, in Devonshire, was the first introduction of this kind of paint in England. The affinity which it has for iron, and its cheap price as compared with red lead, soon led to its adoption on a large scale; and as it was specified by Government engineers for use on public works, it rapidly came into notice. It is now generally employed for ironwork, and the experience of some years confirms opinion in its favour. The manufacture of the paint is not confined to Torbay, and though generally made from the same sort of material, it is sold under various names. It costs 20s. to 35s. per cwt., depending in great measure on the colour, red and purple being the cheapest. It is usually prepared for use by mixing with linseed oil. There are many inferior sorts made and sold.

3. *Bituminous Paints.*—These are largely made from the products of coal and other mineral oils. They have various degrees of fineness, the cheapest kinds bearing a great resemblance to tar, and they are admirably suited for painting the inside of pipes, or for ironwork fixed under water, such as bridge cylinders and screw piles. The fine sorts, while possessing the same properties, give a smoother surface and can be used in ordinary situations, especially where water or foul vapours have to be resisted. The price varies from 18s. to 30s. per cwt., and the paint is mixed for use with specially prepared mineral oil.*

* A tar varnish composed as follows is very effective:—30 *gallons of coal tar fresh with all its naphtha retained;* 6 *lbs. tallow;* 1½ *lbs. resin;* 3 *lbs.*

A paint made from bitumen dissolved in paraffine and linseed oils while in a state of great heat, is said to possess special qualities of durability, in that it can resist the action of ordinary detergents, and of all alkalies and acids. When mixed ready for use, this paint costs from 40s. to 60s. per cwt., according to colour and fineness.

A more refined paint of this sort, made partly of vegetable gums, somewhat resembles enamel or varnish, and when applied to ironwork produces a surface not unlike that of glazed earthenware. It has been used with success for purposes of decoration, but it is a matter of taste how far the peculiar glaze is suitable to ironwork.

4. *Silicate Paint.*—Mineral paints of which the basis is more or less silicious have been introduced during the last few years, and they are recommended for the hard or petrified surface they give to ironwork. For some of these paints it is claimed that they are made from a natural silica, but there is no doubt that various other silicious substances—such as refuse "slag" from the iron furnace, &c.—are also used. These paints, if mixed with proper oils, will resist the action of salt water or acids better than lead or iron oxide paints. They cost from 25s. to 40s. per cwt. dry, or from 30s. to 50s. when mixed with oil; but weight for weight, they will cover a larger surface than lead paints.

The value of any kind of paint depends very much on the quality of the oil, turpentine, or other vehicle with which it is mixed, and when, for the sake of cheapness, inferior sorts of these are used, the paint will neither adhere properly nor permanently.

There have been many kinds of paint introduced under new names during the last ten years, some of them claiming to be specially suitable for ironwork, and although their composition is kept a secret, they all come within the four classes

lampblack; 30 lbs. fresh slacked lime, finely sifted. Mix intimately, and apply hot. When hard, this varnish can be painted on by ordinary oil paint if desired. If grey or other light colour is thus used as a finishing coat, when it cracks or peels off, it exposes the tarred surface and affords a conspicuous warning that it is time to repaint.

enumerated above. Some of these paints have proved themselves to be good; and as their price allows the use of good oil varnish, or other mixing materials, it is probably to these that they owe much of their efficiency.

There are some processes of coating iron which depend, not only on the kind of paint, but on the mode of application. These may be almost described as "japanning" processes, for they require the application of heat. The iron to be coated is placed in a heated chamber or furnace, and the paint then applied is to some extent absorbed into the iron, and forms on it a hard and permanent skin. This process is best suited for cast iron, and for small articles, such as railings, ballusters, brackets, &c.

When iron structures are sold for delivery only, one coat of paint is included in the price, and if the ironwork has to be erected, a second coat after it is fixed is also included. When more than this is required, it should be so stipulated in the contract, and the prices arranged accordingly. For bridges, roofs, and similar structures, three or four coats should be given in all. As a general and approximate rule, 2d. to 4d. per square yard, or 3s. to 5s. per ton on the weight of ironwork, may be taken as the expense of each coat of paint after the first. This does not include decorative painting.

DECORATIVE PAINTING.

Decorative painting falls within the province of the artist or architect, rather than within that of the engineer; but there are some broad rules which are generally applicable, and may be here noted.

The commonest colours for ironwork when it leaves the manufactory are red, brown red, and yellow ochre; and as these are the cheapest, they are often repeated when the ironwork is erected.

Paint should not be used to disguise the character of ironwork, but should, as far as possible in each case, accord with its position and purpose. Columns, or massive ironwork, evidently sustaining a great weight, should not have an artificially light appearance given to them. Dark green, indigo green, or dark brown, are suitable colours. Ornamental capitals to columns may be relieved with lighter tints. Lattice girders or roof principals may be painted with lighter colours, such as grey, light blue, &c.

Bronze green is a very good colour for both cast and wrought ironwork. Sometimes above a coat of yellow ochre the green is applied, and while the latter is wet it is rubbed off at certain places to show the yellow underneath. For instance, in girders and roofwork, the rounded edges of L iron and one side of each rivet head are so treated, so as to produce a bright appearance resembling bronze or gilding.

Buildings entirely of iron, such as the Sydenham Crystal Palace, afford great scope for colour decoration. Cast iron trellis girders and arched roof ribs may be "picked out" in a variety of ways, so as to show properly against a large roof surface.

In very hot climates, ironwork painted a light tint is not only pleasing to the eye, but is many degrees cooler than if of a dark colour.

Not only good paint but careful treatment is necessary, where the ironwork is at all of an ornamental character. The sharp lines or delicate forms, which have been produced in a casting by the moulder's skill, may be entirely spoilt by paint which is mixed too thick or carelessly applied.

BRONZING AND GILDING IRONWORK.

An artificial resemblance to bronze is given to ironwork with bronze powder, or paint, or varnish. This is very effective on railings, ballusters, lamp pillars, columns, vases, &c.; but it is not suited for ironwork exposed to the weather in an English climate. Electro-bronzing, or the coating of iron with copper by a chemical process so as to resemble bronze, has been tried many times with articles of a limited size. Though largely used with other metals, it is not very successful with iron; and where a permanent bronze appearance is required, especially for articles exposed to the weather, it is better, even at a greater first expense, to have castings of solid bronze metal, or to have castings of zinc covered with copper by the electro process.

Where good and permanent gilding is required, pure gold leaf is the only effective material. As a general rule, gilding should not be spread over large surfaces; and its combination with colour should be so arranged as to assist rather than hide the light and shade of mouldings and other parts in relief. A few gilt mouldings or a few gold lines on a spandrel or a panel, on leaves, rosettes, or rivet heads, will have a better effect and suggest greater richness and value in the gold than if it is used profusely.

Chocolate, bronze green, dark green, black, and French grey, are the colours that are shown off to the best advantage by gold. Railing-spikes, roof spandrels and pendants, and the foliage of column capitals are places where gilding may be used with advantage. In arched bridges or other structures having graceful lines, gold will add materially to the good effect of form and colour. The bridge illustrated in the frontispiece was partially gilded, and affords a good example of a structure suited for such treatment.

In gilding ironwork, special precautions must be taken to prevent rust destroying the gold. The iron should be very carefully cleaned, and then painted with two coats of iron oxide paint. Then two coats of lead paint of light colour should be given as a basis for the final "oil gold size," upon which the gold leaf is placed. Gold leaf varies in colour, quality, and thickness, the latter being specified as single, double, or treble. The gold leaves are about 3½ in. square, and cost from £4 to £7 per thousand. They are sold in small books containing 25 leaves, and from 18 to 20 leaves are required (including waste) to cover one square foot. The cost of gilding depends on the thickness and quality of the gold, the shape of the parts, their position and accessibility, and other conditions. Gilding in the open air is more expensive than in the workshop or under cover. From 4s. to 8s. per square foot may be considered limits wide enough to cover the majority of cases. When properly effected, gilding on ironwork will last from 15 to 30 years.

CHAPTER XXX.

EFFECT OF COLD ON IRONWORK. THE FATIGUE OF IRON.

ALTHOUGH the effects of cold upon iron have never been exactly determined, there is an almost universal belief that iron becomes more brittle and more liable to fracture when very cold than when at a mean temperature, and especially if at the same time the iron is exposed to sudden or percussive strains. More than one series of experiments have been made * to solve this question, but no definite conclusions have been arrived at, although for the most part the evidence obtained is adduced to disprove the idea that extreme cold has any injurious effect whatever. Bars of different lengths and thicknesses of cast iron, wrought iron, and steel, and even darning needles of steel, were inserted in a freezing mixture, and having thus been brought to a very low temperature, they were tested in various ways by direct pressure and by concussion, and the results were stated to be not at all less favourable than those obtained at an ordinary temperature. But even admitting that these experiments, which were made on a small scale, fairly represent the case of larger pieces of iron exposed for a considerable time to extreme cold, it may be said that the real point at issue is not touched at all by the experiments so conducted. The question which really interests engineers is not so much whether an injurious change is produced by extreme cold in bars or other simply shaped pieces free to move in all directions, but whether in the many forms and positions given to manufactured iron for structural purposes, the differences in temperature do not have an important and deteriorating effect.

In considering this subject, cast iron may be referred to first and chiefly. Taking the molten state as the condition of extreme expansion in cast iron, the contraction in cooling is about 1 per cent. Thus it is necessary with patterns for the foundry to make

* See reference to experiments by Sir W. Fairbairn, Dr. Joule, and others, in *Nature*, January 26th, 1871.

them larger than the size desired in the casting by ⅛ in. for every foot of size. In simple forms the cooling has equal effect at all points, and the casting contracts all over into the permanent crystalline state which is natural to it when cold, although—and this also bears upon the question—the crystals near the surface are much smaller than those inside. But if made of irregular shape and thickness, the contraction will not be everywhere the same, and the casting will be liable to unequal strains. The thick part takes longer to cool, and draws towards it the thinner part which has already cooled, and which cannot yield without being strained. The designer, having a knowledge of these facts, makes his proportions accordingly, and it is part of the art of the founder to regulate the cooling of the iron. But while the facts are so well known, that with a given shape the fracture of a casting when cooling may be predicted with absolute certainty, and with another shape an equally certain immunity from fracture may be foretold, there are, of course, cases where no such positive knowledge can be arrived at. Castings may be, and sometimes are, made of such peculiar shape and proportions that in cooling they are strained nearly to the limit of elasticity, and if such castings are afterwards subjected to percussion, they may break. While, therefore, there may be nothing in the outward appearance of the casting to denote the tension to which, in some of its parts, it is subjected, a sudden blow may break it.

If castings, when first cooled from the foundry have, as above stated, some of their parts already in a state of tension, their liability to fracture under percussion will be increased if the temperature is still further and *unequally* reduced. For instance, one part of a casting may be at a freezing point, and covered with snow, while at another part it may be exposed to the rays of the sun.

But altogether apart from the strains produced in cast iron by unequal temperature, there is little doubt that extreme cold alters the molecular arrangements of the iron, and renders it more brittle. Science has not yet authoritatively determined the exact arrangement and relation towards each other of the crystals or atoms which constitute a piece of iron, and till this is done no certain knowledge with regard to the effect of cold on iron will be arrived at.

For the reasons indicated above, only the simpler forms of cast iron are used in railway bridges, and in very cold climates* it is for such purposes prohibited altogether. In countries where an extremely low temperature does not occur, there is no risk in having columns or stanchions of cast iron, and girders of the shape shown on page 53 are generally safe, but a trellis girder, as shown on page 54, would not be suitable for a railway bridge anywhere. Of course much depends on the quality of the metal, and this forms another argument against the use of the cheap, brittle iron described on page 7. The arched shape in cast iron is some safeguard against fracture, as it, to a certain extent, acts as an elastic spring. In the pulley of a machine, curved arms are less liable to fracture than when made straight, and this also is the case in an arched bridge.

That wrought iron is affected by cold is proved by evidence too strong to be disputed, and it is probable that in this respect it differs from cast iron only in degree. Iron will not bend so safely in winter as in summer, and it is more easily broken by a sharp blow. In America, authentic statistics show that rails break under the load of a passing train much more frequently in winter than in summer, though this may, to some extent, be caused by the hard unyielding nature of the road during frost. Chains are more liable to break in winter than in summer, and workmen are accustomed to warm them before using them. Hammers also, during intense frost, fly to pieces under ordinary blows.

But the superior ductility and the high limit of elasticity possessed by wrought iron (as compared to cast iron), afford so large a margin of safety that it may—as applied to structural purposes—be considered practically unaffected by cold. How far the margin of safety during intense cold might be reduced by the *fatigue of iron*, there is as yet no experience to show.

* In Russia, even short, simple girders of cast iron are not used for railway bridges, and many of the smaller parts of a bridge which, in England, would be of cast iron, are there made of wrought iron.

THE FATIGUE OF IRON.

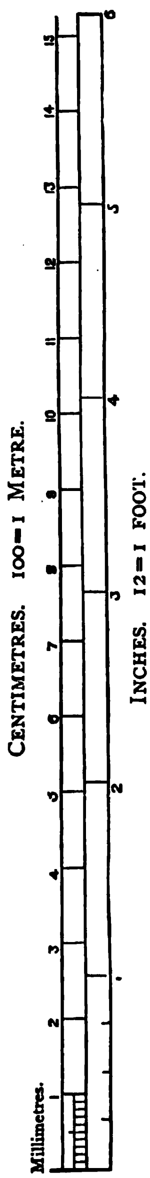
The *fatigue of iron* is the name which has been given to the effect produced by oft-repeated strains or blows.* For instance, the axle of an ordinary cart or carriage will, after long service, break, and show in its fractured part a crystalline appearance entirely unlike its original condition. An anvil, after being hammered for years, offers a similar example. To determine the facts more exactly, especially with a view to the concussions caused by railway traffic on bridges, careful experiments have been made, which show that girders are practically unaffected if the working strains be in due proportion † to the ultimate or breaking strength of the iron, and to its limit of elasticity,‡ except after a period of time when the bridge, for other reasons, would be probably renewed. The repeated blows to which the tyres and axles of railway trains are subjected have perhaps a more important effect, especially in tyres which have been shrunk on to the wheels, and which are always in a state of tension.

The steel springs of chronometers, after some years' use, undergo an alteration in the molecular arrangement, and consequently in their elasticity; but it is also found that the latter is restored by some years' rest.

* Professor Wohler's experiments on this subject are very interesting. *Ueber die Festigkeitsversuche mit Eisen und Stahl.* Von A. Wohler. Berlin: Ernst and Korn. A careful review and partial translation of this book, together with engravings of the apparatus used in the experiments, are given in *Engineering*, March to June, 1871.

† See pages 12, 103, 225.

‡ "Limit of elasticity." (See page 11.)



CHAPTER XXXI.

ENGLISH AND FOREIGN MEASURES.

FOR many years, opinions in England have been divided on the question of decimal measures. The advantages that would result from the establishment of a common standard for all countries are universally acknowledged, but on the manner of obtaining such a standard there is not the same agreement. In discussing the expediency of abandoning the present English measures in favour of the French mètre system, two distinct questions have to be considered: first, the intrinsic merits of the systems; and, secondly, which shall in practice give way to the other.

With regard to the first question, as both the measures and weights of the French system are derived from the same unit,* calculations in which both are used are rendered very simple. Moreover, the French decimal system agrees with the universal method of counting, which happens to be decimal, and thus any quantity, whether composed of units or fractions of units, can be dealt with directly by the existing notation.

The duodecimal system, which is the more convenient for divisions used in common life—the half, the quarter, the eighth, the third—had been adopted for weights and measures in all countries before the higher arithmetical method was applied to ordinary transactions. When, however, it was so applied, the incongruity was evident, and as the decimal system of counting could not be transformed into a duodecimal one, the duodecimal

* The unit of the decimal system, established in France in 1801, is the *mètre*, which is $\frac{1}{10,000,000}$ part of the length of the meridian of Paris.

weights and measures were (in France) made to give way to the decimal system. From this point of view, the superiority of the decimal system of weights and measures may be strongly asserted. Indeed, the advantages are so apparent that they would long ago have prevailed in England were it not for the very great inconveniences which must attend a change.

With regard to the second point stated above, *i.e.*, as to which system shall in practice give way to the other, the argument assumes somewhat the same position as it did in the "Battle of the Gauges," when it had to be determined whether the broad or narrow gauge should be universally adopted on English railways. Apart altogether from the respective absolute merits of the systems, it became also a question as to which was most largely and firmly established, and, therefore, which should, for the sake of uniformity, give way to the other. So with the decimal system of measures—those who, on the subject, adopt the conservative policy, affirm that, as the English measures prevail wherever the English language is spoken, and as the language is gradually spreading all over the world, so will the METRE system have finally to give way, notwithstanding that it prevails in the greater part of Europe and in South America at the present time. No doubt the use of English measures on foreign railways and other public works, constructed by Englishmen abroad, and their use in goods exported from England, tend also to the same end. Up to the present time repeated applications to Parliament * to legislate in favour of the decimal system have been unavailing, and the only steps that have been taken in that direction have been towards the permissive use of decimal measures and in the construction of some of the Indian State railways with a gauge of one metre.

The difficulties which in England would attend a change may be realised if it be remembered how—even speaking for engineers alone—the rules and formulæ employed in calculations, the dimensions for wheels and the threads of screws, the innumerable shapes and sizes of rolled iron, are all expressed in English measures, for which no exact equivalents can be given according to the French decimal system.

* Blue Book: Standards Commission. Second and Fifth Reports of the Commissioners. London, 1868-71.

But notwithstanding all that may be urged with regard to the probable endurance and spread of the English measures, and the objections to change on account of inconvenience, the presumption in favour of the universal adoption of the metre system is increased by the attention which it receives from scientific men in all countries, and by the fact that in all kinds of measurement, calculations (which are ever becoming more subtle and exact) are always carried out in decimal fractions.

The following is a description of the measures used in different countries at the end of the year 1872. In Great Britain, India, and the Colonies, and in the United States, the *foot* is the unit of length. Although the *yard* is the English national standard measure, it is seldom used by engineers except for describing superficial area, and the cubic content of earthwork or masonry. The *pound* (lb) is the unit of weight, and with the *hundredweight* (cwt.) of 112 lbs., and the *ton* of 20 cwt., is invariably employed for designating the weight of ironwork. In France, Belgium, Holland, Switzerland, Italy, Spain, and Portugal, the French decimal system (see tables on pages 306-7) based on the METRE has been legally adopted, so that these countries have all the advantages of a common standard. In the great majority of cases it is used by engineers, although the various old national measures still prevail to a considerable extent in country districts. In Germany the optional use of the *metre* system was recognised some years ago as legal in all parts of the Zollverein (the Customs Union whose boundaries mainly coincide with those of the German Empire), but from January, 1872, it was absolutely adopted. In Austria, the Vienna *foot* (=1·037 Engl. ft. or 0·316 metre) and *klafter* (6 Austrian feet) were the legal units of length as the Vienna lb. (=1·234 Engl. lb. or 0·56 kilo.) was of weight. The various nationalities included in the Empire have also local standards which to some extent prevail. As a considerable proportion of Austrian trade is with Germany, the Zollverein measures have to be used for many international transactions, and great inconvenience has often been occasioned by the want of a common standard. The Austrian Government, however, decided that the French decimal measures should be employed optionally from the 1st January, 1873, and exclusively adopted from the 1st January, 1876.

In Russia, the English *foot* was adopted by Peter the Great, and is, together with the *sagene* (7 feet), generally used as the standard of length for engineering purposes. The French measures are also sometimes employed. The *Pood* (Pud) =36·113 lbs. English, is the national standard of weight.

In Norway, Sweden, and Denmark, English measures are frequently used, and owing to the large imports of English machinery, railway material, &c., engineers are generally familiar with English weights. But the national measures and weights are exclusively employed on Government Works and other public undertakings. The *foot* and *pound* are the measures of length and weight, but they do not agree exactly with the English measures, and they also differ slightly in the three countries.

In Turkey and Egypt the French measures are generally employed for engineering purposes, and this is also the case in the Brazilian and Spanish States of South America.

ENGLISH MEASURES COMPARED WITH THE FRENCH OR DECIMAL SYSTEM.

LONG MEASURE.

English.

12 Inches.................. = 1 Foot
3 Feet... . ... = 1 Yard
1760 Yards..................... = 1 Mile

English.	*French.*
1 Inch........... =	·0254 Metres
1 Foot.......... =	·30479 „
1 Yard.......... =	·91437 „
1 Mile........... =	1609 31 „

SOLID MEASURE.

English.

1728 Cubic Inches.. = 1 Cubic Foot
27 Cubic Feet...... 1 Cubic Yard
40 Cubic Feet...... = 1 Ton(freight)

English.	*French.*
1 Cub. In. =	16387·064 Cub. Millimetres
1 Cub. Ft. =	·02832Cub.Metre
1 Cub. Yd. =	·7649 „

STRAINS.*

English.		*French.*
I Ton per Sq. Inch.	=	157·5 Kilos. per Sq. Centimetre
A load of 1 lb. per Sq. Foot	=	4·88 Kilos. per Square Metre

SQUARE MEASURE.

English.

144 Square Inches = 1 Square Foot
9 Square Feet... = 1 Square Yard
100 „ „ ... = 1 Sq of Roofing
4840 Square Yards = 1 Acre

English.	*French.*
1 Sq. In. =	645·1613 Sq. Millimetres
1 „ „ =	6·451 Sq. Centimetres
1 Sq. Ft. =	·0929 Square Metre
1 Sq. Yd. =	·8361 „ „
1 Acre... =	4046.7 „ „

WEIGHTS.

English (Avoirdupois Weight).

16 Ounces (oz.) = 1 Pound (lb.)
28 lbs .... = 1 Quarter
4 Quarters..... = 1 Hundrdwt.(cwt.)
20 cwt............ = 1 Ton

English.	*French.*
1 lb ...... =	·4536 Kilogrammes
1 cwt..... =	50·787 „
1 Ton ... =	1015·965 „
1 „ ... =	1·016 Ton French

DRY AND FLUID MEASURE.

English.

2 Pints...... = 1 Quart
4 Quarts.... = 1 Gallon
2 Gallons... = 1 Peck
4 Pecks..... = 1 Bushel
1 Gallon.... = 277·27 Cubic Inches

English.

1 Gallon.... = ·16 Cubic Foot
1 Gallon of Distilled Water weighs 10 lbs.

English.	*French.*
1 Gallon =	4·543 Litres.

For the Weight of Iron and Steel, see page 20.

* For Loads on Bridges, see page 103; on Roofs, see page 224.

THE FRENCH OR DECIMAL SYSTEM COMPARED WITH ENGLISH MEASURES.

LONG MEASURE.

French.

10 Millimetres.. = 1 Centimetre
10 Centimetres. = 1 Decimetre
10 Decimetres.. = 1 METRE

French.	*English.*
1 Millimetre... =	0·0393 Inch
1 Centimetre... =	0·3937 „
1 Decimetre... =	3·937 „
1 METRE ... .. =	39·37 „
1 METRE ...... =	3·281 Feet
1 METRE ...... =	1·0936 Yard

SOLID MEASURE.

French.

A Cubic Metre is called a STERE.

10 Millisteres.. = 1 Centistere
10 Centisteres. = 1 Decistere
10 Decisteres.. = 1 STERE

French.	*English.*
1 Centistere =	610·28 Cubic Inches
1 Decistere. =	3·532 Cubic Feet
1 STERE ... =	35·32 „ „
1 STERE ... =	1·3079 Cubic Yards

STRAINS.*

French.	*English.*
1 Kilo. per Square Centimetre =	14·22 lbs. per Sq. In.
A load of 1 Kilo per Sq. Metre =	·205 lbs. per Sq. Foot

SQUARE MEASURE.

French.

A Sq. Metre is called a Centiare.

10 Milliares = 1 Centiare
10 Centiares = 1 Deciare
10 Deciares = 1 ARE
1 ARE .... = 100 Square Metres
100 ARES...... = 1 Hectare

French.	*English.*
1 Sq. Centimetre =	0·155 Sq. Ins.
1 Milliare.......... =	155· „
1 Centiare......... =	10·764 Sq. Ft.
1 Centiare......... =	1·196 Sq. Yds.
1 Deciare .... =	11·96 „
1 ARE .... =	119·6 „
1 Hectare .... =	2 acres, 1 rood & 35 perches

WEIGHTS.

French.

10 Decigrammes = 1 GRAMME
10 GRAMMES..... = 1 Decagramme
10 Decagrammes = 1 Hectogramme
10 Hectogrammes = 1 Kilogramme
1000 Kilogrms... = 1 French Ton

French.	*English.*
1 GRAMME ...... =	·0022 lbs.
1 Kilogramme ... =	2·2046 lbs.
1 „ ... =	·019 cwt.

DRY AND FLUID MEASURE.

French.

10 Millilitres... = 1 Centilitre
10 Centilitres .. = 1 Decilitre
10 Decilitres... = 1 LITRE
1 LITRE........ = 1 Cub. Decimetre

French.	*English.*
1 LITRE =	61·028 Cubic Inches
1 LITRE =	1·761 Pints

1 Cubic Metre of Distilled Water weighs 1000 Kilogrammes

For the Weight of Iron and Steel, see page 20.

* For Loads on Bridges, see page 103; on Roofs, see page 224.

CHAPTER XXXII.

FOREIGN TECHNICAL WORDS.

THE want of polyglot technical vocabularies has long been felt by those engaged in the trades and professions connected with engineering; but their compilation is for many reasons difficult. The list of useful words is always growing and changing, and often, even where words of different languages apparently correspond, it will be found, on investigation, that the meanings are not exactly identical. The number of technical terms in France and Germany is as great as in England, and not only may the general equivalents of the English words be found, but in either of the two former countries it would probably be asserted that the language was even richer, in this respect, than English. With regard to purely scientific terms, this may, to some extent, be true; but for the names of tools and processes connected with engineering, English has always been the leading language.

The translation of books connected with even specially scientific subjects is greatly facilitated by the copiousness of the best French and German dictionaries,* and several technological † dictionaries have been recently published. But industrial processes multiply so quickly, and are becoming so subdivided, that it is all but impossible to include in any one book, the infinite variety of words used in modern manufactures.

In Italy there is great difficulty in choosing proper equivalents for English technical words. The science of engineering, and the manufactures connected with it, are much behind those

* Dictionaire Général Français-Anglais. A. Spiers.

Grand Dictionaire Français-Anglais. Firmin Didot Frères, Paris.

Bellows' English and French Pocket Dictionary. Trübner, London.

Flügel's Complete Dictionary of the German and English languages, London.

† Technological Dictionary, English-German-French, published by Dr. Oscar Mothes, Wiesbaden, 1870. London, Trübner & Co.

Technological Dictionary, English-German-French, by Tollhausen and Gardissal. Paris, 1864.

of England, France and Germany, and the English and French languages are very often employed instead of Italian. So universally is French spoken amongst the educated and professional classes, that it is often used even by Italian engineers in their own country for subjects connected with railways and mechanical trades. This is perhaps the more unnecessary, because of the great richness of the Italian language, and the scope it affords for all kinds and shades of meaning. But Italy has so recently become a united kingdom, that there are not common standards as in France and Germany, and there are wide differences in the colloquial language of the different provinces, differences which are to a great extent maintained by the want of education amongst the working classes. For instance, the names of tools and processes used by workmen in the engineering factories differ considerably in Genoa, Florence, and Naples, according to the local dialects; and, as is the case even in England, the words so coined or adapted by workmen soon come into general use amongst engineers.

The difficulties attending the translation of engineering terms into Spanish are as great as in the case of Italian, but not quite in the same way. Though French is—after Spanish—the language most frequently employed in Spain, it is not used or understood there to nearly the same extent as it is in Italy. Spanish has, therefore, to be used in almost all cases; but there is no recognised standard for technical terms. The English engineers and contractors who constructed the Spanish railways and other public works, introduced many of their own words into the country, and also gradually adopted, for the names of tools and processes, the Spanish words which were the nearest equivalents. As these words were often obtained from illiterate workmen, whose dialect varied according to their province, it is now the case that the vocabulary of engineers, mechanics, railway workmen, and others, differs considerably in Galicia, Catalonia, Castille, and other provinces. But besides this, the different countries of Spanish America, while all recognising "pure Castilian" as the classical Spanish language, have no such standard for the technical terms they are compelled to employ. In countries so far apart as Mexico, the Argentine Republic, and Peru, the words used by engineering and other workmen differ very considerably, the choice between old Spanish words adapted to new meanings and foreign words being to a large extent determined by the nationality or origin of the first engineer who introduced them. The want of a common standard for technical terms is of even more importance for Spanish than for Italian; because, of all European languages, Spanish, next to English, is most used out of Europe.

In the following vocabulary no attempt is made towards a general list of engineering terms. Only the technical terms used in connection with Bridges, Roofs, and other iron structures are given. Many of the foreign words—especially amongst the Italian and Spanish—are not exact equivalents of the English words, but merely convey the meaning as far as the language allows.

VOCABULARY

OF

TECHNICAL TERMS

USED IN THE

DESIGN, MANUFACTURE, AND COMMERCE OF IRON STRUCTURES.

ENGLISH—FRENCH—GERMAN—ITALIAN—SPANISH.

TECHNICAL VOCABULARY.

English.	French.	German.
ABUTMENT	culée ; butée *f*	Widerlager *n*
Adhesion	adhérence *f*	Adhäsion ; Anziehungskraft *f*
Adjustment	ajustage ; ajustement *m*	Stellvorrichtung *f*
Agreement (contract)	contrat ; convention *f*	Vertrag ; Contract *m*
Air-pump	pompe à air *f*	Luftpumpe *f*
Alluvial deposit	attérissement *m* ; alluvions *f*	angeschwemmter Boden *m*
Anchorage	amarrage *m*	Verankerung *f*
Angle iron	cornière *f* ; fer d'angle *m*	Winkeleisen ; Eckeisen *n*
Anneal, to	recuire ; adoucir	ausglühen ; im Feuer härten
Annealing	recuit *m*	Ausglühen *n*
Anvil	enclume *f*	Amboss *m*
Apparatus	appareil *m*	Apparat *m* ; Zeug *n*
Approach (bridge)	abords d'un pont *m*	Auffahrt (einer Brücke) *f*
Aqueduct	aqueduc *m*	Aquaduct *m*
Arc	arc *m*	Bogen *m*
Arch	arche ; voûte *f*	Bogen *m* ; Gewölbe *n*
Arched bridge	pont en arc *m*	Bogenbrücke *f*
Arched roof	toit cintré *m*	Bogendach *n*
Architect	architecte *m*	Baumeister ; Baukünstler *m*
Area	superficie ; aire *f*	Flächeninhalt *m*
Asphalte	asphalte *m*	Asphalt *m*
BALLAST	ballast ; empierrement *m*	Kies *m* ; Kiesaufschüttung *f*
Bank of a river	rive *f*	Ufer *n* ; Damm *m*
Bar iron	fer en barre *m*	Stabeisen *n* ; Stangeneisen *n*
Base line	ligne de base ; base *f*	Grundlinie *f*
Batter	fruit d'un mur *m*	Böschung *f*
Bead	nervure *f*	Rundstab *m* ; Schnur *f*
Beam	poutre *f*	Balken ; Träger *m*
Bear (punching)	bride à percer *f*	Handstanzmaschine *f*
Bearing (support)	support *m*	Lager *n*
Bed (masonry)	lit *m*	Grundschicht *f*
Bed of a river	lit d'une rivière *m*	Flussbett *n*
Bed of the sea	fond de la mer *m*	Meeresboden *m*
Bed-plate	plaque d'appui *f*	Grundplatte *f*

TECHNICAL VOCABULARY.

Italian.	Spanish.	English.
spalla di ponte *f*; coscia *f*	estribo *m*	ABUTMENT
aderenza *f*	adhesion *m*	Adhesion
aggiustamento *m*	ajuste *m*	Adjustment
convenzione *f*	contrato ; convenio *m*	Agreement (contract)
macchina pneumatica *f*	bomba de aire *f*	Air-pump
alluvione *m*	depósito de aluvion *m*	Alluvial deposit
ancoragio *m*	anclaje *m*	Anchorage
ferro d'angolo; ferro a squadra	hierro de angulo *m*	Angle iron
ricuocere ;	templar	Anneal, to
ricuocitura ; ricotto	templadura *f*	Annealing
incudine *f*	yunque *m*	Anvil
apparecchio *m*	aparato *m*	Apparatus
strada d'accesso *f*	aproches *m*	Approach (bridge)
acquedotto *m*	aqueducto *m*	Aqueduct
arco *m*	arco *m*	Arc
volta *f*	arco *m* ; bóveda *f*	Arch
ponte arcato *m*; ponte ad arco *m*	puente de bóveda *m*	Arched bridge
tetto arcuato	techo abovedado *m*	Arched roof
architetto *m*	arquitecto *m*	Architect
area *f*	área *f*	Area
asfalto *m*	asfalto *m*	Asphalte
ghiaja *f*; massicciata *f*	balast ; lastre *m*	BALLAST
riva ; sponda *f*	orilla ; ribera *f*	Bank of a river
ferro in verga *m* ; barre *f*	hierro en barras *m*	Bar iron
línea di base *f*	linea de base *f*	Base line
pendio *m* ; scarpa *f*	talud de un muro *m*	Batter
nervatura *f*	nervadura *f*; astrágalo *m*	Bead
trave *m*	viga *f*	Beam
punzone a mano	punzonera *f*	Bear (punching)
appoggio *m* ; cuscinetto *m*	largo de apoyo *m*	Bearing (support)
letto ; corpo (muratura) *m*	lecho *m*	Bed (masonry)
alveo di fiume *m*	lecho *m* (de un rio)	Bed of a river
fondo del mare *m*	fondo del mar *m*	Bed of the sea
piastra di fondazione	placa de fundacion *f*	Bed-plate

English.	French.	German.
Bessemer steel	acier (ou métal) Bessemer *m*	Bessemer-stahl *m*
Bill of lading	connaissement *m*	Ladungsschein;Frachtbrief *m*
Bill of quantities	avant-métré *m*	Materialien-Nachweis *m*
Blacksmith	maréchal ; forgeron *m*	Schmied *m*
Blast furnace	haut fourneau *m*	Hochofen *m*
Blistered steel	acier cémenté *m*	blasiger Stahl *m*
Block and fall	palan avec corde *m*	Flaschenzug *m*
Bolt	boulon *m*	Bolzen ; Schraubenbolzen *m*
Bolt-head	tête de boulon *f*	Schraubenkopf *m*
Bolt-hole	trou à boulon *m*	Schraubenloch *n*
Bond (in brickwork)	liaison *f*	Mauersteinverband *m*
Boring-bar	tige du forêt *f*	Bohrspindel ; Bohrstange *f*
Bottom flange	table (ou bride) inférieure *f*	untere Gurtung *f*
Boulder	caillou *m*	Rollstein *m*
Bow-string girder	poutre cintrée *f*	Parabelträger *m*
Box girder	poutre tubulaire *f*	Kastenträger *m*
Brace to	entretoiser	verbinden ; versteifen
Bracing	entretoisement *m*	Versteifungskreuz *n*
Bracket	console *f*	Console *f* ; Vorsprung *m*
Brand (trade-mark)	marque de fabrique *f*	Fabrikstempel *m*
Breaking joint	assemblage à joints croisés *m*	versetzterStoss; Stosswechsel
Breaking strain	force de rupture *f*	Zerreissungs-Festigkeit *f*
Breakwater	brise-lames *m* ; digue *f*	Wellenbrecher ; Damm *m*
Bricklayer	maçon en briques *m*	Maurer *m*
Brickwork	briquetage *m*	Ziegel-mauerwerk *n*
Bridge	pont *m*	Brücke *f*
Bridge of boats	pont de bateaux *m*	Pontonbrücke; Schiffbrücke *f*
Bridge parapet	parapet *m*	Brückengeländer *n*
Bridge roadway	voie charretière *f*; tablier *m*	Brückenbahn *f*
Buckled plate	fer arrondi *m*	Bukelplatte : Schildplatte *f*
Builder	entrepreneur de batiments *m*	Baumeister ; Erbauer *m*
Building	édifice *m* ; construction *f*	Gebäude *n*
Butt joint	assemblage bout à bout *m*	stumpfe Fuge *f*
Buttress	contrefort *m*	Strebepfeiler ; Strebebogen *m*
CAISSOON	caisson *m*	Senkkasten *m*
Callipers	compas d'épaisseur *m*	Taster *m*
Camber	fléche *f*	Schweifung *f*
Canal	canal *m*	Kanal *m*
Cantilever	poutre saillante *f*	vorspringender Arm *m*
Capital (of a column)	chapiteau *m*	Capitäl ; Säulenhaüpt *n*
Cargo	cargaison *f*	Schiffsladung *f*
Carpenter	charpentier *m*	Zimmermann *m*
Carry, to : (to sustain)	porter ; supporter	tragen ; stützen
Cast, to	fondre ; couler	giessen
Casting	fonte *f* ; pièce en fonte *f*	Gussstück *n*
Cast iron	fonte *f*	Gusseisen *n*
Cast iron bridge	pont en fonte *m*	gusseiserne Brücke *f*

Italian.	Spanish.	English.
acciajo (qualità bessemer) *m*	acero de Bessemer *m*	Bessemer steel
polizza di carico *f*	conocimiento *m*	Bill of lading
preventivo *m* ; perizia *f*	lista de cantidades *f*	Bill of quantities
fabbro-ferrajo *m* ; fabbro *m*	herrero *m*	Blacksmith
alto forno *m*	horno soplante *m*	Blast furnace
acciajo cementato *m*	acero cementado *m*	Blistered steel
paranco *m* ; girella *f*	mufla *f*; moton *m*	Block and fall
chiavarda *f*; vite *f*; bollone *m*	tornillo *m*	Bolt
testa della chiavarda *f*	cabeza de tornillo *f*	Bolt-head
buco della chiavarda *m*	agujero de tornillo *m*	Bolt-hole
legame (in muratura) *m*	trabazon *f*	Bond (in brickwork)
gambo del trapano *m*	taladro *m*	Boring-bar
tavola inferiore *f*	reborde inferior *m*	Bottom flange
trovante *m* ; ciottola *f*	guijarro *m*	Boulder
travata *f*	viga cimbrada *f*	Bow-string girder
travata vuota *f*	viga celular *f*	Box girder
legare ; puntellare	abrazar	Brace to
spranga	abrazadera *f*	Bracing
mensola *f*; sostegno *m*	ménsula *f*	Bracket
marca d'un commerciante	marca de fábrica *f*	Brand (trade-mark)
giunture alternate *f*	junta embonada *f*	Breaking joint
sforzo di rottura *m*	fuerza de rotura *f*	Breaking strain
molo *m*	rompe-olas *m*	Breakwater
muratore *m*	albañil *m*	Bricklayer
muratura in mattone *f*	albañileria de ladrillos *f*	Brickwork
ponte *m*	puente *m*	Bridge
ponte di barche *m*	puente de barcos *m*	Bridge of boats
parapetto del ponte *m*	parapeto *m*	Bridge parapet
passaggio sopra un ponte *m*	camino de puente *m*	Bridge roadway
lastra concava *f*	plancha combada *f*	Buckled plate
edificatore *m*	constructor *m*	Builder
edifizio *m*	edificio *m*	Building
	junta á tope *f*	Butt joint
barbacane *m* ; contrafforto *m*	machon ; estribo *m*	Buttress
cassone *m*	cajon *m*	CAISSOON
compassi di spessore *m*	compas de espesores *m*	Callipers
curvatura *f* ; saetta *f*	sagita *f*	Camber
canale *m*	canal *m*	Canal
modiglione *m*	viga saliente *f*	Cantilever
capitello *m*	capitel (de una columna) *m*	Capital (of a column)
carico *m*	cargamento *m*	Cargo
falegname *m*	carpintero *m*	Carpenter
portare	soportar	Carry, to : (to sustain)
fondere	fundir	Cast, to
pezzo di fuzione *m*	fundicion *f*	Casting
ferro fuso *m* ; ghisa *f*	hierro fundido ; hierro colado	Cast iron
ponte in ferro fuso *m*	puente de hierro colado *m*	Cast iron bridge

English.	French.	German.
Cast iron girder	poutre en fonte *f*	gusseiserner Träger *m*
Cast steel	acier fondu *m*	Gussstahl *m*
Catenary curve	chainette *m*	Kettenlinie *f*
Caulk, to	calfater	kalfatern
Centering (of arches)	cintrage *m*	Lehrgerüst *n*
Centre of gravity	centre de gravité *m*	Schwerpunkt *m*
Centre of pressure	centre de pression *m*	Drucklinie *f*
Centre line	l'axe *f*; ligne centrale *f*	Mittellinie *f*
Centrifugal pump	pompe à force centrifuge *f*	Centrifugalpumpe *f*
Chain	chaîne *f*	Kette *f*
Chain pump	pompe avec chaîne à godets *f*	Kettenpumpe *f*; Pumpwerk *n*
Chain sling	chaîne à double crochets *f*	Kettenschlinge *f*
Chain shackle	entraves *f*	Schäckel *m*
Chalk	craie *f*	Kalk *m*; Kreide *f*
Channel iron	fer en U; fer à rebords *m*	U Eisen *n*
Chip	rognure de fer *f*	Span *m*
Chip, to	buriner; entailler	meisseln
Chipping-piece	portée d'adjustement	Anpassungsfläche *f*
Chisel	ciseau *m*	Flachmeissel *m*
Chisel, cross-cut	burin; ciseau *m*	Kreuzmeissel *m*
Chord line	corde *f*	Sehne *f*
Circle	cercle *m*	Kreis *m*
Circular	circulaire	kreisförmig
Circumference	circonférence *f*	Umfang *m*
Civil engineer	ingénieur civil *m*	Civil-Ingenieur *m*
Clay	argile *f*	Thon; Letten *m*
Cofferdam	bâtardeau; caisson *m*	Fangdamm *m*
Cohesion	cohésion *f*	Cohäsion *f*
Cold-blast iron	fonte à l'air froid *f*	kalt erblasenes Eisen *n*
Column	colonne *f*	Säule *f*
Compression	compression *f*	Zusammenpressung *f*; Druck *m*
Concave	concave	concav; hohl
Concession	concession *f*	Concession *f*
Concrete	béton *m*	Beton *m*
Conditions of contract	cahier des charges *m*	Vertragsbedingungen *pl f*
Conservatory	jardin d'hiver *m*; serre *f*	Gewächshaus *n*
Construction	construction *f*	Construction *f*; Bau *m*
Continuity	continuité *f*	Continuität *f*
Continuous girder	poutre continue *f*	continuirlicher Träger *m*
Contract, to (shorten)	se contracter	schwinden
Contract, to (undertake)	entreprendre	einen Vertrag abschliessen
Contract (document)	contrat *m*; convention *f*	Vertrag; Contract *m*
Contract (undertaking)	entreprise *f*	Uerbernahme eines Vertrages
Contraction	retrait *m*	Schwinden *n*
Contractor	entrepreneur *m*	Bauunternehmer *m*
Contractor's agent	agent; représentant *m*	Unternehmers Agent *m*
Contractor's plant	matériel d'entrepreneur *m*	Baugeräth *n*

Italian.	Spanish.	English.
trave in ghisa *m*	viga de hierro colado *f*	Cast iron girder
acciajo fuso *m*	acero colado *m*	Cast steel
catenaria *f*	cadenita *f*; curva catenaria *f*	Catenary curve
calafatare	calafatear	Caulk, to
armatura *f*	cimbra *f*; galapágos	Centering (of arches)
centro di gravità *m*	centro de gravedad *m*	Centre of gravity
centro di pressione *m*	centro de presion *m*	Centre of pressure
linea centrale *f*; asse *m*	eje *m*	Centre line
pompa a forza centrifuga *f*	bomba centrífuga	Centrifugal pump
catena *f*	cadena *f*	Chain
noria *f*	bomba de cadena *f*	Chain pump
catena di sospensione *f*	cadina con doble gancho	Chain sling
annello di unione *m*		Chain shackle
creta *f*; marna *f*	creta *f*	Chalk
ferro scanalato *m*	hierro acanalado *m*	Channel iron
scheggia *f*	brizna *f*	Chip
scheggiare ; sbriciolare	burilar	Chip, to
		Chipping-piece
scarpello *m*	cortafrio *m* ; escoplo *m*	Chisel
	cincel *m*	Chisel, cross-cut
corda *f*	cuerda *f*	Chord line
circolo *m*	círculo *m*	Circle
circolare	circular	Circular
circonferenza *f*	circunferencia *f*	Circumference
ingegnere civile ; ingegnere	ingeniero civil *m*	Civil engineer
argilla *f*	arcilla *f*	Clay
cassero *m* ; cassone *m*	ataguia *f*	Cofferdam
coesione *f*	coherencia *f*	Cohesion
	fundicion al aire frio *f*	Cold-blast iron
colonna *f*	columna *f*	Column
compressione *f*	compresion *f*	Compression
concavo	concavo	Concave
concessione *f*	concesion *m*	Concession
calcestruzzo *m* ; beton *m*	hormigon *m*	Concrete
condizione di contratto *f*	pliego de condiciones *m*	Conditions of contract
conservatorio *m*	estufa *f*	Conservatory
costruzione *f*	construccion *f*	Construction
continuità *f*	continuidad *f*	Continuity
trave continua *f*	viga continua *f*	Continuous girder
raccorciare	contratarse	Contract, to (shorten)
intraprendere	contratar	Contract,to(undertake)
contratto *m*	contrato *m*	Contract (document)
impresa *f*	contrata *f*	Contract(undertaking)
contrazione *f*	contraccion *f*	Contraction
impresario *m*	contratista *m* ; empresario *m*	Contractor
agente dell'impresario *m*	agente del contratista *m*	Contractor's agent
materiale dell'impresario *m*	material del contratista *m*	Contractor's plant

English.	French.	German.
Convex	convexe	convex ; erhaben
Coping	couronnement *m*	Mauerkappe *f*
Core (in a casting)	noyau *m*	Kern ; Formkern *m*
Core-box	boîte à noyau *f*	Kernkasten *m*
Core-print	portée *f* ; empreinte *f*	Kernmarke *f*
Cornice	corniche *f*	Kranzgesims *n*
Corrosion	corrosion *m*	Rosten *n*
Corrugated iron	tôle ondulée *f*	Wellenblech *n*
Cottar (key)	clavette *f*	Keil *m*
Countersink, to	fraiser	kegelförmig ausbohren
Countersunk hole	trou fraisé *m*	versenktes Loch *n*
Cover plate	couvre-joint *m*	Stossplatte *f*
Crab	treuil *m*	Winde *f*
Crane	grue *f*	Krahn *m*
Cross-cut chisel	ciseau bec d'âne *m*	Kreuzmeissel *m*
Cross girder	poutre transversale *f*	Querträger *m*
Cross section	coupe en travers *f*	Querschnitt *m*
Crowbar	pince *f* ; levier *m*	Brechstange *f* ; Hebebaum *m*
Crown of an arch	sommet *m*	Scheitel eines Bogens *m*
Crucible steel	acier fondu au creuset *m*	Tiegelstahl *m*
Crushing force	force broyante *f*	rückwirkende Festigkeit *f*
Cubic content	volume *m* ; cube *m*	Cubikinhalt *m*
Culvert	aqueduc *m*	Abzugsgraben ; Durchlass *m*
Cup-headed rivet	rivet à champignon *m*	rundköpfige Niete *f*
Cupola (foundry)	four à coupole ; cubilot *m*	Cupolofen *m*
Curb (on foot path)	bordure (du trottoir) *f*	Rinnstein-Schwelle
Current	courant *m*	Strömung *f*
Curvature	courbure *f*	Krümmung ; Pfeilhöhe *f*
Curve	courbe *f*	Curve *f*
Curve, to	courber ; cintrer	biegen ; krümmen
Curve of equilibrium	courbe d'équilibre *f*	Drucklinie
Cutting (railway)	tranchée *f*	Einschnitt ; Durchstich *m*
Cutwater of a bridge	avant bec *m*	Eisbrecher *m* ; Pfeilerspitze *f*
Cylinder	cylindre *m*	Cylinder *m*
Cylindrical	cylindrique	cylinderförmig
DAM	digue *f* ; batardeau *m*	Damm *m*
Dam, to	diguer ; endiguer	eindämmen, abdämmen
Datum line	repère *m*	Grundlinie ; Normale *f*
Dead load	poids mort *m*	Eigenlast *f*
Deck cargo	chargement sur tillac *m*	Decklast *f*
Deflect, to	devier	durchbiegen
Deflection	déflexion *f* ; tassement *m*	Durchbiegung *f*
Density	densité ; pesanteur *f*	Dichtigkeit *f*
Depth	profondeur *f*	Tiefe ; Höhe *f*
Derrick	chèvre *f*	Ausleger *m*
Design	plan ; dessin *m*	Zeichnung *f* ; Plan *m* ; Project *n*
Detail drawing	dessin avec détails *m*	Detailzeichnung *f*

Italian.	Spanish.	English.
convesso	convexo	Convex
corona del muro *m*	albardilla *f*	Coping
anima *f*; torso *m*	alma *f*	Core (in a casting)
scatola per l'anima *f*	molde; cajon de molde *m*	Core-box
impronta dell'anima *f*	piton *m*	Core-print
cornice *f*	cornisa *f*	Cornice
corrosione *f*	corrosion *f*	Corrosion
lamiera ondulata *f*	hierro ondulado *m*	Corrugated iron
chiavetta *f*	chabeta *f*	Cottar (key)
	embutir	Countersink, to
	agujero para cabeza embutida	Countersunk hole
coprigiunta; placca di giunta	tapajunta *f*	Cover plate
argano *m*; vericello *m*	torno *m*	Crab
grù *f*	grua *f*	Crane
scarpello *m*		Cross-cut chisel
travicello trasversale *m*	viga trasversal; vigueta *f*	Cross girder
sezione; profile trasversale *f*	seccion trasversal	Cross section
leva di ferro *f*	palanca *f*	Crowbar
corona dell'arco *f*	remate *m*	Crown of an arch
acciajo fuso nel crogiuolo *m*	acero de copela *m*	Crucible steel
forza di schiacciamento *f*	fuerza de presion *f*	Crushing force
capacità; "il cubo;" volume	cubo; volumen *m*	Cubic content
condotto *m*	alcantarilla *f*	Culvert
rivé a testa rotonda *m*	redoblon con cabeza redonda	Cup-headed rivet
forno a cupola	cúpula *f*	Cupola (foundry)
sponda *f*	acera; guarda rueda *f*	Curb (on foot path)
corrente *m*	corriente *f*	Current
incurvatura *f*	curvatura *f*	Curvature
curva *f*	curva *f*	Curve
curvare	encorvar	Curve, to
curva d'equilibrio *f*	curva de equilibrio *f*	Curve of equilibrium
trincea *f*	desmonte *m*	Cutting (railway)
becco *m*; pigna *f*	espolon; tajamar *m*	Cutwater of a bridge
cilindro *m*	cilíndro *m*	Cylinder
cilindrico	cilíndrico *m*	Cylindrical
diga *f*; chiusa	dique *m*	DAM
chiudere	represar	Dam, to
linea di livello *f*	plano de nivel *m*	Datum line
carico morto *m*	peso muerto *m*	Dead load
carico sopra coperta *m*	cargamento sobre cubierta *m*	Deck cargo
piegare	desviar	Deflect, to
piegatura *f*; depressione *f*	desviacion *f*	Deflection
densità *f*	densidad *f*	Density
profondità *f*	profundidad *f*	Depth
martinello di artimone *m*	palo *m*	Derrick
disegno *m*	proyecto *m*	Design
disegno in detaglio *m*	dibujo de detalles *m*	Detail drawing

English.	French.	German.
Diagonal brace	entretoise diagonale *f*	Diagonalverband *n*
Diagonal strut	contrefiche diagonale *f*	Diagonalstrebe *f*
Diagonal tie	tirant diagonal *m*, attache *f*	Diagonal-Zugstange *f*
Diagram of strains	épure des efforts *f*	Spannungsdiagramm
Diameter	diamètre *m*	Durchmesser *m*
Dimensions	dimensions *f*	Maasse *pl*
Diver	plongeur *m*	Taucher *m*
Diversion of a road	déviation d'une voie *f*	Ablenkung einer Strasse *f*
Diving-bell	cloche à plongeur *f*	Taucherglocke *f*
Dolly (for riveting)	tas à river *m* ; turque *m*	Nietstock *m*
Dolphin(floatingfendr.)	patte d'oie *f*	Abweiser *m*
Dome roof	dôme *m*	Kuppeldach *n*
Double line of railway	double voie *f*	Doppelgeleise *n*
Draughtsman	dessinateur *m*	Zeichner *m*
Drawing	dessin *m*	Plan *m* ; Zeichnung *f*
Drawing paper	papier à dessin *m*	Zeichenpapier *n*
Dredger	drague *f*	Bagger *m*
Dredge, to	draguer	baggern
Drill	machine à forer	Bohrer *m*
Drill, to	percer	bohren ; ausbohren
Drilling machine	machine à forer *f*	Bohrmaschine *f*
Drive piles, to	battre les pieux	Pfähle einrammen
Ductile	ductile	streckbar
Ductility	ductilité *f*	Streckbarkeit *f*
EARTHWORK	terrassement *m*	Erdschüttung *f*
Eaves (roof)	avant-toit *m*	Dachtraufe *f*
Eaves gutter	cheneau *m* ; gouttière *f*	Traufrinne *f*
Elastic	élastique	elastisch
Elasticity	élasticité *f*	Elasticität ; Federkraft *f*
Elevation (drawing)	élévation *f*	Aufriss *m*
Embank, to	remblayer	eindeichen ; eindämmen
Embankment	remblai *m*	Damm *m*
Engineer	ingénieur *m*	Ingenieur *m*
Entablature	entablement *m*	Simswerk *n*
Equilibrium	équilibre *m*	Gleichgewicht *n*
Erect, to (fix in place)	monter	aufstellen ; montiren
Erect, to, a bridge	monter	bauen ; aufstellen
Estimate of cost	devis ; détail estimatif *m*	Kostenanschlag *m*
Excavate, to	déblayer	ausgraben
Excavation	fouille *f*	Ausgrabung *f*
Excavator	terrassier *m*	Erdarbeiter *m*
Expansion	extension	Ausdehnung *f*
FACE (of masonry)	parement ; revêtement *m*	Stirnfläche ; Bekleidung *f*
Face (ironwork), to	façonner ; raboter	bearbeiten
Façade	façade *f*	Façade *f*
Fascia—facia	face *f*	Verkleidung *f*
Factory	fabrique *f*	Fabrik *f*

Italian.	Spanish.	English.
a croce di San Andrea	abrazadera diagonal *f*	Diagonal brace
puntello o crociera diagonale	tornapunta *f*	Diagonal strut
legame diagonale *m*	tirante diagonal *m*	Diagonal tie
disegno degli sforzi *m*	grafico de las fuerzas *m*	Diagram of strains
diametro *m*	diámetro *m*	Diameter
dimensione *f*	dimensiones *f*	Dimensions
palombaro *m*	buzo *m*	Diver
deviazione di strada *f*	cambio de via *m*	Diversion of a road
campana di palombaro *f*	campana de buzo *f*	Diving-bell
puntello per la ribaditura *m*	botador *m*	Dolly (for riveting)
guarda pile *m*		Dolphin(floatingfendr)
tetto a cupola *m*	media-naranja *f*	Dome roof
strada a doppi a rotaja *f*	doble via *f*	Double line of railway
disegnatore *m*; dilinatore *m*	delineante *m*	Draughtsman
disegno *m*	dibujo *m*	Drawing
carta da disegno *f*	papel de dibujo *m*	Drawing paper
draga *f*; cucchiaja *f*	draga *f*	Dredger
dragare	dragar	Dredge, to
trepano *m*; succhiello *m*	broca *f*	Drill
trepanare ; forare	taladrar	Drill, to
macchina perforatrice *f*	máquina de taladrar *f*	Drilling machine
battere pali col battipalo *m*	clavar pilotes	Drive piles, to
duttile ; flessibile	dúctil	Ductile
duttilità *f*	ductilidad *f*	Ductility
movimento di terra *m*	esplanacion *f*	EARTHWORK
gronde *f*	alero *m*	Eaves (roof)
canale delle gronde *m*	canalon *m*	Eaves gutter
elastico	elástico	Elastic
elasticità *f*	elasticidad *f*	Elasticity
elevazione *f*	alzado *m*	Elevation (drawing)
interrare ; arginare	terraplenar	Embank, to
terrapieno *m*; diga *f*; argine *m*	terraplen *m*	Embankment
ingegnere *m*	ingeniero *m*	Engineer
architrave *m*	entablamento *m*	Entablature
equilibrio *m*	equilibrio *m*	Equilibrium
collocare	colocar	Erect, to (fix in place)
costruire un ponte *m*	colocar	Erect, to, a bridge
valutazione del costo *f*	presupuesto *m*	Estimate of cost
scavare	escavar	Excavate, to
scavamento *m*	escavacion *f*	Excavation
scavatore *m*	escavador *m*	Excavator
distensione *f*; espansione *f*	expansion *f*	Expansion
paramento *m*; faccia *f*	paramento *m*	FACE (of masonry)
piallare il ferro	aplanar	Face (ironwork), to
facciata *f*	fachada *f*	Façade
fascia *f*	faja *f*	Fascia—facia
fabbrica	fábrica *f*	Factory

English.	French.	German.
Felt	feutre *m*	Filz *m*
Fender-pile	pilot de défense *m*	Schutzpfahl *m*
File	lime *f*	Feile *f*
File, to	limer	feilen
Fillet	nervure *f*	Hohlleiste *f*
Fish-bellied-girder	poutre à ventre de poisson *f*	Fischbauchträger *m*
Fish plate	éclisse *f*	Lasche *f*
Fit, to (ironwork)	ajuster	montiren ; aufstellen
Fitter	ajusteur *m*	Monteur *m*
Flange (of a girder)	table ; semelle *f* ; bride *f*	Gurtung *f*
Flexible	flexible ; souple	biegsam ; geschmeidig
Flood	inondation *f*	Fluth ; Ueberschwemmung
Flood arch	deversoir *m*	Fluthöffnung *f*
Floor	plancher ; tablier *m*	Fussboden *m*
Floor beams	poutre ; solive *f*	Deckbalken *m*
Flush	à fleur de ; affleuré	abgegleichen
Flush-rivet	rivet à tête fraisée *m*	versenkte Niete *f*
Fluted column	colonne cannelée *f*	cannelirte Säule *f*
Foot (measure)	pied *m*	Fuss *m*
Foot bridge	passerelle *f* ; pont à piétons *m*	Geh-Brücke *f* ; Steg *m*
Footings (brickwork)	empatement *m*	Mauerfuss *m*
Footpath	trottoir *m*	Fussteig *m* ; Trottoir *n*
Force	force *f*	Kraft *f*
Foreman	contremaître *m*	Werkführer *m*
Forge	forge *f*	Schmiede *f* ; Heerd *m*
Forge, to	forger	schmieden
Foundation	fondation *f*	Fundament *n*
Foundation plate	plaque de fondation *f*	Fundamentplatte *f*
Framing	encadrement *m*	Gerüst *n* ; Rahmen *m*
Freight	frêt *m*	Fracht ; Ladung *f*
Freight by weight	frêt au poids *m*	Fracht nach Gewicht
Freight by measuremnt	frêt à la mesure *m*	Fracht nach Maass
Friction	frottement *m*	Reibung *f*
Friction rollers	galet *m* ; glissières	Frictionsrolle *f*
Fulcrum	support ; point d'appui *m*	Stützpunkt *m*
Full-size (drawing)	grandeur naturelle *f*	in natürlicher Grösse
Furnace	fournaise *f* ; fourneau *m*	Ofen *m*
GABLE	pignon *m*	Giebel *m*
Galvanised iron	fer galvanisé *m*	verzinktes Eisen *n*
Gauge of railway	largeur de la voie *f*	Spurweite *f*
Gauge of iron	jauge *f*	Lehre ; Drahtlehre *f*
Gib	clavette *f*	Nasenkeil *m*
Girder	poutre ; solive *f*	Träger *m*
Girder bridge	pont en poutre *m*	Trägerbrücke *f*
Gradient	pente *f*	Steigung *f*
Granite	granit *m*	Granit *m*
Gravel	gravier *m*	Kies *n*

Italian.	Spanish.	English.
feltro *m*	fieltro *m*	Felt
parapalo *m*	baraderos	Fender-pile
lima *f*	lima *f*	File
limare	limar	File, to
striscia *f*; filetto	filete *m*	Fillet
trave a ventre di pesce *m*		Fish-bellied-girder
ganascia *f*; stecca *f*	eclisa *f*; chapa de junta	Fish plate
adattare ; acconciare	ajustar	Fit, to (ironwork)
meccanico *m*	ajustador *m*	Fitter
tavola *f* (d'una trave)	reborde *m*	Flange (of a girder)
flessibile	flexible	Flexible
inondazione *f*; piena *f*	inundacion *f*; creciente *f*	Flood
canale scaricatore *m*	arco para avenidas *m*	Flood arch
pavimento *m*	piso *m*	Floor
travi del soffitto	vigas *f*	Floor beams
a livello	á flor de	Flush
caviglio colla testa nascosta *m*	roblon embutido *m*	Flush-rivet
colonna scanalata *f*	columna estriada *f*	Fluted column
piede *m*	pie *m*	Foot
ponte per pedoni ; ponticello	puente para peatones	Foot-bridge
fondamenta *f*	base *f*	Footings (brickwork)
sentiero *m* ; marciapiede *m*	acera *f*	Foot-path
forza *f*	fuerza *f*	Force
primo lavorante *m* ; capo *m*	capataz *m*	Foreman
fucina *f*	fragua *f*	Forge
fucinare	forjar ; fraguar	Forge, to
fondazione *f*	cimiento *m* ; fundacion *f*	Foundation
placca di fondazione *f*	placa de fundacion *f*	Foundation plate
armatura *f*; impalcatura *f*	armazon *m*	Framing
nolo *m*	flete *m*	Freight
nolo a peso *m*	flete por peso *m*	Freight by weight
nolo a misura *m*	flete por medida *m*	Freight by measurement
attrito *m*	rozamiento *m*	Friction
cilindri di attrito *m*	rodetes *m*	Friction rollers
punto a bilico *m*	punto de apoyo *m*	Fulcrum
disegno al vero *m*	dibujo al tamaño natural *m*	Full-size (drawing)
fornace *f*	horno *m*	Furnace
gronda *f*; rochetto *m*	socarren *m*	GABLE
ferro galvanizzato *m*	hierro galvanizado *m*	Galvanised iron
larghezza del binario	anchura (de la via) *f*	Gauge of railway
grossezza del ferro *f*	anchura *f*	Gauge of iron
contrachiavetta *f*	chabeta	Gib
trave *m*	viga *f*	Girder
ponte a trave	puente con vigas *m*	Girder bridge
pendenza *f*; rampa *f*	pendiente *f*	Gradient
granito *m*	granito *m*	Granite
ghiaja *f*	ascajo *m*	Gravel

English.	French.	German.
Gusset, or stay (girder)	gousset *m*	Blechzwickel *m*
Guy rope	hauban *m*	Topreep *n*; Sturmleine *f*
HAMMER	marteau *m*	Hammer *m*
Hand-rail	garde corps *m*	Handleiste *f*
Handspike	levier *m*	Handspake
Hatchway of a ship	écoutille *f*	Schiffsluke *f*
Head of a bolt	tête *f* (de boulon)	Schraubenkopf *m*
Headway (bridge)	hauteur sous clef *f*	lichte Höhe *f*
Hearth (smith's)	foyer *m*	Schmiedeheerd *m*
Height	hauteur *f*	Höhe *f*
Hexagon nut	écrou à six pans *m*	sechskantige Mutter *f*
High water	hautes eaux; haute mer *f*	Hochwasser *n*; hohe Fluth
Hip (roof)	croupe *f*	Walm (Dach) *n*
Hip principal	demi-ferme de croupe *f*	Walmsparren *m*
I iron	fer en double T *m*	Doppel T Eisen *n*
Hollow pile	pilotis *m* (tubulaire)	hohler Pfahl *m*
Homogeneous	homogène	homogen
Hot blast-iron	fonte à l'air chaud *f*	heissgeblasenes Eisen *n*
Hydraulic cement	ciment hydraulique *m*	hydraulischer Cement *m*
Hydraulic jack	cric hydraulique *m*	hydraulische Winde *f*
ICE guard (bridge)	brise-glace *m*	Eisbrecher *m*
Inch	pouce *m*	Zoll *m*
"In the clear"	dans œuvre	im lichten
Inclined plane	plan incliné *m*	schiefe Ebene *f*
Inertia	inertie; force d'inertie *f*	Trägheit *f*
Insurance policy	police d'assurance *f*	Assecuranzpolice *f*
Inverted arch	voûte renversée *f*	umgekehrter Bogen *m*
Invoice	facture *f*	Factur *f*
Iron	fer *m*	Eisen *n*
Iron bridge	pont en fer *m*	eiserne Brücke *f*
Iron building	bâtiment en fer *m*	eisernes Gebäude *n*
Iron cement	ciment de fer *m*	Eisenkitt *m*
Iron-founder	fondeur *m*	Eisengiesser *m*
Iron-foundry	fonderie *f*	Eisengiesserei *f*
Iron ore	minerai de fer *m*	Eisenerz *n*
Iron oxide	oxyde de fer *m*	Eisenoxyd *n*
Iron pier (or jetty)	jetée en fer *f*	eiserne Landungsbrücke *f*
Iron pile	pilotis en fer; pieu en fer *m*	eiserner Pfahl *m*
Iron roof	toit en fer *m*	eisernes Dach *n*
Iron trade	commerce de fer *m*	Eisen Geschäft *m*
Ironwork	ouvrage en fer *m*	Eisenbestandtheile *pl*
Ironworks	usine à fer *f*	Eisenwerk *n*; Eisenhütte *f*
JACK (lifting)	cric; vérin *m*	Setzwinde
Jetty	jetée *f*	Landungsbrücke *f*
Joint	joint *m*	Fuge; Verbindung *f*
Joint cover plate	couvre joint *m*	Verbindungsblech *n*

Italian.	Spanish.	English.
trave d'appoggio *f*		Gusset, or stay (girder)
cavo di ritegno *f*	maroma *f*	Guy rope
martello *m*	martillo *m*	HAMMER
balaustrata *f*; ringhiera *f*	pasa-mano *m*	Hand-rail
manovella *f*; leva	palanca *f*; espeque *m*	Handspike
boccaporto *m*	escotilla *f*	Hatchway of a ship
capocchia *f*; testa *f*	cabeza (de un tornillo) *f*	Head of a bolt
altezza libera ; luce netta	luz vertical *f*	Headway (bridge)
fucina *f*	fogon *m*	Hearth (smith's)
altezza *f*	altura *f*	Height
chiocciola esagonale *m*	tuerca hexagonal *f*	Hexagon nut
marea alta *f*	altas mareas *f*	High water
tetto a quattro falde *m*	tejado á cuatro aguas *m*	Hip (roof)
centina principale *f*	media forma de lima hoya *f*	Hip principal
		I iron
palo vuoto *m*	pilote hueco *m*	Hollow pile
omogeneo	homogéneo	Homogeneous
	fundicion al aire caliente *f*	Hot blast-iron
cemento idraulico *m*	cal hidráulica *f*	Hydraulic cement
argano idraulico *m*	gato hidráulico *m*	Hydraulic jack
guardiano delle pile	rompehielo *m*	ICE guard (bridge)
pollice *m*	pulgada *f*	Inch
netto	luz *f*	"In the clear"
piano inclinato *m*	plano inclinado *m*	Inclined plane
inerzia *f*	inercia *f*	Inertia
polizza d'assicurazione *f*	póliza de seguro *f*	Insurance policy
arco a rovescio *m*	arco invertido *m*	Inverted arch
fattura *f*	factura *f*	Invoice
ferro *m*	hierro *m*	Iron
ponte in ferro *m*	puente de hierro *m*	Iron bridge
fabbricato in ferro *m*	edificio de hierro *m*	Iron building
cemento per ferro *m*	cemento de hierro *m*	Iron cement
fonditore in ferro *m*	fundidor *m*	Iron-founder
fonderia *f*	fundicion *f*	Iron-foundry
minerale di ferro *m*	mineral de hierro *m*	Iron ore
ossido di ferro *m*	óxido de hierro *m*	Iron oxide
pila in ferro *f*; molo in ferro *m*	muelle de hierro *m*	Iron pier (or jetty)
palo in ferro *m*	pilote de hierro *m*	Iron pile
tetto in ferro *m*	techo de hierro *m*	Iron roof
traffico in ferro *m*	comercio de hierro *m*	Iron trade
ferramenta *f*	obra de hierro *f*	Ironwork
ferriera *f*	fábrica de hierro *f*	Ironworks
martinello *m* ; crico *m*	gato ; criq *m*	JACK (lifting)
molo *m*	muelle *m*	Jetty
giunta *f*	junta *f*	Joint
placca di giunta *f*	tapa-junta *f*	Joint cover plate

English.	French.	German.
Joist (iron)	solive *f*	Fussbodenträger
KEY (cottar)	contre-clavette *f*	Keil *m*
Keystone (of an arch)	clef *f*	Schlussstein *m*
King-rod (roof)	poinçon ; tirant	Hängesäule *f*
LABOURER	manœuvre ; ouvrier *m*	Arbeiter *m*
Ladder	échelle *f*	Leiter *f*
Lap-joint	assemblage à recouvrement *m*	überlappende Fuge *f*
Lath	latte *f*	Latte *f*
Lathe	tour *m*	Drehbank *f*
Lattice girder	poutre en treillis *f*	Gitterträger *m*
Layer	couche *f*	Schicht *f*
Lead	plomb *m*	Blei *n*
Lean-to roof	toit en appentis *m*	Pultdach *n*
Length	longueur *f*	Länge *f*
Level (*adj.*)	horizontal; de niveau	eben
Level, to make	niveler	ebenen ; gleich machen
Level (spirit)	niveau à bulle d'air *m*	Wasserwage ; Libelle *f*
Levels, to take	niveler	nivelliren
Lever	levier *m* ; pince *f*	Hebel *m*
Leverage	rapport des leviers *m*	Hebelkraft *m*
Lewis bolt	boulon de sellement *m*	Steinschraube *f*
Lifting jack	cric *m*	Setzwinde *f*
Light-house	phare *m*	Leuchtthurm *m*
Lime	chaux *f*	Kalk *m*
Lime stone	calcaire; carbonate de chaux *m*	Kalkstein *m*
Limit of elasticity	limite d'élasticité *f*	Elasticitätsgrenze *f*
Line of rails	ligne *f*	Schienenweg *m*
Link (iron)	chaînon *m*	Gelenk ; Glied *n*
Load	charge *f*	Ladung ; Last *f*
Locomotive	locomotive *f*	Locomotive *f*
Longitudinal	longitudinal	der Länge nach ; Längs- -
Longitudinal elevation	élévation longitudinale *f*	Längen-Aufriss *m*
Longitudinal section	coupe longitudinale *f*	Längenschnitt *m*
Louvres	persiennes *f*	Schalldach *n*
Louvre blade	lame de persienne *f*	Schallblech *n*
Louvre standard	mannette de persienne *f*	Schalldachpfosten *m*
Low-water(tideorflood)	étiage *m* ; bassemer *f*	Ebbe *f*; Niederwasser *n*
Lubricate, to	graisser	schmieren
Lubrication	graissage *m*	Schmierung *f*
Lug	tasseau *m*	Ohr *n*
MACADAM	Macadam	Schotter ; Makadam *m*
Machinery	machines	Maschinerie *f*; Mechanismus *m*
Malleable cast iron	fonte malléable *f*	hämmerbares Gusseisen *n*
Manual labour	travail manuel *m*	Handarbeit *f*
Manufactory	usine *f*	Fabrik *f*
Manufacture, to	fabriquer	fabriciren ; verfertigen

Italian.	Spanish.	English.
travicello di ferro *m*	vigueta *f*	Joist (iron)
chiavetta *f*	chabeta *f*	KEY (cottar)
chiave d'un arco *f*	clave *f*	Keystone (of an arch)
monaco principale *m*	pendolon *m*	King-rod (roof)
manovale *m*	peon *m*	LABOURER
scala portabile *f*	escala *f*	Ladder
giunta a ribaditura *f*	junta *f*	Lap-joint
assicella *f*	liston *m*	Lath
tornio *m*	torno *m*	Lathe
trave àll'americano *f*	viga enrejada *f*	Lattice girder
letto *m*	capa *f*	Layer
piombo *m*	plomo *m*	Lead
tetto inclinato *m* ; tettoja	tejado á una agua *m*	Lean-to roof
lunghezza *f*	largo *m* ; longitud *f*	Length
a livello *m*	nivel *m*	Level (*adj.*)
livellare	nivelar	Level, to make
bolla d'aria *f* ; livella *f*	nivel de aire *m*	Level (spirit)
	nivelar	Levels, to take
leva *f*	palanca *f*	Lever
rapporto delle leve	potencia de la palanca *f*	Leverage
allivella *f*	tornillo empotrado *m*	Lewis bolt
martinello *m* ; crico *m*	gato ; criq *m*	Lifting jack
faro *m*	faro *m*	Lighthouse
calce *f* ; calcina *f*	cal *f*	Lime
pietra calcarea *f*	piedra calcárea *f*	Lime stone
limite d'elasticità *m*	límite de elasticidad *m*	Limit of elasticity
linea *f* ; binario *m*	fila *f*	Line of rails
anello *m*	eslabon *m*	Link (iron)
carica *f* ; soma *f* ; peso *m*	carga *f*	Load
locomotiva *f*	locomotora *f*	Locomotive
longitudinale	longitudinal	Longitudinal
elevazione longitudinale *f*	elevacion longitudinal *f*	Longitudinal elevation
sezione longitudinale *f*	corte longitudinal *m*	Longitudinal section
persiane *f*	persianas *f*	Louvres
stecche di persiana *f*	hoja de persianas *f*	Louvre blade
modello di persiana *m*	manivela de persianas *f*	Louvre standard
bassa marea *f*	baja marea *f*	Low water (tide or flood)
ugnere	lubrificar	Lubricate, to
untura *f*	engrasacion *f*	Lubrication
orecchio ; beccatello ; tasso	oreja *f*	Lug
macadam *m*	macadam *m*	MACADAM
meccanismo *m*	maquinaria *f*	Machinery
ghisa malleabile	hierro fundido maleable *m*	Malleable cast iron
lavoro manuale *m*	mano de obra *f*	Manual labour
fabbrica *f*	fábrica *f*	Manufactory
fabbricare	fabricar	Manufacture, to

English.	French.	German.
Manufacturer	fabriquant *m*	Fabrikant *m*
Marl	marne *f*	Mergel *m*
Mason	maçon *m*	Maurer *m*
Masonry	maçonnerie *f*	Mauerwerk *m*
Materials	matériaux *m*	Baumaterialen
Measure, to	mesurer	messen ; abmessen
Measurement	mesurage *m* ; mesure *f*	Aufmessung *f*
Measures	mesures *f*	Maasse *pl*
Measuring rule	règle à mesurer *f*	Maassstab *m*
Mechanic (workman)	mécanicien *m*	Maschinenarbeiter *m*
Mechanical powers	les forces mécaniques *f*	mechanische Kraft *f*
Mechanics	mécanique *f*	Mechanik *f*
Mechanism	mécanisme *m*	Mechanismus *m*
Melt, to	fondre	schmelzen
Melting furnace	fourneau de fusion *m*	Schmelzofen *m*
Melting point	point de fusion *m*	Schmelzpunkt *m*
Metal	métal *m*	Metall *n*
Metalling	empierrement *m*	Beschotterung *f*
Metre (decimal)	mètre *m*	Meter *m*
Metrical measures	les mesures métriques *f*	metrische Maasse
Mile	mille *m*	englische Meile *f*
Military bridge	pont militaire *m*	Militärbrücke *f*
Mine	mine *f*	Grube ; Zeche *f*
Mitre joint	assemblage à onglet *m*	Gehrstoss *m*
Mole (breakwater)	môle *m* ; digue *f*	Mole *f* ; Steindamm
Moment of inertia	moment d'inertie *m*	Trägheitsmoment *n*
Monkey (pile driver)	mouton *m*	Rammbär *m*
Mortar	mortier *m*	Mörtel *m*
Mould, to (foundry)	mouler	formen
Moulder (ditto)	fondeur *m* ; motueur *m*	Former *m*
Moulding (bead)	moulure *f*	Gesims ; Sims *n*
Moving load	poids moteur *m*	mobile Last *f*
Mud	limon *m* ; boue *f*	Schlamm *m*
Mullion	meneau *m*	Mönch *m*
NAIL	clou *m*	Nagel *m*
Nave (of building)	nef *f*	Schiff *n*
Nut (bolt)	écrou *m*	Schraubenmutter *f*
OAK	chêne *m*	Eichenholz *n*
Oak paving	pavé en chêne *m*	eichenes Stöckelpflaster *n*
Oil	huile *f*	Oel *n*
Oil, to	huiler	Schmieren ; oelen
Ore	minerai *m*	Erz *n*
Outline	contour *m*	Riss *m* ; Contour *m*
"Over all"	hors œuvre	äussere Dimension
Overhanging eaves	bout des toits saillants *m*	überhangende Traufe *f*
Oxidation	oxydation *f*	Oxidation *f*
Oxide	Oxyde *m*	Oxyd *n*

Italian.	Spanish.	English.
fabbricante *m*	fabricante *m*	Manufacturer
marna *f*	marga *f*	Marl
muratore *m*; fabbricatore *m*	albañil *m*	Mason
muratura *f*; fabbrica *f*	albañileria *f*	Masonry
materiali *m*	materiales *m*	Materials
misurare	medir	Measure, to
misura *m*	medicion *f*	Measurement
misure *f*	medidas *f*	Measures
regolo per misurare *m*	regla para medir *f*	Measuring rule
meccanico *m*	mecánico *m* (obrero)	Mechanic (workman)
forze meccaniche *f*	fuerzas mecánicas *f*	Mechanical powers
meccanica *m*	mecánica *f*	Mechanics
meccanismo *m*	mecanismo *m*	Mechanism
fondere	derretir, fundir	Melt, to
forno di fusione *m*	horno de fundicion *m*	Melting furnace
punto di fusione *m*	grado de fundicion *m*	Melting point
metallo *m*	metal *m*	Metal
inghiajamento *m*	piedra machacada *f*	Metalling
metro *m*	metro *m*	Metre (decimal)
misure metriche *f*	medidas métricas *f*	Metrical measures
miglia *m*	milla *f*	Mile
ponte militare *m*	puente militar *m*	Military bridge
miniera *f*	mina *f*	Mine
giuntura da cornice *f*	ensamblaje á inglete *m*	Mitre joint
molo *m*	muelle *m*	Mole (breakwater)
momento d'inerzia *m*	momento de inercia *m*	Moment of inertia
montone(di battipalo);maglio	maza *f*	Monkey (pile driver)
malta *f*	mortero *m*	Mortar
modellare	moldar	Mould, to (foundry)
modellatore *m*	fundidor *m*	Moulder (ditto)
modanatura *f*	moldura *f*	Moulding (bead)
carico mobile *m*	peso motor *m*	Moving load
fango *m*	lodo; barro *m*	Mud
	crucero de ventana *m*	Mullion
chiodo *m*	clavo *m*	NAIL
navata *f*; nave *f*	nave *f*	Nave (of building)
chiocciola *f*; madrevite *f*	tuerca *f*	Nut (bolt)
quercia *f*	roble *m*	OAK
pavimento di quercia *m*	pavimento de roble *m*	Oak paving
olio *m*	aceite *m*	Oil
oliare	untar	Oil, to
minerale *m*	mineral *m*	Ore
contorno *m*	contorno *m*	Outline
misura esterna *f*	tamaño mayor *m*	"Over all"
gronde pendenti *f*	aleros sobresalientes *m*	Overhanging eaves
ossidazione *f*	oxidacion *f*	Oxidation
ossido *m*	óxido *m*	Oxide

English.	French.	German.
Oxidise, to	s'oxyder	oxydiren
PACKED	emballé	emballirt zum Transport
Packing case	caisse d'emballage *f*	Emballage
Packing piece (iron)	fourrure *f*	Füllungsblech *n*
Paint	peinture ; couleur *f*	Farbe *f*
Paint, to	peindre	malen
Painter	peintre *m*	Anstreicher ; Maler *m*
Parabolic curve	parabole *f*	Parabel *f*
Parallel	parallèle	parallel
Parapet	parapet *m*	Brustmauer *f*
Patent	brevet *m* ; lettres-patentes *f*	Patent *n* ; privilegium *n*
Pattern (for foundry)	modèle *m*	Gussmodell *n*
Pattern maker	modeleur *m*	Modellschreiner *m*
Pavement	pavé ; pavage *m*	Strassenpflaster *n*
Paving	pavage *m*	Pflaster *n*
Permanent set	déflexion permanente	bleibende Einsenkung *f*
Permanent way	voie *f*	Bahnoberbau *m*
Pick-axe	pic ; marteau à deux pointes	Spitzhacke *f*
Pier (bridge)	pile *f*	Brückenpfeiler *m*
Pier (or jetty)	jetée *f*	Damm ; Hafendamm *m*
Pig iron	fonte crue *f* ; fer cru *m*	Roheisen *n*
Pilaster	pilastre *m* ; colonne *f*	Pilaster *m*
Pile	pieu ; pilot *m*	Pfahl *m*
Pile driver	sonnette *f*	Ramme ; Kunstramme *f*
Pile head	tête de pieu *f*	Pfahlkopf *m*
Pile screw	vis de pieu *f*	Pfahlschraube *f*
Pile shoe	sabot *m*	Pfahlschuh *m*
Pin (bolt)	boulon *m*	Boizen *m*
Plan (project)	projet *m*	Plan *m* ; Project *n*
Plan (drawing)	plan *m*	Grundriss *m*
Plane (surface)	surface *f* ; plan *m*	Ebene *f*
Plane, to	raboter	ebnen ; hobeln
Planing machine	machine à raboter *f*	Hobelmaschine *f*
Plank	planche *f*	Bohle *n* ; Planke *f*
Plate girder	poutre en tôle *f*	Blechträger *m*
Plate iron	tôle *f*	Eisenblech *n*
Platform (bridge)	tablier *m*	Brückenbahn *f*
Plumb line	fil à plomb *m*	Lothleine *f*
Pneumatic	pneumatique	pneumatisch
Point of suspension	point de suspension *m*	Aufhängepunkt *m*
Points and crossings	aiguilles et croisement de voie	Bahnkreuzung *f*
Pontoon	ponton *m*	Ponton *m*
Pontoon bridge	pont de bateaux *m*	Pontonbrücke *f*
Portable engine	locomobile *f*	Locomobile
Portable hearth	forge portative *f*	Feldschmiede *f*
Portico	portique *m*	Vorhalle *f*
Portland cement	ciment de Portland *m*	Portland-Cement *m*

Italian.	Spanish.	English.
ossidare	oxidarse	Oxidise, to
imballato *m*	embalado	PACKED
cassa d'imballaggio *f*	cajon de embalage *m*	Packing case
pezzo di rialzo *m*	llena hueco *m*	Packing piece (iron)
colore *m*	pintura *f*	Paint
colorire	pintar	Paint, to
coloritore *m*	pintor *m*	Painter
curva parabolica *f*	parábola *f*	Parabolic curve
paralello	paralelo	Parallel
parapetto *m*	parapeto *m*	Parapet
brevetto d'invenzione *m*	privilegio de invencion *m*	Patent
modello *m*	modelo *m*	Pattern (for foundry)
falegname di fonderia *m*	modelador *m*	Pattern maker
pavimento *m*	pavimento *m*	Pavement
lastricato *m*; selciata *f*	adoquinado *m*	Paving
cedimento permanente *m*	flexion permanente *f*	Permanent set
armamento *m*; via permanente	via *f*	Permanent way
zappa a punta; marra; piccone	pico *m*	Pick-axe
pila *f*	pila *f*; estribo *m*	Pier (bridge)
molo *m*	muelle *m*	Pier (or jetty)
ferro in pani *m*; ghisa *f*	hierro en galápagos *m*	Pig iron
pilastro *m*	pilastra *f*	Pilaster
palo *m*	pilote *m*	Pile
battipalo *m*	martinete *m*	Pile driver
testa del palo *f*	cabeza de pilote *f*	Pile head
vite del palo *m*	rosca de pilote *f*	Pile screw
scarpa del palo *f*	azuche *m*	Pile shoe
chiavarda *f*	tornillo con chabeta *m*	Pin (bolt)
progetto *m*	proyecto *m*	Plan (project)
piano *m*	plano *m*	Plan (drawing)
superficie piana *f*	plano *m*	Plane (surface)
piallare; appianare	cepillar	Plane, to
macchina a piallare *f*	máquina para cepillar *f*	Planing machine
tavole *m*	tabla *f*	Plank
trave in lamiera di ferro *f*	viga de palastro *f*	Plate girder
lamiera di ferro *f*	hierro en planchas *m*	Plate iron
piattaforma *f*	tablero *m*	Platform (bridge)
filo a piombo *m*; piombino *m*	plomada *f*	Plumb line
pneumatico	neumatico	Pneumatic
punto di sospensione *m*	punto de suspension *m*	Point of suspension
cambiavie *m*	cambio y cruzamiento de vias	Points and crossings
pontone *m*; chiatta *f*	ponton *m*	Pontoon
ponte di chiatte *m*	ponton *m*	Pontoon bridge
locomobile	locomóvil *f*	Portable engine
fucina portabile *f*	fragua portátil *f*	Portable hearth
portico *m*	pórtico *m*	Portico
cimento inglese (Portland) *m*	cemento de Portland *m*	Portland cement

English.	French.	German.
Pound (weight)	livre *f*	Pfund *n*
Power	force *f*	Kraft *f*
Principal (roof)	arbalétrier *f* (ferme)	Dachbinder *m*; Hauptgebind *n*
Puddled clay	argile pétri *f*	durchgearbeiteter Thon *m*
Puddling furnace	four à puddler *m*	Puddelofen *m*
Pulley block	moufle *m*	Rolle *f*; Rollkloben *m*
Pump	pompe *f*	Pumpe *f*
Pump, to	pomper	pumpen
Pumping engine	machine d'épuisement *f*	Wasserhaltungsmaschine *f*
Punch	poinçon *m*	Stempel; Dorn *m*
Punch and die	poinçon et matrice	Stempel und Matrize
Punch, to	poinçonner	lochen
Punching machine	machine à poinçonner *f*	Lochmaschine *f*
Purline	panne *f*	Pfette; Dachpfette *f*
QUALITY of iron	qualité du fer *f*	Qualität des Eisens *f*
Quantities, bill of	avant-métré *m*	Gewichts Bestimmung *f*
Quantities, to take out	toiser	Gewichte berechnen
Queen-rod (roof)	poinçon secondaire *m*	zweite Hängesäule *f*
RADIUS	rayon *m*	Radius *m*
Raft	radeau *m*	Floss *n*
Rafter	chevron *m*	Sparren *m*
Railing	grille *f*; parapet en fer *m*	Geländer *n*
Railway	chemin de fer *m*	Eisenbahn *f*
Railway bridge	pont de chemin de fer *m*	Eisenbahnbrücke *f*
Railway station	gare *f*; station *f*	Bahnhof *m*
Railway train	convoi *m*; train *m*	Bahnzug *m*
Ram (pile driver)	mouton *m*	Ramme *f*; Rammblock *m*
Ratchet brace	cliquet pour percer *m*	Ratschbohrer *m*
Ravine	ravin *m*	Schlucht *f*
Retaining wall	mur de soutènement *m*	Futtermauer; Stützmauer *f*
Rib	nervure *f*	Rippe *f*
Ridge of a roof	faîtage *m*; faîte *m*	Firste *f*
Rigid	rigide	steif; unbiegsam
Rimer	alésoir *m*	Reibahle *f*
Rimer holes, to	élargir un trou	aufräumen
Rise (of an arch)	flèche *f*	Pfeilhöhe *f*
River	rivière *f*	Fluss; Strom *m*
River channel	chenal d'une rivière *m*	Stromprofil *n*
River bed	lit d'une rivière *m*	Flussbett *n*
Rivet	rivet *m*	Niete *f*
Rivet, to	river	nieten
Rivet head	tête d'un rivet *f*	Nietkopf *m*
Rivet hearth	forge à rivets *m*	Nietfeuer *n*
Rivet tongs	pince pour rivets *f*	Nietzange *f*
Riveting hammer	marteau à river *m*	Niethammer *m*
Riveting machine	machine à river *f*	Nietmaschine *f*
Riveting set	chasse-rivet *m*	Nietstempel *m*

Italian.	Spanish.	English.
libbra *f*	libra *f*	Pound (weight)
forza *f*	potencia ; fuerza *f*	Power
centina principale *f*	forma *f*	Principal (roof)
argilla puddlé (battute)	arcilla trabajada *f*	Puddled clay
fornace di pudellatura *m*	horno de pudlar *m*	Puddling furnace
girella *f*	polea *f*	Pulley block
pompa *f*	bomba *f*	Pump
pompare	sacar agua	Pump, to
pompa a vapore *f*	máquina de agotamiento *f*	Pumping engine
ponzone *m*	punzon *m*	Punch
ponzone e stampa		Punch and die
forare col ponzone	punzar	Punch, to
ponzone a macchina *m*	máquina para punzar	Punching machine
arcareccio *m* ; paradosso *m*	carriola ; carrera *f*	Purline
qualità di ferro *f*	calidad del hierro *f*	QUALITY of iron
perizia *f*	lista de cantidades *f*	Quantities, bill of
calcorare una perizia	calcular las cantidades	Quantities, to take out
	péndola *f*	Queen-rod (roof)
radio *m*	radio *m*	RADIUS
zattera *f*	balsa *f*	Raft
travicello *m* ; puntono *m*	cábrio *m*	Rafter
cancello *m* ; balaustro *m*	verja *f*	Railing
strada ferrata *f*	ferro-carril *m*	Railway
ponte di ferrovia *m*	puente de ferro-carril *m*	Railway bridge
stazione di ferrovia *f*	estacion de ferro-carril *f*	Railway station
convoglio *m* ; treno *m*	tren *m*	Railway train
montone(di battipalo);maglio	maza *f*; ariete *m*	Ram (pile driver)
crichetto *m* ; rajetto *m*	carraca *f*	Ratchet brace
borrone *m* ; burrone *m*	barranco *m*	Ravine
muro di sostegno *m*	muro de sostenimiento *m*	Retaining wall
	nervadura *f*	Rib
comignolo *m*; cima del tetto *f*	caballete *m*	Ridge of a roof
rigido ; duro	rigido	Rigid
ferro per ingrandire buchi	escariador *m* ; bolante *f*	Rimer
ingrandire buchi	aumentar un taladro	Rimer holes, to
monta *f*; freccia *f*	sagita *f*	Rise (of an arch)
fiume *m*	rio *m*	River
canale *m*; letto *m* (d'un fiume)	cauce de rio *m*	River channel
alveo *m* ; letto (d'un fiume)	lecho de rio *m*	River bed
ribaditura *f*	redoblon ; roblon *m*	Rivet
ribadire	remachar	Rivet, to
testa di ribaditura *f*	cabeza de redoblon *f*	Rivet head
fucina per le ribaditure *f*	fragua *f*	Rivet hearth
molle per le ribaditure *f*	tenazas *f*	Rivet tongs
martello per le ribaditure *m*	martillo de remachar *m*	Riveting hammer
macchina per le ribaditure *f*	máquina para remachar *f*	Riveting machine
bollo per le ribaditure *m*	hembrilla *f*	Riveting set

English.	French.	German.
Road	route *f*; chemin *m*; chaussée	Strasse *f*
Road bridge	pont-route	Fahrbrücke *f*
Road metalling	empierrement *f*	Strassenbeschotterung *f*
Roadway	voie *f*; voie charretière *f*	Fahrstrasse *f*
Roadway plate (bridge)	tôle du tablier *f*	Eindeckungsplatte *f*
Rock	roc *m*; roche *f*	Fels *m*
Roll (iron), to	laminer	walzen
Rolling mill	laminoir *m*	Walzwerk *n*
Roman cement	ciment romain *m*	Roman-Cement *m*
Roof	toit *m*	Dach *n*
Roof covering	couverture d'un toit *f*	Dachbedeckung *f*
Roof principal	ferme *f*	Dachbinder *m*
Roofing slate	ardoise pour toiture *f*	Dachschiefer *m*
Roofing tile	tuile *f*	Dachziegel *m*
Rope	cordage *m*; corde *f*	Seil *n*
Round iron	fer rond *m*	Rundeisen *n*
Rule (measuring)	règle *m*	Maassstab *m*
Rust	rouille *f*	Rost *m*
Rust, to	se rouiller (rouiller)	rosten
Rust joint	assemblage au mastic de fer	Eisenkittfuge *f*
SAG, to	courber; s'affaisser	sich senken, einbiegen
Sand	sable *m*	Sand *m*
Sandstone	grès *m*	Sandstein *m*
Sash-bar	chassis *m*	Fensterstange *f*
Scaffolding	échafaudage *m*	Gerüst; Baugerüst *m*
Scaffold-pole	baliveau *m*; bois d'échafaudage	Gerüstbaum *m*
Scale (of measures)	échelle *f*	
Schedule of prices	liste des prix *f*	Preisverzeichniss *n*
Scour, to (bed of river)	s'affouiller	unterwaschen
Scouring	affouillement *m*	Unterwaschung *f*
Scrap-iron	ferraille *f*	Abfalleisen; Spaneisen *n*
Screw	vis *f*	Schraube *f*
Screw piles, to	visser les pieux	Schraubenpfähle eintreiben
Screw bolt	boulon *m*	Schraubenbolzen *m*
Screw-jack	cric *m*	Schraubenwinde *f*
Screw pile	pieu à vis *m*	Schraubenpfahl *m*
Section	coupe *f*	Durchschnitt *m*
Sectional area	surface d'une section *f*	Querschnittsinhalt *m*
Segment	segment *m*	Segment *n*; Abschnitt *m*
Segmental arch	arc en segment *m*	Stichbogen *m*
Semicircular arch	are en plein cintre *m*	Halbkreisbogen; Rundbogen
Set (smith's)	tranche *f*	Setzhammer *m*
Settlement (sinking)	affaissement; tassement *m*	Senkung *f*; Setzen *n*
Shear, to	cisailler	abscheeren; abschneiden
Shearing machine	machine à cisailler *f*	Blechscheere *f*
Shearing strain	effort tranchant *m*	Scheerkraft *f*
Sheave	poulie *f*	Rolle *f*

Italian.	Spanish.	English.
strada *f*	camino *m*; carretera *f*	Road
ponte stradale *m*	puente *m*	Road bridge
pietruzzi *f*; pietrisco *m*	empedrado *m*	Road metalling
via *f*	calzada *f*	Roadway
placca per piattaforma *f*	plataforma de la calzada *f*	Roadway plate(bridge)
roccia *f*; rupe *f*	roca *f*	Rock
laminare	estirar; laminar	Roll (iron), to
laminatojo *m*	laminador *m*	Rolling mill
calastruzzo romano	cemento romano *m*	Roman cement
tetto *m*	techo *m*	Roof
copertura della tetto *f*	cubierta *f*	Roof covering
trave principale *f*	armadura *f*	Roof principal
lavagna *f*	pizarra *f*	Roofing slate
tegola *f*; tegolo *m*	teja *f*	Roofing tile
corda *f*; fune *f*	cuerda *f*	Rope
ferro rotondo *m*	hierro redondo *m*	Round iron
regolo (per misurare) *m*	regla *f*	Rule (measuring)
ruggine *f*	moho *m*	Rust
arugginare	enmohecerse	Rust, to
	junta con moho *f*	Rust joint
piegare	bajarse	SAG, to
sabbia *f*	arena *f*	Sand
pietra arenaria *f*	piedra arenisca *f*	Sandstone
treno *m*	bastidor; crucero *m*	Sash-bar
impalcatura *f*; armatura *f*	andamiaje *m*	Scaffolding
palo da impalcatura; cardela *f*	palo de andamio *m*	Scaffold-pole
scala *f*	escala *f*	Scale (of measures)
elenco di prezzi *m*	lista de precios *f*	Schedule of prices
nettare	limpiar	Scour, to (bed of river
nettamento *m*	limpia *f*	Scouring
	zocata *f*	Scrap-iron
vite *f*	tornillo *m*	Screw
piantar pali a vite	atornillar pilotes	Screw piles, to
chiodo a vite; bollone a vite	perno *m*	Screw bolt
cric; martinello a vite *m*	gato *m*	Screw-jack
palo a vite *m*	pilote atornillado *m*	Screw pile
sezione *f*	corte *m*	Section
area della sezione *f*	seccion *f*	Sectional area
segmento *m*	segmento *m*	Segment
arco in segment *m*	arco rebajado circular *m*	Segmental arch
arco semicircolare *m*	arco de medio punto *m*	Semicircular arch
trancia da fabbro *f*	cortafrio *m*	Set (smith's)
cedimento *m*	aplanamiento *m*	Settlement (sinking)
tagliare	cizallar	Shear, to
cesoja; macchina pertondere	cizalla *f*	Shearing machine
sforzo per tagliare *m*	fuerza cortante *f*	Shearing strain
carrucola *f*	polea *f*	Sheave

English.	French.	German.
Sheers ; sheer legs	chèvre ; bigue *f*	Bockspieren *pl f*
Sheet piling	file *f* ; batardeau *m*	Spundpfähle *pl m*
Shifting sand	sable mouvant *m*	Flugsand ; Triebsand *m*
Shifting spanner	clef anglaise *f*	engl. Schraubenschlüssel *m*
Shingle	galet *m*	Meerkies *m*
Ship, to (on board)	mettre à bord	verladen
Shrink, to	se retirer	schwinden
Shrinkage	retrait *m*	Schwinden *n*
Siding (railway)	voie de garage *f*	Weiche *f*
Silt (alluvial)	vase *f*	Alluvialschlamm *m*
Single line of railway	unique voie *f*	eingleisige Bahn *f*
Sink cylinders, to	enfoncer ; avaler	Cylinder versenken
Site of a work	emplacement ; pied d'œuvre	Lage *f*
" Six foot " (railway)	entrevoie *f*	Zwischenraum *m*
Skew arch	voûte en biais *f*	schiefer Bogen *m*
Skewback	sommier *m*	Auflage des Anfängers *f*
Skew bridge	pont biais *m*	schiefe Brücke *f*
Slate	ardoise *f*	Schiefer *m*
Slope	pente *f* ; talus *m*	Böschung *f*
Slot	mortaise *f*	Nuthe *f*
Slot, to	mortaiser	Nuthen stossen
Slotting machine	machine à mortaiser *f*	Nuthen-Stossmaschine *f*
Smelt, to	fondre	schmelzen
Smelting furnace	fourneau de fusion *m*	Schmelzofen *m*
Smith	forgeron *m*	Schmied *m*
Smith's hearth	forge *f*	Schmiedeesse *f*
Smith's tongs	tenailles *f*	Schmiedezangen *f pl*
Smith's work	ouvrage de forge *m*	Schmiedearbeit *f*
Snap riveting tool	bouterolle *f*	Nietkopfmacher *m*
Snatch block	poulie *f*	Leitrolle *f*
Snug	tasseau *m*	Knagge *f*
Sound (in water), to	sonder	sondiren
Spade	pelle *f*	Spaten *m*
Span	ouverture *f* ; travée *f*	Spannweite *n*
Spandrel	panneau *m*	Bogendreieck *n*
Spanner	clef *f* ; clef à boulon	Schraubenschlüssel *m*
Specification	cahier des charges *m*	Verzeichniss *n* ; Nachweis *m*
Specific gravity	poids spécifique *m*	specifische Gewicht *n*
Spelter (zinc)	zinc *m*	Spiauter ; Rohzink *m*
Spirit level	niveau à bulle d'air *m*	Nivellirwage *f* ; Wasserwage *f*
Springing (arch)	naissance de la voute *f*	Bogenanfang *m*
Square	carré	viereckig
Square foot	pied carré	Quadrat-Fuss *m*
Stability	stabilité *f*	Stabilität *f*
Staging	échafaudage *m*	Gerüst *n*
Stanchion	étançon *m*	Stütze *f* ; Pfosten *m*
Standard measure	étalon *m*	Normalmaass *m*
Steam crane	grue à vapeur *f*	Dampfkrahn *m*

Italian.	Spanish.	English.
argano a sartie *m*	cábria *f*	Sheers ; sheer legs
steppafitte *f* ; palafitte	estacada *f*	Sheet piles
arena movibile *f*	arena movediza	Shifting sand
chiave inglese *f*	llave inglesa *f*	Shifting spanner
ciottoli *f*	galete *m*	Shingle
imbarcar mercanzie	cargar	Ship, to (on board)
restringersi	encojerse	Shrink, to
restringimento *m*	encojimiento *m*	Shrinkage
binario di servizio *f*	via de apartadero *f*	Siding (railway)
melma *f*	fango ; limo *m*	Silt (alluvial)
strada ad un solo binario *f*	via única *f*	Single line of railway
affondare cilindri	hincar	Sink cylinders, to
luogo d'un lavoro *m*	emplazamiento *m*	Site of a work
interbinario ; intervallo *m*	entrevia *f*	" Six foot " (railway)
arco obliquo *m*	arco oblicuo *f*	Skew arch
nascimento ; cuscinetto *m*	arranque *m*	Skewback
ponte obliquo *m*	puente oblicuo *m*	Skew bridge
lavagna *f*	pizarra *f*	Slate
scarpa *f*	talud *m* ; pendiente *f*	Slope
incastro *m*	escopladura *f*	Slot
incastrare	escoplear	Slot, to
macchina d'incastrare	maquina para escoplear	Slotting machine
fondere	fundir	Smelt, to
forno di fuzione *f*	horno de fundicion *m*	Smelting furnace
fabbro *m*	herrero *m*	Smith
fucina *f*	fragua *f*	Smith's hearth
molle da fabbro *f* ; tanaglia *f*	tenazas *f*	Smith's tongs
lavoro da fabbro *m*	obra de fragua *f*	Smith's work
buttarola *f*	hembrilla *f*	Snap riveting tool
girella *f*	polea *f*	Snatch block
tasselo *m*	ménsula *f*	Snug
scandagliare	sondear	Sound (in water), to
vanga *f* ; badile *m*	pala *f*	Spade
apertura *f* ; luce *f*	luz *f*	Span
timpano *m*	tímpano *m*	Spandril
chiave *f*	llave *f*	Spanner
specificazione *f*	pliego de condiciones *m*	Specification
peso specífico *f*	gravedad específica *f*	Specific gravity
peltro *m* : zinco *m*	zinc *m*	Spelter (zinc)
livello a bolla d'aria *m*	nivel de aire *m*	Spirit level
imposta dell'arco *f*	arranque *m*	Springing (arch)
quadro	cuadrado *m*	Square
	pié cuadrado *m*	Square foot
stabilità *f*	estabilidad *f*	Stability
palco di tavolone *m*	andamio *m*	Staging
puntello *m*	puntal *m*	Stanchion
misura di modello *f*	marco *m*	Standard measure
grù a vapore *f*	grua de vapor	Steam crane

English.	French.	German.
Steam engine	machine à vapeur *f*	Dampfmaschine *f*
Steam hammer	marteau à vapeur *m*	Dampfhammer *m*
Steam pile-driver	sonnette à vapeur *f*	Dampframme *n*
Steam winch	treuil à vapeur *m*	Dampfwinde *f*
Steel	acier *m*	Stahl *m*
Steel wire	fil d'acier *m*	Stahldraht *m*
Stone	pierre *f*	Stein *m*
Stone bridge	pont en pierre *m*	Steinbrücke *f*
Stonework	maçonnerie *f*	Steinmauerwerk *f*
Strain	effort *m* (résistant)	Spannung *f*
Stratum	couche ; strate *f*	Schicht ; Lage *f*
Strength of materials	résistance des matériaux *f*	Festigkeit der Materialen *f*
Stress	effort *m* (actif)	Anstrengung *f*
Strike (a blow), to	frapper ; donner un coup	schlagen
Strike (centre of arch)	décintrer	Lehrbogen schlagen
Strike (workmen), to	faire grève	die Arbeit einstellen
Strike (of workmen)	grève *f*	Arbeitseinstellung *f*
Striker (for a smith)	frappeur *m*	Zuschläger *m*
Striking hammer	marteau de frappeur *m*	Zuschlaghammer *m*
Structure	construction *f*	Bauwerk *n*
Strut	contrefiche.(barrecomprimée)	Strebe *f*
Sub contractor	sous-entrepreneur *m*	Lieferant *m*
Superstructure	superstructure *f* ; édifice *m*	Oberbau *m*
Survey, to	arpenter	vermessen
Surveyor	arpenteur *m*	Vermesser ; Feldmesser *m*
Suspension bridge	pont suspendu *m*	Hängebrücke *f*
Suspension chain	chaîne de suspension *f*	Tragkette *f*
Suspending rod	tige de suspension *f*	Hängestange *f*
Swage	étampe *f*	Gesenkhammer *m*
Swing bridge	pont tournant *m*	Drehbrücke *f*
T IRON	fer à T *m*	T eisen *n*
Take levels, to	niveler	nivelliren
Tap (screw)	taraud *m*	Schraubenbohrer *m*
Tap (to screw)	tarauder	Gewinde bohren
Tape (measuring)	ruban mesure *m*	Bandmaass *n*
Tar	goudron *m*	Theer *m*
Template	gabarit *m*	Lehre ; Schablone *f*
Temporary bridge	pont de service *m*	Interimsbrücke *f*
Tender (offer)	soumission *f*	Offerte *f*
Tender, to	soumissioner	eine Offerte machen
Tensile strain	effort de traction *m*	Zugspannung *f*
Tensile strength	résistance à la traction *m*	Widerstand gegen Zug *m*
Tension	traction ; tension *f*	Zug *m*
Test	épreuve *f*	Probe *f*
Test, to	éprouver	probiren
Test (a bridge), to	faire l'épreuve (d'un pont)	Belastungsprobe anstellen
Theodolite	théodolite *m*	Theodolit *m*

Italian.	Spanish.	English.
macchina a vapore *f*	máquina de vapor *f*	Steam engine
martello a vapore *m*	martillo de vapor *m*	Steam hammer
battipalo a vapore *m*	martinete de vapor *m*	Steam pile-driver
manubrio a vapore *m*	cábria de vapor *f*	Steam winch
acciajo *m*	acero *m*	Steel
filo d'acciajo *m*	alambre de acero *m*	Steel wire
pietra *m*	piedra *f*	Stone
ponte in pietra *m*	puente de piedra *m*	Stone bridge
lavoro in pietra *m*	silleria *f*	Stonework
sforzo *m*	fuerza *f*	Strain
strato *m*	capa *f*	Stratum
resistenza del materiale *f*	resistencia de materiales *f*	Strength of materials
forza *f*	fuerza *f*	Stress
battere	golpear	Strike (a blow), to
disarmare	descimbrar	Strike (centre of arch)
fare sciopero	declararse en huelga	Strike (workmen), to
sciopero *m*	huelga *f*	Strike (of workmen)
battitore *m* ; battimassa *m*	golpeador *m*	Striker (for a smith)
mazza *f*	martillo de golpear *m*	Striking hammer
struttura *f*	estructura *f*	Structure
puntello *m*	travesaño : puntal *m*	Strut
cottimista *m*	sub-contratista *m*	Sub contractor
edifizio	superstructura *f*	Superstructure
	levantar plano	Survey, to
agrimensore *f*	agrimensor	Surveyor
ponte sospeso *m*	puente colgado *m*	Suspension bridge
catena di sospensione *f*	cadena de suspension *f*	Suspension chain
verga di sospensione *f*	espiga de suspension *f*	Suspending rod
stampo *m* ; bollo di fabbro *m*	remachador *m*	Swage
ponte girante *m*	puente rodado *m*	Swing bridge
ferro a T *m*	hierro con forma de T *m*	T iron
livellare	nivelar	Take levels, to
maschio della madrevite	tarraja *m*	Tap (screw)
fare una madrevite	taladrar	Tap (to screw)
rolletta *f*	cinta de medir *f*	Tape (measuring)
catrame *m*	alquitran *m*	Tar
sagoma *f*; modello *m*	plantilla *f*	Template
ponte di servizio *m*	puente de servicio *m*	Temporary bridge
offerta *f*	proposicion *f*	Tender (offer)
offrire	proponer	Tender, to
sforzo di trazione *m*	fuerza de tension *f*	Tensile strain
resistenza alla trazione *f*	resistencia á la tension *f*	Tensile strength
tensione *f*	tension *f*	Tension
prova *f*	prueba *f*; ensayo *m*	Test
provare	hacer la prueba	Test, to
provare un ponte	id. (de un puente)	Test (a bridge), to
teodolito *m*	teodolito *m*	Theodolite

English.	French.	German.
Thread (of a screw)	filet *m*	Gewinde *n*
Thrust	poussée *f*	Schub *m*
Tie	tirant *m*	Band *n*
Tie rod	tirant *m*	Zugstange *f*
Tile	tuile *f*	Dachziegel *m*
Timber	bois ; bois de construction *m*	Bauholz *n*
Timber (sawn)	bois de sciage *m*	geschnittenes Holz *n*
Timber bridge	pont en bois *m*	hölzerne Brücke
Tongs	tenailles *f pl.*	Zange *f*
Tool	outil *m*	Werkzeug *n*
Tool chest	coffre d'outils *m*	Werkzeugkasten *m*
Top flange	table (ou semelle) supérieure *f*	obere Gurtung *f*
Torsion	torsion *f*	Drehung *f*
Tower (suspens. bridge)	pile *m*	Pilone *f*; Thurm *m*
Trace, to (a drawing)	calquer	pausen
Tracing (drawing)	calque *m*	Pause *f*
Tracing paper	papier à calquer *m*	Pausepapier *n*
Traffic (on a road)	circulation *f*; traffic *m*	Verkehr *m*
Train	train ; convoi *m*	Eisenbahnzug *m*
Trammel	compas à verge *m*	Stangenzirkel *m*
Tramroad	chemin à rails *m*	Schienenweg *m*
Transport of ironwork	transport *m*	Transport der Eisentheile *m*
Transverse strain	effort transversal *m*	Biegungsspannung *f*
Transverse section	section transversale *f*	Querschnitt *m*
Transverse strength	résistance transversale *f*	Biegungsfestigkeit *f*
Travelling crane	grue mobile *f*	Lauf krahn *m*
Trellis girder	poutre en treillis *f*	Fachwerkträger *m*
Trench (foundation)	tranchée ; rigole *f*	Fundamentgrube *f*
Trestle	tréteau *m*	Bock *m* ; Gestell *n*
Trestle bridge	pont de chevalets *m*	Jochbrücke *f*
Trial boring	sondage *m*	Bohrversuch *m*
Truss	ferme ; travée *f*	Hängewerk *n* ; Hängebock *m*
Truss bridge	pont à poutres armées *m*	Spengwerkbrücke *f*
Truss girder	poutre armée *f*	Spengwerkträger *m*
Truss roof	toit à fermes renforcées *m*	Hängewerkdach *n*
Tubular bridge	pont tubulaire *m*	Röhrenbrücke *f*
Turn (in a lathe), to	tourner au tour	drehen
Turner	tourneur *m*	Dreher *m*
VALLEY gutter	chéneau de goulet *m*	Kehlrinne *f*
Ventilating louvres	persiennes *f*	Shalldach *n*
Vernier	vernier *m*	Vernier *n*
Vertical strut	étai ; support vertical *m*	Pfosten *m*
Viaduct	viaduc ; pont *m*	Viaduct *m*
Vibration	vibration *f*	Swingung ; Vibration *f*
Vice	étau *m*	Schraubstock *m*
Vice-bench	établi *m* (d'un étau)	Werkbank *f*
WAGES	salaire *m* ; gages *m pl.*	Wochenlohn *m*

Italian.	Spanish.	English.
filetto d'una vite *m*	rosca *f*	Thread (of a screw)
spinta *f*	empuje *m*	Thrust
legame *m*	ligazon *f*	Tie
tirante *m*	tirante *m*	Tie rod
tegola *f*	teja *f*	Tile
legname da costruzione *f*	madera *f*	Timber
legname da segare *m*	madera (serrada) *f*	Timber (sawn)
ponte di legno *m*	puente de madera *m*	Timber bridge
molle *f*	tenazas *f*	Tongs
strumento *m* ; utensile *m*	herramienta *f*	Tool
cassone per ripor utensili	cajon para herramientas *m*	Tool chest
tavola superiore *f*	reborde superior *m*	Top flange
torcimento *m*; torsione *m*	torsion *f*	Torsion
torre del ponte sospeso *f*	torre *f*	Tower (susp. bridge)
fare un lucido	calcar	Trace (to drawing)
lucido *m*	calco *m*	Tracing (a drawing)
carta lucida *f*	papel vegetal *m*	Tracing paper
traffico *m*	tráfico *m*	Traffic (on a road)
convoglio *m*	tren *m*	Train
compasso a verghe *m*	compas de piezas *m*	Trammel
strada ferrata a cavallo *f*	tramvia *m*	Tramroad
trasporto di ferramenta *m*	trasporte *m*	Transport of ironwork
sforzo trasversale *m*	fuerza trasversal *f*	Transverse strain
sezione trasversale *f*	corte trasversal *m*	Transverse section
resistenza trasversale *f*	resistencia trasversal *f*	Transverse strength
grù mobile *f*	grua móvil *f*	Travelling crane
trave a traliccio *f*	viga enrejada *f*	Trellis girder
fosso *m*	zanja *f*	Trench (foundation)
cavalletto *m*	caballete *m*	Trestle
ponte a cavalletto *m*	puente de caballete *m*	Trestle bridge
scandaglio	sondaje *m*	Trial boring
capriata *f*	armazon *m*	Truss
ponte a traviamata *m*	puente enrejado *m*	Truss bridge
trave armata *f*	viga armada *f*	Truss girder
tetto armato *m*	techo armado *m*	Truss roof
ponte tubulare *m*	puente tubular *m*	Tubular bridge
tornire	tornear	Turn (in a lathe), to
tornitore *m*	tornero *m*	Turner
canale fra due falde *m*	canalon *m*	VALLEY gutter
persiane *f*	persianas ventiladoras *f*	Ventilating louvres
verniere *f*	nonio *m*	Vernier
puntello verticale *m*	puntal vertical *m*	Vertical strut
viadotto *m*	viaducto *m*	Viaduct
vibrazione *f*	vibracion *f*	Vibration
morsa *f*	torno *m*	Vice
banco da fabbro *m*	banco para torno *m*	Vice-bench
salario *m*	jornales *m*	WAGES

English.	French.	German.
Waling	moise *f*; clayonnage *m*	Verschalung *f*
Wall	mur *m*; muraille *f*	Mauer; Wand *f*
Warren girder	poutre système Warren *f*	Warren's (Neville's) Träger *m*
Washer	rondelle *f*	Unterlagscheibe *f*
Waterway of a bridge	débouché d'un pont *m*	Fluthraum; Durchflussprofil
"Wear and tear"	usure; détérioration *f*	Abnutzung *f*
Web of a girder	paroi verticale *f*; l'âme *m*	Verticalwand eines Trägers
Wedge	coin *m*	Keil *m*
Weigh, to	peser	wägen
Weight	poids *m*	Gewicht *n*
Weir	barrage *m*; déversoir *m*	Wehr *n*
Weld (the part welded)	soudure *f*	Schweissstelle *f*
Weld, to	souder	schweissen
Welding heat	chaude soudante *f*	Schweisshitze *f*
White heat	chaude blanche	Weissglühhitze *f*
Width	largeur *f*	Breite; Weite
Winch	treuil *m*	Winde *f*
Windlass	cabestan *m*	Haspel *m*
Wind-bracing (roof)	contreventment *m*	Windverstrebung *f*
Window	fenêtre *f*	Fenster *n*
Wing-wall (of bridge)	mur en aile *m*	Flügelmauer *f*
Wood	bois *m*	Holz *n*
Wood pavement	pavé en bois *m*	Holzpflaster *n*
Wooden pile	pieu en bois *m*	hölzerner Pfahl *m*
Woodwork	charpente; ouvrage en bois *m*	Holzwerk *n*
Work	travail; ouvrage *m*	Arbeit *f*
Working drawings	dessin d'exécution *m*	Arbeitszeichnung *f*
Workman	ouvrier; artisan *m*	Arbeiter *m*
Workmanship	ouvrage *m*; main d'œuvre *f*	Arbeit *f*
Wrought iron	fer forgé	Schmiedeisen *n*
Wrought iron bridge	pont en fer *m*	schmiedeiserne Brücke *f*
Wrought iron girder	poutre en fer *f*	schmiedeiserner Träger *m*
ZINC	zinc *m*	Zink *n*
Zinc roof covering	couverture en zinc *f*	Zinkdachdeckung *f*

Italian.	Spanish.	English.
palafitta *f*	puntales ; crucero *m*	Waling
muro *m*	muro *m*	Wall
trave (sistema Warren)	viga de sistema Warren *f*	Warren girder
rosetta *f*	rodaja *f*	Washer
corridojo dell 'acqua *m*	salida *f*	Waterway of a bridge
consumo *m*	deterioro *m*	" Wear and tear "
anima d'una trave o doppio *f*	chapa vertical *f*	Web of a girder
conio *m* ; cunio *m*	cuña *f*	Wedge
pesare	pesar	Weigh, to
peso *m*	peso *m*	Weight
emissario *m* ; sfioratore	presa *f*	Weir
unione di ferro caldo *f*	soldadura *f*	Weld (the part welded)
battere il ferro caldo	soldar	Weld, to
calore giusto per unione *m*	calor necesario para soldar *m*	Welding heat
calore bianco *m*	calor candente *m*	White heat
larghezza *f*	ancho *m*	Width
manubrio *m* ; manovella *f*	cábria *f*	Winch
argano *m*	cabrestante *m*	Windlass
spranga obliqua *f*	contraviento *m*	Wind-bracing (roof)
finestra *f*	ventana *f*	Window
muro d'ala (d'un ponte) *m*	muro en ala *m*	Wing-wall (of bridge)
legno *m*	madera *f*	Wood
pavimento di legno *m*	adoquin de madera *m*	Wood pavement
palo di legno *m*	pilote de madera *m*	Wooden pile
lavoro in legno *m*	obra de madera *f*	Woodwork
lavoro *m*	obra *f*	Work
disegni in detaglio *m*	dibujos definitivos *m*	Working drawings
operajo *m*	obrero	Workman
lavoro *m* ; manifattura *f*	mana de obra *f*	Workmanship
ferro lavorato *m*	hierro forjado *m*	Wrought iron
ponte di ferro *m*	puente de hierro forjado *m*	Wrought iron bridge
trave di ferro *f*	viga de hierro forjado *f*	Wrought iron girder
zinco *m*	zinc *m*	ZINC
copertura di zinco pel tetto *f*	cubierta de zinc *f*	Zinc roof covering

OPINIONS OF THE PRESS, ON THE FIRST EDITION.

FROM THE ENGINEER, MARCH 21, 1873.

Mr. Matheson is a thoroughly practical engineer, and the handsome volume betore us bears ample testimony to the fact that he possesses what is a very rare combination of qualifications for writing such a book. In the first place, he has really a thorough knowledge of what he undertakes to write about: and, in the second place, he knows how to say what he has to say in well-chosen language. We suppose that, altogether, some thousands of books must have been written on the construction ot bridges and roofs; but very few indeed of these do more than treat of the theory of such structures, Mr. Matheson has taken new ground, and shows how a bridge or a roof ought to be designed, made. and put up; and he illustrates what he has to say with examples selected from his own practice and that of the firm in which he is a partner—Handyside and Co., of Derby. It may be urged that our author should have gone further afield for his examples; but we think differently. The book would only have been extended in dimensions with doubtful advantage. We cannot better explain what the object of the work is than by using the author's own words: "Not professing to deal with the pure science of engineering practice, it treats of practical considerations which affect the choice of design in regard to iron structures; the qualities of material, the classification of different systems, the incidents of transport, and the methods of erection are stated from a manufacturer's point of view, with special reference to comparative cost." The book contains 298 pages of matter, and a copious vocabulary of terms connected with bridge and roof building in English, French, German, Italian, and Spanish.

We shall not attempt to give any detailed idea of the contents of this volume. We really in no sense exaggerate its value when we state that it must prove of infinite use to every student who has got beyond the rudiments of his profession; while the engineers who cannot turn to its pages with advantage for guidance when they are in doubt on points connected with bridges and roofs must be very few.

A word of praise is due to Mr. Matheson for the way in which he has turned out his work. The paper, printing, and engravings—of which there are a profusion—are alike admirable. It is quite possible that the work will give no manner of satisfaction to those who hold that a book on bridges or roofs must deal exclusively in theory, leaving practice to take care of itself; but the great body of engineers will, we feel certain, arrive at a very different conclusion when they have made themselves acquainted with what Mr. Matheson has to tell them.

FROM ENGINEERING, MAY 16, 1873.

In writing the book before us, Mr. Matheson appears to have been actuated by a desire to correct the shortcomings of previous treatises, and to supply his readers with an immense variety of facts and practical data respecting bridge and roof building, which, so far as we are aware, are not to be found in any other published work on the subject. Supposing this to have been the object Mr. Matheson had in view, we are pleased to say that he has attained it well, and his book is one which will be valued by a large class of readers. We may state at once that the volume under notice lays no claim to being a treatise on bridge and roof construction in the ordinary sense of the term; but is rather a collection of facts, hints, and data, concerning matters which are well-known and understood by contractors and practical bridge builders, but which are less familiar to many engineers, and particularly to the junior members of the profession. For instance, in his opening chapter, treating of cast and wrought iron, malleable cast iron and steel, our author not merely describes the characteristics of these materials, but explains the nature and extent of the tests which may be prescribed in specifications and enforced without, on the one hand, imposing undue restrictions upon the contractor, or on the other, giving an opening for the employment of bad material. He also in this chapter, gives some data concerning the relative prices of iron of different classes, which will be useful in framing estimates.

In his second chapter, Mr. Matheson explains the character and extent of the information which it is necessary to supply to an engineer or contractor to enable a bridge to be designed for a given situation, and this chapter is followed by another giving illustrated descriptions of a great variety of foundations, and explaining the circumstances under which each is applicable. "Cast Iron in Bridges" forms the subject for the fourth chapter, and then we have two others containing, respectively, a classification of the various types of wrought-iron girders, and information concerning their constructive details, this latter division containing some useful practical hints. Some notes on arched and suspension bridges form the next two chapters, and then we have an excellent chapter on bridge-platforms and roadway materials, giving a quantity of handy data as to the weight and cost of the different types of construction, including timber and iron floors, and concrete, macadamised, stone, wood, asphalte, and iron roadways.

Next, Mr. Matheson treats of loads and strains on bridges giving the test-loads required by the French and Austrian Governments, &c., while in the succeeding chapter he gives numerous hints concerning the transport of bridges by railway, by sea and by canal, with information regarding marine insurance, and other kindred matters of a very useful kind.

The erection of bridges forms the subject of the next chapter, and here we find Mr. Matheson treating of staging, lifting appliances (illustrated by some very neat little sketches of different forms of derricks, shears and cranes,) the strength of ropes and chains, modes of erecting bridge piers, launching bridges, and floating them to site, and lastly giving some notes on the cost of bridge erection.

Chapters XIII. to XVI. we find occupied with descriptions of executed bridges of spans varying from 12 feet to 400 feet. Altogether thirty-two examples are described—comprising as many different types—most of the descriptions being accompanied by an illustration. Some of these illustrations, by the way, are most admirable little vignettes of great artistic merit. In describing the various examples referred to, Mr. Matheson gives the principal dimensions, points out the chief features of interest in the constructive details, and states in all cases the weights and prices, the latter being referred to assumed standard values for pig iron and wrought iron of different classes. These standard prices being given, it is easy to compare them with current prices, and then to collect the cost of bridge-work accordingly, so as to get a good approximation to the value of any particular type of bridge-work represented by the examples. In fact, for quickly preparing approximate estimates, Mr. Matheson's book will be exceedingly useful, and we know of no other work giving the required information in so handy a form. In his next chapter our author describes in a similar manner two examples of landing piers, and these descriptions bring the first division of the volume to a conclusion.

In the second part of his work Mr. Matheson treats of iron roofs and buildings, giving first some notes on the information necessary for designing, and then a classified account of the different types of roofs, and illustrated descriptions of a variety of constructive details. Here we find our author giving a number of useful notes about roof coverings, their weight and mode of fixing, and their characteristic qualities, the hints given being of a thoroughly practical kind. Next come some short chapters treating respectively of strains on roofs, of ornamental ironwork, of iron windows, and the ventilation of buildings, and of the erection of iron roofs and buildings, these being followed by illustrated descriptions of twenty-six executed roofs and iron structures, dealt with in the same manner as the examples of bridges already mentioned. The works described embrace a great variety of structures, including dwelling-houses, conservatories, roofs for work-shops, railway stations, kiosks, markets, &c., and the information given concerning them is of a very useful kind. The remainder of the book treats of painting and decorating, of the effect of cold on iron, and of foreign weights and measures; while, in conclusion, Mr. Matheson gives a technical vocabulary, containing a large collection of technical words, with their equivalents in French, German, Italian and Spanish.

It will be seen from the summary we have given that Mr. Matheson has produced a book treating of a vast number of interesting matters connected with the practical construction of "Works in Iron," and it is a pleasure to us to bear testimony to the care and ability with which he has performed his task. In the selection of his examples, chosen as they are from works executed by Messrs. Handyside and Co., of Derby, he has shown much judgment, and his descriptions and treatment of the various sections of his subject are very clear and concise. The work, too, is an admirable specimen of typography, and the engravings are particularly well executed, so that altogether we can decidedly recommend the book as a desirable addition to an engineer's library.

From THE BUILDER, April 12, 1873.

Numerous examples of executed bridges and roofs are given in Mr. Matheson's "Works in Iron." and the means and cost of erection, besides the fundamental principles of construction to which we have referred: and altogether the book will be very useful to architects and engineers; and the vocabulary of French and German equivalents of English technical terms which is appended will render the book particularly valuable to those going abroad.

From THE ARCHITECT, March 8, 1873.

We do not think worse of Mr. Matheson's book because the author belongs to an eminent engineering firm, and that nearly every one of the works which are illustrated or described have been carried out by that firm. On the contrary, we think it is worthy of especial regard, because there is the novelty of having structures in iron considered not merely as to their design, but as to their construction as well as their cost. There is, consequently, no need to compare the work before us with other treatises on the subject. The class of information contained in it will not be found elsewhere, and it may therefore be read with profit by those who are familiar with the many excellent books on the theory of iron construction which have been published in England during late years.

Mr. Matheson's book is divided into two parts, viz., Bridges; Roofs and Buildings. Commencing with a practical description of the varieties of iron employed, there follow chapters on the design of bridges, their construction, foundations, transport and erection. To this part of the work about a hundred and thirty pages are given, which are written in a remarkably clear style and without any of that affectation of mathematical refinement in the reasoning which renders many an engineering work no more than a delusion. Examples of thirty bridges follow. These are of all sizes, from simple cattle passes of 12 feet span up to bridges of 150 feet span, and all of them have been manufactured by the author's firm, Messrs. Handyside & Co., of Derby.

The second part of the book is devoted to iron roofs, windows, and to buildings in general of that material. Among the works described, are the roof of the Agricultural Hall, at Islington; Mr.

Bessemer's conservatory at Denmark Hill, which was designed by Messrs. Banks and Barry; the winter garden at Leeds, by Sir Gilbert Scott, R.A.; the conservatory in the Horticultural Gardens, an Indian kiosk designed by Mr. Owen Jones. This part is of especial interest to architects. Appended to the book is an excellent vocabulary of French, German, Italian, and Spanish technical terms. In conclusion, we have no hesitation in stating that Mr. Matheson's work is one of the most practical books we have lately met with.

FROM IRON (*Mechanics' Magazine*), MARCH 22, 1873.

One hundred and thirty-two pages are devoted by Mr. Matheson to a highly practical and fully-illustrated account of everything relating to the erection, cost, and quality of bridges, and roofs of various spans, and for different purposes; then follow a hundred and forty-six pages, giving drawings, sections, and explanations of sixty of the principal works in iron constructed by his firm. Of these there are 18 bridges in England, 3 in South America, 1 in Japan, 2 in Australia, 1 in Norway, 6 in Russia, and 3 in India. Of the roof structures described, there are 13 in England, 2 in South America, 1 in Africa, 2 in Spain, 1 in Holland, and 6 in India.

The especial feature of Mr. Ewing Matheson's book is the essentially and eminently practical character of its information—viewed, as every subject is, purely from the actual constructor's point of view, the data being, in all cases, regarded from the same stand-point, brought and reduced to the test of practical working out. This is a feature which strikes us as being somewhat uncommon and not, therefore, unwelcome.

FROM THE PALL MALL GAZETTE, MAY 30, 1873.

The character of this book is accurately and modestly described in the preface:—"Not professing to deal with the pure science of engineering practice, it treats of practical considerations which affect the choice of design in regard to iron structures. The qualities of material, the classification of different systems, the incidents of transport and the methods of erection, are stated from a manufacturer's point of view, with a special reference to comparative cost." The value of such a book—supposing it to be written with clearness and knowledge—to a large and increasing number of manufacturers and builders is manifest; and Mr. Matheson has done his work in an exhaustive and business-like way. We imagine that of the class for whom the treatise is written few will fail to discover in it something to make them wiser, while for many every chapter will furnish a valuable hint or useful bit of knowledge. The book abounds with pictorial illustrations and diagrams.

FROM THE SCOTSMAN.

Under the title of *Works in Iron* we have before us an elaborate and very profusely illustrated book, chiefly devoted to iron bridges and roofs. As the production of a partner in a well-known manufacturing firm, it can easily be imagined that the works of that firm—Messrs. Andrew Handyside & Co., of Derby—come in for the chief consideration; but all practical men who are acquainted with the very beautiful work for which the firm have long been celebrated will feel that in issuing such a book the author ought to give much valuable information and excellent examples. For a long time the iron castings of the Britannia Works, Derby, have been famous for their fineness of finish; and the great conservatory of the Royal Horticultural Society, at South Kensington, is a familiar instance of the perfection in iron structures attained by that firm. There is a novelty in the idea of a publication like this; it is in no respect like the illustrated and descriptive catalogues we too often see, but is really a masterly classification of all the details which those require to know who are engaged in such works either as constructors or as persons requiring them—not even omitting the calculations as to cost of erection, of transport, &c. The illustrations are very numerous, and are beautifully clear and well selected. In addition to which there is at the end of the book a polyglot vocabulary, giving the technical names in English, French, German, Italian, and Spanish. No pains have been spared to make it a very useful book, and by most engineers it will be warmly welcomed.

FROM THE LEEDS MERCURY, MAY 10, 1873.

To do anything like justice to the splendid volume on *Works in Iron*, would require more technical knowledge than we can claim to possess, and would make a larger demand upon our space than is on this occasion at our disposal. We can, therefore, do little more than draw the attention of our engineering readers to the fact of its publication, and indicate very briefly the aim and object the author has set before him in giving it to the world. The author of the volume before us has confined himself entirely to roofs and bridges, and has produced a work which, while almost indispensable to those who have to do with such structures, will also be of the greatest use to those who are concerned in a more general way with the introduction of iron into engineering works. As might be expected from his position, he is thoroughly practical in every branch of his subject, and deals with it as only a man of large and varied experience could do.

FROM THE LIVERPOOL MERCURY.

This work is a very valuable addition to the engineering literature of the present day, and it will commend itself to all whom it may concern, by its eminently practical character. Many of the engravings are gems of art, and the whole arrangement of the work is highly creditable.