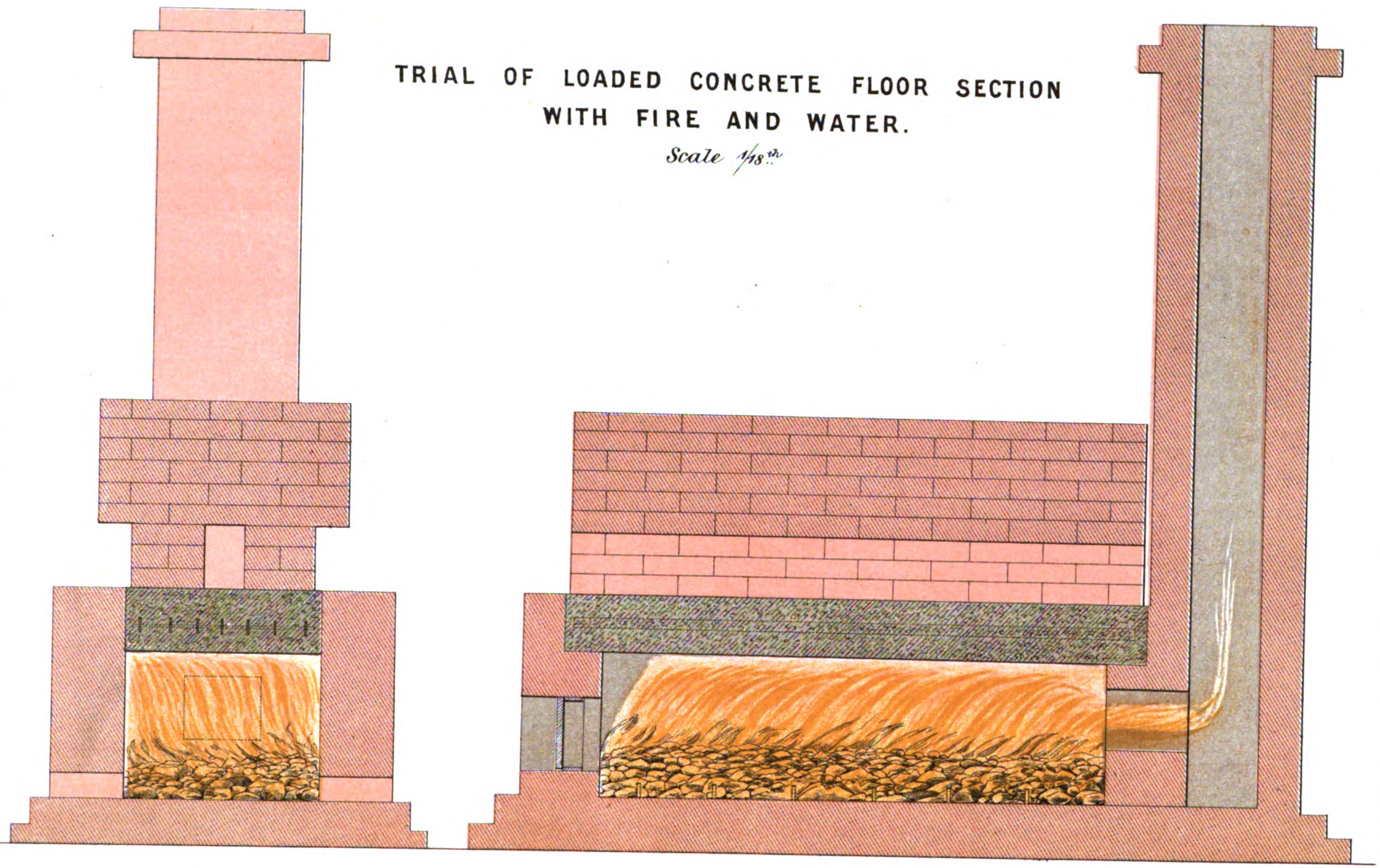
Hyatt

PLATE Q.

TRIAL OF LOADED CONCRETE FLOOR SECTION
WITH FIRE AND WATER.

Scale 1/18th.



FRONTISPIECE.

An Account of Some Experiments with

PORTLAND-CEMENT-CONCRETE

COMBINED WITH IRON, AS A BUILDING MATERIAL,

WITH

REFERENCE TO ECONOMY OF METAL IN CONSTRUCTION, AND FOR SECURITY AGAINST FIRE IN THE MAKING OF ROOFS, FLOORS, AND WALKING SURFACES.

BY

THADDEUS HYATT.

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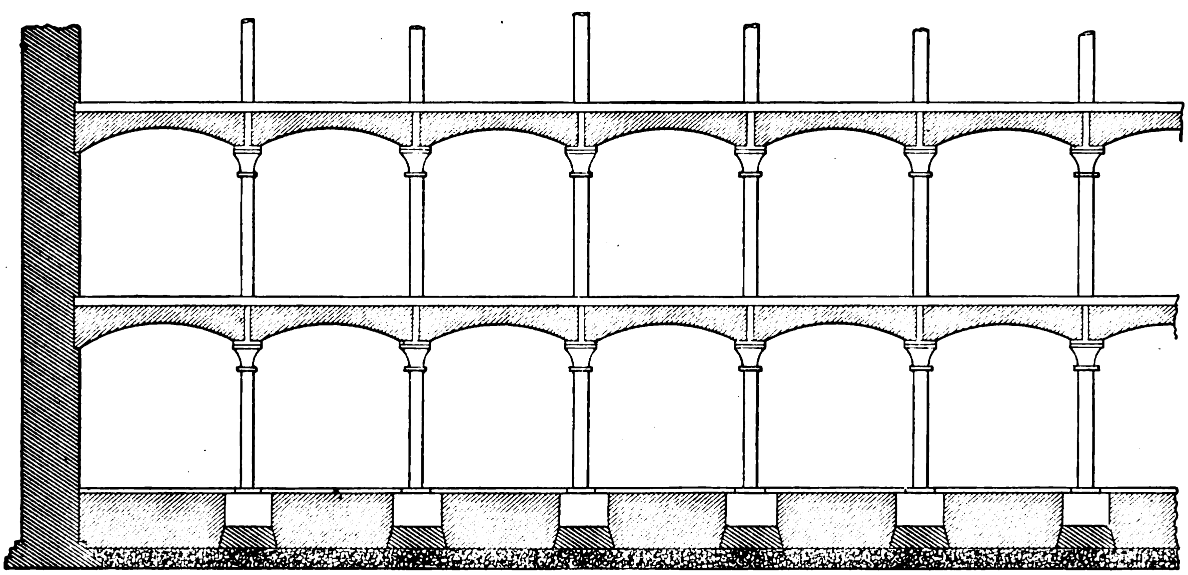
1877.

PORTLAND-CEMENT-CONCRETE.

THE experiments made by the writer, and which will be explained in the following pages, had for their object a possible means of obtaining cheaper and more reliable fireproof constructions than those in common use.

Fairbairn, in his work "On the Application of Cast and Wrought Iron to Building Purposes," tells us that "the first instance on record of the successful "application of cast-iron beams to the purposes of building is that of a fireproof cotton mill



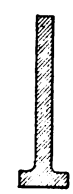


FIG. 2.

FIG. 1.

"erected by Messrs. Phillips and Lee of Manchester. This mill was built in the year 1801: "the iron beams and columns were designed by Messrs. Boulton and Watt. . . . . The "above woodcut (fig. 1) exhibits a longitudinal section of portions of the basement and first "storeys of the mill, with sections of the iron beams and arches." Fig. 2 represents the form of beam used by Boulton and Watt. "This beam," says Fairbairn, "was the first of the kind made; "and considering the limited state of our knowledge at that period, it reflects great credit on the "skill of the designer." Fig. 3 (from the same work) illustrates the method of construction employed at the date of the author's publication, 1854; and contrasting the two as represented by the figures, it will be seen that the only difference between the structure of 1801 and that of 1854 consists in the improved form of *the beam.* Any one who reads Mr. Fairbairn's work will perceive that down to the date of the last edition of his book (the fourth, 1870) the author continues to regard iron as practically and substantially a *fireproof* material; and it may be asserted without exaggeration that all the so-called fireproof floors that have ever been made, with scarcely an exception,[1] have been constructed in accordance with this belief. A filling between the iron beams of some material other than iron was made simply because the metal

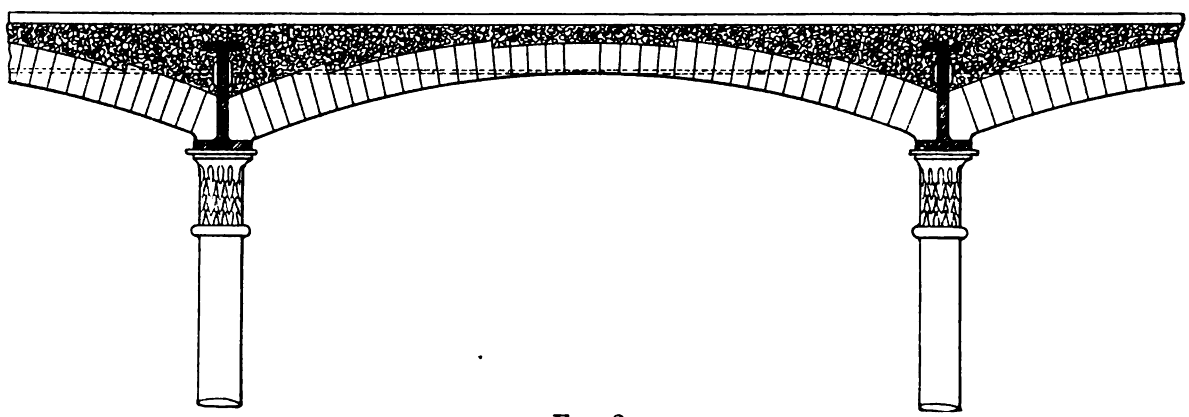


Fig. 3.

itself was too dear to make the entire floor of it; otherwise the floor would have been constructed wholly of iron. Now, it is important at the outset to have a clear line of distinction drawn between two systems so entirely opposite as those, in one of which iron is regarded as a fireproof material, and in the other of which iron is regarded as incombustible only, and not fireproof.

The purpose of the writer in the foregoing illustrations from Mr. Fairbairn's work, and others that are to follow, is to show that the original mistake as to the ability of naked iron to resist heat and flame, has vitiated every floor construction of the kind made from that day to this; and that, notwithstanding the knowledge of late years, gained at a frightful cost, the early mistake is still kept up, and hence, that genuine fireproof floors do not, as a rule, exist. This fact is so well known among men whose business it is to risk their lives in burning buildings that it has become a standing rule among them to beware of "fireproof buildings."[2] An inspection of

[1] The Safe Deposit Building, London, is probably one of the exceptions.

[2] It is well known that firemen dread the so-called "fireproof" structures more than those built of wood, and would sooner trust their lives in the latter than in the former. The time required to burn a stick of timber can be pretty well calculated. Not so with unprotected iron beams, carrying a load of brick arches or concrete. Some

figs. 1 and 3 will show the weak point of the construction with respect to fire. Leaving out of account the unprotected iron columns on which the girders rest, it will be seen that the bottom flanges of all the beams are naked and exposed to flame. Now, when it is considered that this flange is *the tie*, and that the integrity of the whole beam is consequently dependent upon it, no argument is needed to show that the fireproof filling between the beams is of not the slightest account so long as the ties are exposed: soften the tie by heat, and the resistance of the beam begins to give way; at each successive increment of deflection the leverage of the load upon it increases, the destructive influence of combined load and flame acting with wedge-like power until the destruction of the beam is effected. Such unquestionably is the philosophy of fireproof floor destruction, and the only way to account for its suddenness and completeness. Fireproof floors can be made, and within reasonable limits as to thickness (span considered) and cost, that can be guaranteed as good for 3, 6, 9, 12, 24, or even 48 hours under the play of the fiercest flames and the heat of the hottest fires,—in short, equal to the best fireproof safes ever yet invented; but not if the bottom flanges of the beams are left exposed, or too lightly covered. The bottom flange or tie is the vital part of the construction, and must be protected at all hazards. To make fireproof floors it is necessary to know the law of heat conduction with respect to the material relied upon to protect the bottom flanges of the beams, in order to calculate the thickness of material needed to give protection during the hours determined on as the fireproof capacity of the floor. As has been already remarked, the system or method according to which iron beams were originally employed in building constructions, proceeded upon the assumption that iron is a fireproof material; which assumption has been kept up ever since so far as the practice of making such structures is concerned, however much the theories respecting iron may have changed in the public mind. The system adopted by the writer proceeds upon the assumption that iron is not fireproof, and that in a floor where this material is the sole or main reliance for strength the first thing to be done is to protect it with a fireproof coating on all sides sufficient to give it a power of resisting fire during the number of hours required; this application of fireproof material being based upon actual

public experiments have recently been made in elucidation of this fact, and to call attention to the value of *solid* timber floors, or floors constructed on what the writer has termed " the all-beam " principle. As this method of construction is being now largely advertised as the patented property of other parties, it becomes necessary for the writer to claim his invention by calling the attention of the public to his patent, No. 3381, 1873, for the construction of solid wood floors as a safeguard against fire. He would also state that a floor of this kind was laid by him at his Patent Light Works, 25, Waverly Place, New York, U.S. America, in the early part of the year 1873, and also a footway of the same construction, which formed a flat, non-condensing roof, warm and dry, to a portion of the basement, that by this means was extended twenty feet out under the street to the kerb line.

experiment;[1] the law of quantity being known, and the fire-resisting quality of the material used being also known from careful experiment.

But before setting forth his own system, the writer desires to present a brief account of the history of fireproof construction as partially illustrated by the preceding figures and quotations. The only improvements in fireproof floor construction of any importance, between the years 1801 and 1877, relate to the beams only, and mainly with reference to cost. The difference in the amount of metal required between the beam, fig. 2, and those represented in fig. 3, is just one-half—that is to say, if beam, fig. 2, were required to weigh 1,000 lbs., a beam shaped like those represented in fig. 3, to do the same work, would weigh 500 lbs. This saving in material, and consequent cost, is due to the experiments of Hodgkinson, made in the years 1827-30. The next step was made during the years 1849-50, when the elaborate experiments required to determine the construction of Stephenson's tubular bridges were made, resulting in the general substitution of wrought for cast-iron beams; this step being followed by the manufacture of *solid* rolled beams of nearly all depths. How recent have been these advances may be seen from the following, taken from "The New American Encyclopædia," published at New York in the year 1861, viz.:—

"Wrought-iron beams have been used only within the last few years; the successful con-" struction of the tubular bridges in 1849, over the Conway and Menai Straits . . . . was one " of the earliest applications, and on the most gigantic scale . . . . These applications of wrought-" iron beams have been followed by their more modest, but even more useful application to fire-" proof buildings, whereby at the same time perfect security and a material reduction in the " cost of fireproof constructions have been attained. . . . . Their strength being about three " times that of cast-iron beams of equal weight, while the comparative cost is in a much less " ratio, they are not only more safe, but also more economical. . . . . The manufacture of *solid* " rolled beams has effected a further important reduction in the cost of fireproof construction " . . . . These beams have been adopted by the various departments of the Government of the " United States in the construction of the many Custom-houses, marine hospitals, and other " public buildings erected since their introduction, to the entire exclusion of the system of " groined arches. This reduction in the cost of construction has also led to the erection of many " fireproof banking-houses, warehouses, manufactories, &c., within the last three years, and the " system is rapidly coming into general use. For filling in between the beams for fireproof " floors, various systems have been adopted. In France, where fireproof construction with iron " beams is extensively used, the filling in is generally a concrete of refuse materials and plaster of

[1] See Thermal Chart, page 28.

" Paris: . . . . a flat centring is placed *against the bottoms of the beams*,[1] and broken bricks or " other refuse materials suitable for concrete, are put upon the centring, and plaster of Paris " being poured in, the whole mass soon becomes sufficiently set to allow the centring to be re- " moved. . . . . In some cases the plastic concrete fills up the whole space between the beams, " and flooring tiles are laid directly upon it; in others, the depth of the concrete *is less than that* " *of the beams*[2] . . . . a finishing coat of plaster put directly on the concrete forms the ceiling " below. Hollow potteries placed upon the iron lattice-work, with the interstices filled with " plaster, are frequently used instead of concrete. . . . . The system of light segmental brick " arches springing from the lower flanges of the beams, and levelled up with concrete, is that " most generally employed in this country and in England. It is more strictly fireproof than " any other, and much more economical than the use of arched plates or corrugated sheet iron; " and, except in France, where plaster is cheap, than the French systems. The weight of the " floors themselves, with a filling of solid concrete or brick arches, forms a much greater part " than in the light French systems, of the total load to be carried by the beams; but, on the " other hand, the arches and concrete add materially to the strength and rigidity of the beams, " not only by preventing lateral deflections, but by adding to some extent the resistance to com- " pression of so much of the arches or concrete as is above the neutral line to that of the upper " parts of the beams, whereby they become, in fact, an integral part of the beams themselves."

These last remarks will be made clear by reference to figs. 4 and 5, the former being a brick arch floor, and the latter a floor of beams and solid concrete filling. " The lighter French

SEGMENTAL BRICK ARCHES.

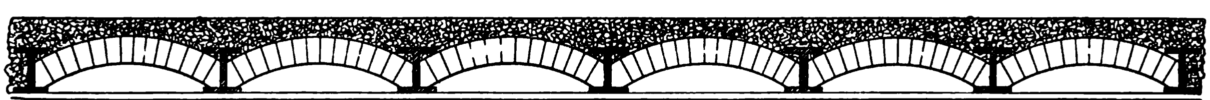


FIG. 4.

SOLID CONCRETE FLOOR.

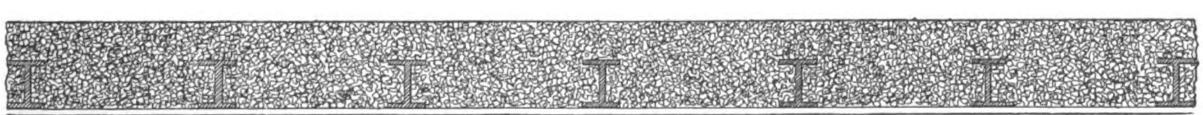


FIG. 5.

[1] This shows that the idea of *protecting the bottom flanges* of the beams did not exist in the minds of the constructors.

[2] Here we have another proof that the metal was regarded as being fireproof, and needing no protection for itself.

" systems " alluded to are very fully described and illustrated in Mr. Fairbairn's work, from which again we quote the following, viz.:—

" A system of fireproof flooring has been in use for some time on the Continent, and indeed " has been partially employed in this country. In France two principal systems have been " introduced, called respectively the *Système Vaux* and *Système Thuasné*, from the names of their " inventors. . . . In the *Système Vaux* it will be seen that the beams for supporting the flooring " consist of simple plates of wrought iron, split and bent at the end to obtain a firm holding in " the wall. These are bound together by tie-rods which are crossed by other rods supporting " the ceiling.

Système Vaux.

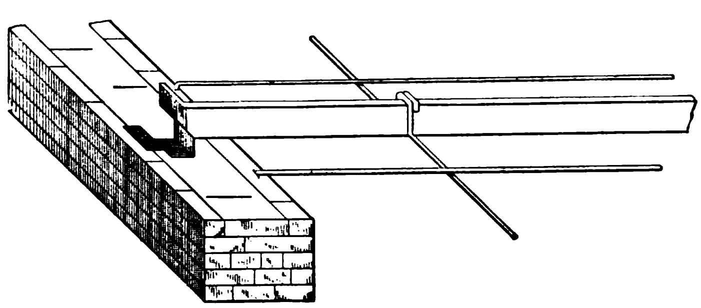


Fig. 6.

Système Thuasné.

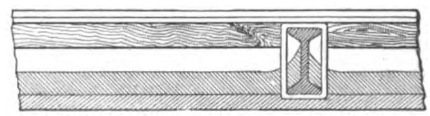


Fig. 7.

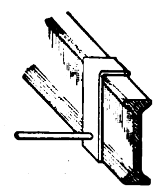


Fig. 8.

" In the *Système Thuasné*, wrought-iron flanged joists have been substituted for the plates, " and a different method of attaching the tie-rod is employed. The beams . . . vary in depth, " thickness, and length, according to the width of the room and the length of the span. At first " they were placed at distances of one metre apart=3 feet 3½ inches; but that distance was " found to be inconvenient, not giving sufficient strength and rigidity to the floor; and hence " they are now placed at about 2 feet asunder. The usual manner of forming the ceiling is " to force upwards *against the bottom of the iron joists*[1] flat boards, which answer as a centring, " and then to fill up the spaces between the joists and tie-rods to a depth of 2½ or 3 inches, " with a coarse grout of plaster of Paris. . . . . Sometimes the French floors are constructed in " a different manner: the joists being laid as before, cross tie-rods are placed at about every " 3 feet 6 inches, and on these slender wrought-iron rods rest, three between each joist. These " rods are run through perforated bricks built in a slightly arched manner, the space below " them being filled up with plaster of Paris, as shown. In this description of floor there is

[1] This again shows that the filling was only put *between* the beams, not *under* them; the ceiling, whatever its thickness or its thinness, being the only covering to the bottom of the lower flanges.

" every security from fire; and the plaster being a bad conductor of heat, equalizes the tempera-
" ture of the room. . . . This description of building is in general use in Paris and other towns
" in France; and viewing it as a permanent fireproof structure, I should earnestly recommend
" its adoption in this country."—*Fairbairn*, pages 103-4.

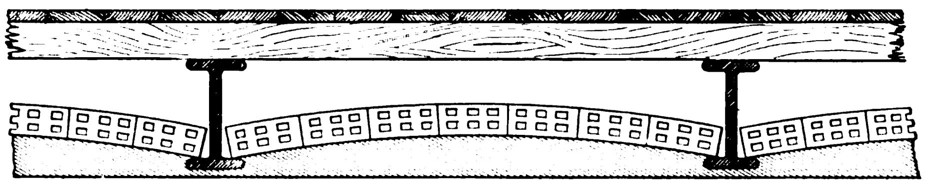


FIG. 9.

This woodcut illustrates the floor construction above described and is taken from Mr. Fairbairn's work.

No engineer, to-day, of Mr. Fairbairn's eminence would "earnestly recommend" such a construction as the above "for adoption," or "as a permanent fireproof structure." The upper half of the beams are wholly exposed to fire, and the bottom flanges are covered with only a skin of plaster of Paris, which would not protect them for thirty minutes against a hot fire.

The illustrations here given fairly represent the different systems of fireproof floors at present in use, however much some of them may differ in matters of detail. None of them are actually fireproof, and all of them are objectionable on the ground of cost. Those spoken of as "more strictly fireproof," where brick arches between the beams or a solid filling of concrete is employed as represented by figs. 4 and 5, are objectionable on the score of loading the beams excessively without giving any adequate compensation for it. The material is not only in excess of what is required for fireproofing purposes, but fails to give protection at the points where most needed. In his new building in Farringdon Road, the writer has introduced a construction where the fireproofing materials are massed at the ceiling line, and then brought up round the beams, just sufficient material being employed to give the requisite protection. Figs.

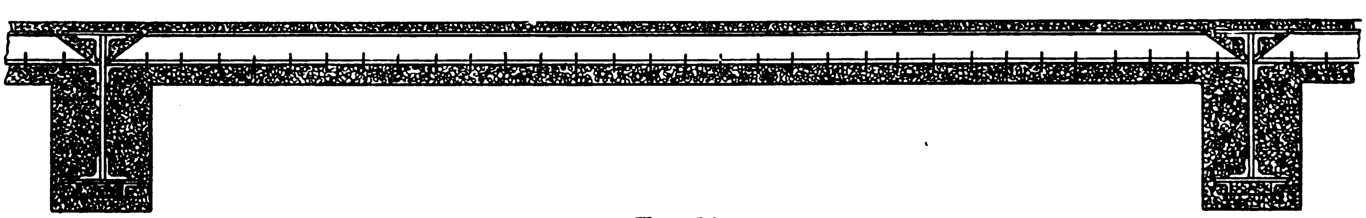


FIG. 10.

10, 11, and 12 illustrate this method of construction. Girders rest upon the main walls. To the underside of the bottom flanges are riveted angle irons, which carry quarter-inch wires crosswise, for holding the fireproofing material. The cross joists are bolted to other angle irons near the top of the web (fig. 10). The ceiling holders or blades of iron

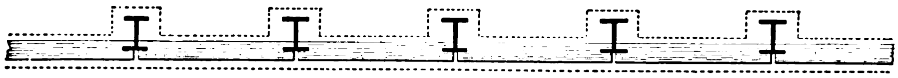


Fig. 11.

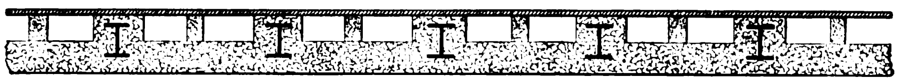


Fig. 12.

(fig. 11), 2½ inches deep, and notched upon the ends to be readily slipped upon the flanges of the joists, are placed from 2 to 3 inches apart. The concrete is then filled in and around them as shown in fig. 12, which represents the completed floor. Light timbers are laid upon the concrete ceiling to nail the flooring to. In this construction the ceiling is made sufficiently strong to carry the load in case the woodwork above it should burn away. Fig. 13 is an

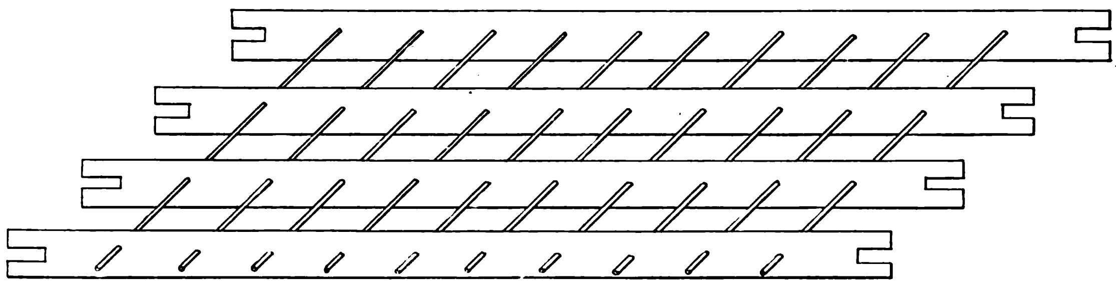


Fig. 13.

enlarged view of four of the ceiling holders, with the wires that cross them, which form an entangling meshwork to hold the concrete. Fig. 14 represents the same floor construction as

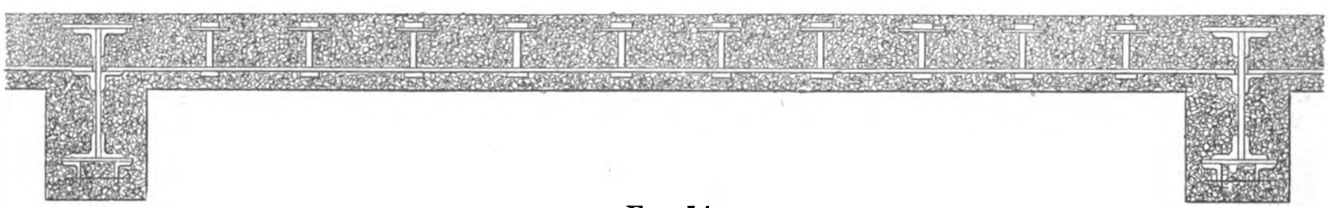


Fig. 14.

fig. 10, the only difference being that the floor joists are dispensed with, flat tie-irons being substituted for the joists; the concrete in this case becoming the compressive member of the beam or slab. These flat ties of iron are ¼ inch thick by 2½ inches wide, and placed at 6 inches from centres. This construction may also be seen at the Lens-Light Works of the writer in Farringdon Road, as also the method of making illuminating fireproof floors and roofs substantially upon this principle; the same being a new development of "Illuminating Gratings," under the name of "The New Stone Light."[1]

The following figures represent floors substantially like the preceding, but modified as to details.

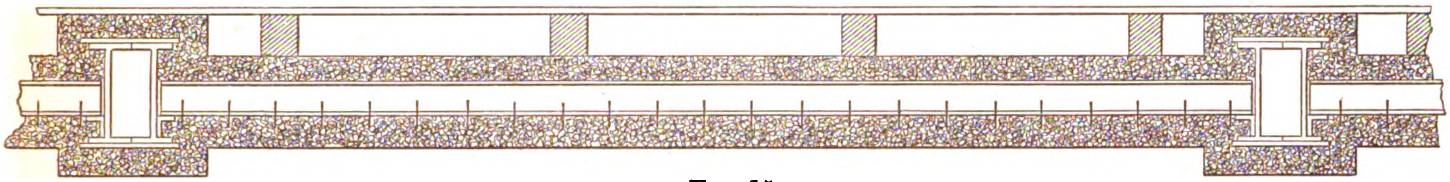


Fig. 15.

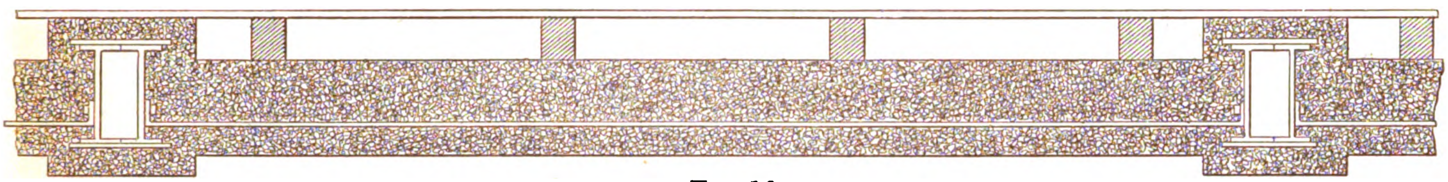


Fig. 16.

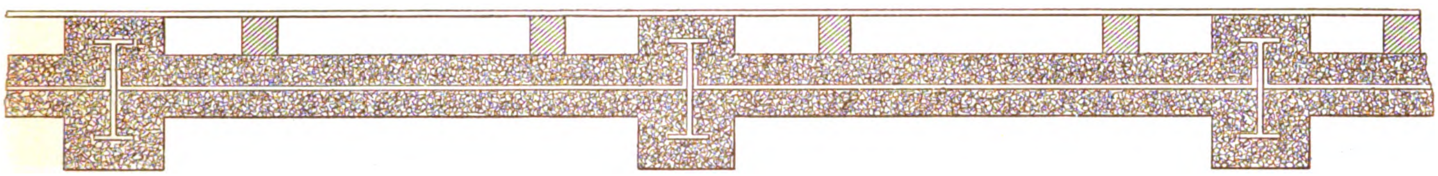


Fig. 17.

Nos. 15, 16, and 17 represent floors of 20 ft. span, 15 and 16 being constructed by means of box-girders placed 12 ft. apart. These girders are 13 in. deep, being made of two 12-in. rolled joists, with 5-in. flanges, united by plates at top and bottom, each girder being calculated to carry 20 tons. In fig. 15 the connection between the girders, like that of fig. 10, is made my means of light rolled joists. Fig. 16 resembles that of 14, iron ties being employed in place of joists. Fig. 17 represents a floor made of rolled beams 13 in. deep, flanges 5 in. wide, the beams being placed at 6 ft. from centres, and connected by iron ties. Each beam is calculated to carry 10 tons.

[1] The attempt of the writer to introduce Basement-Extensions into England has thus far met with but partial success, notwithstanding the fact that subterranean real estate in America of *over one hundred millions of dollars* in value has been by this means redeemed from darkness and waste. But in view of the seven years' battle with prejudice he was compelled to go through in New York over thirty years ago, to convince architects and compel the public to adopt his invention, he is not discouraged now. Real estate in London is more valuable than in New York, and the time cannot be far distant when this great improvement will be estimated at its true value. The municipal regulations of London, which exclude daylight from the basements of buildings, are grounded on the danger of iron and glass as a footway in the public streets, a danger entirely obviated by the new stone lights, which are as safe for walking upon as common flag-stones.

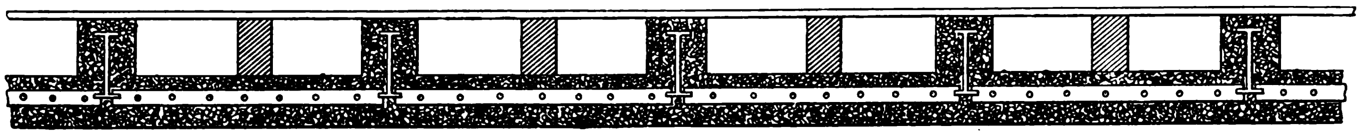


Fig. 18.

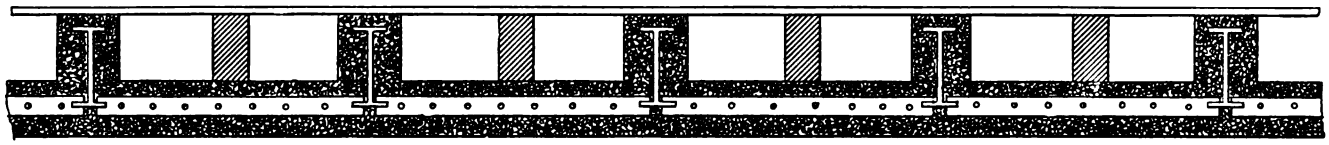


Fig. 19.

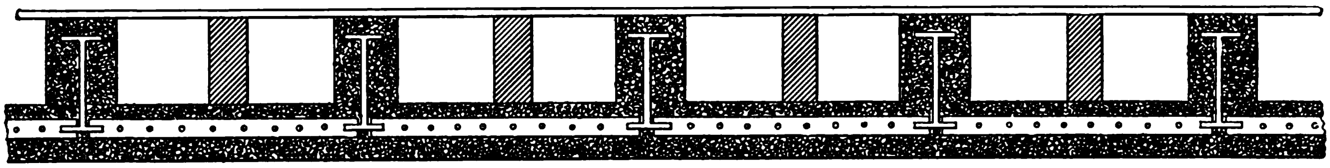


Fig. 20.

Figs. 18, 19, and 20 illustrate a floor construction where the beams are placed at 3 ft. from centres, and rest upon the side or main walls of the building in place of being carried by girders, the spans being 14, 20, and 26 ft. respectively. The beams for the shortest span are 8 in. in depth, 2½ in. wide at flanges, and calculated to carry 3¼ tons gross each. The beams of 20 ft. span are 9½ in. deep, 4 in. flanges, and calculated to carry 5 tons each. For the 26 ft. span the beams are 12 in. deep, with 5 in. flanges, calculated to carry 6½ tons. Ceiling-holders, as represented by fig. 13, are employed to form the load-bearing ceilings of this construction.

It is scarcely necessary to multiply examples for the purpose of showing how simple and easy it is to give perfect protection to the iron beams of floor and roof constructions designed to resist fire. Once establish the principle that each beam must be absolutely surrounded with fireproof material sufficient to protect it, and modifications of the plans here presented may be

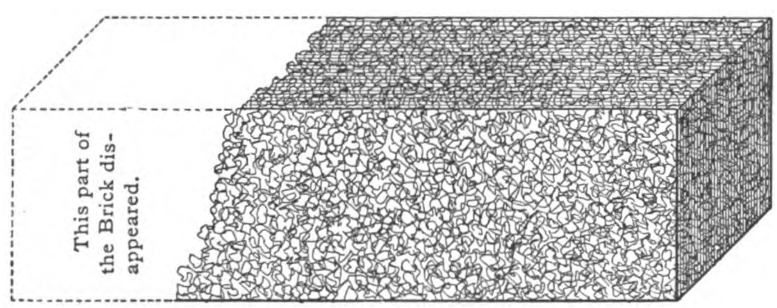


Fig. 21.

multiplied indefinitely. An important question, however, now arises: *Is Portland cement concrete fireproof?* Fig. 21 represents a sample of concrete made of the best Portland cement, moulded in brick form, made in the proportion of one cement to two crushed bricks. When one month old it was heated to redness for six hours in a furnace, and when taken out was then partially plunged into water, the end that came in contact with the fluid falling instantly to pieces and disappearing. Similar blocks heated in the same way and left to cool in the open air became disintegrated within periods varying from six to forty-eight hours; the results in all the experiments being uniform as to samples that had been exposed to the same degree of heat and for

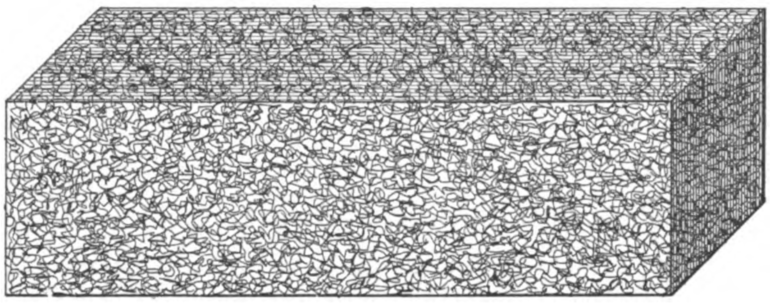


Fig. 22.

the same length of time. Fig. 22 represents a similar block made from a New Portland Cement, specially prepared to resist fire. This block, when heated like the former, was plunged bodily into water and allowed to cool there. With the exception of some fire-cracks it appeared to be perfectly sound when taken out.

Referring once more to the stages of improvement in iron beams by which the weight from 1,000 lbs. has been brought down to 166 lbs.,[1] the writer wishes to call attention to the fact that notwithstanding this amazing gain, scarcely an impression seems yet to have been made upon the combustibility of the world we live in. According to the testimony of Captain Shaw, the city of London is liable at any moment to be devastated by another great fire; and what is true of London is doubtless equally true of every other great city on the globe. That such a state of things will always exist cannot be believed; that it does exist implies a cause either not yet understood or insufficiently considered. Proximately the cause no doubt may be attributed to the greater conveniences existing for making combustible rather than incombustible buildings Combustible building materials, besides being cheap and abundant and to be found everywhere, are easily applied, and the knowledge of their application is universal. Habit and custom and seeming individual self-interest are all in their favour; and the application of iron to building purposes—although the power of the metal has been increased sixfold during the century—is not yet sufficiently economical to meet the necessities of the times; an expenditure of 8 lbs. of iron on a 14 ft. span to each square foot of carrying surface for a safe distributed load of

[1] Hodgkinson reduced the 1,000 lbs. to 500 lbs., and a solid rolled beam weighing 166 lbs. is equal to a cast-iron one weighing 500 lbs.

120 lbs., is an expense too great to become even general, much less universal; and substantially the same proportionate expense for iron is involved in the application of the metal to all other spans,[1] and the beam being in its perfected form, as a result of scientific experiment and investition, leaves no hope as to reduction in cost from any further improvements in it.

Although concrete is worth but from 6*d.* to 1*s.* a cubic foot, as against iron worth 40*s.* the cubic foot, there is less difference in the relative cost of the two materials in practice than might be supposed. Speaking roughly we may say that where the concrete floor is a solid one, the cost of concrete may equal a third to half the cost of the iron; so that if the proposition were to introduce concrete as a new element in place of iron, the gain would not be so great as at first sight might appear. But we are dealing with concrete and iron floors as they exist, and we have already seen that the English and American plan is to make "solid concrete floors" rather than hollow ones, as in the French systems. It is these solid floors of concrete and rolled beams that the writer now proposes to consider, for the purpose of showing that in all cases where such floors are admissible or desirable, it is a waste of metal to use it in beam form.

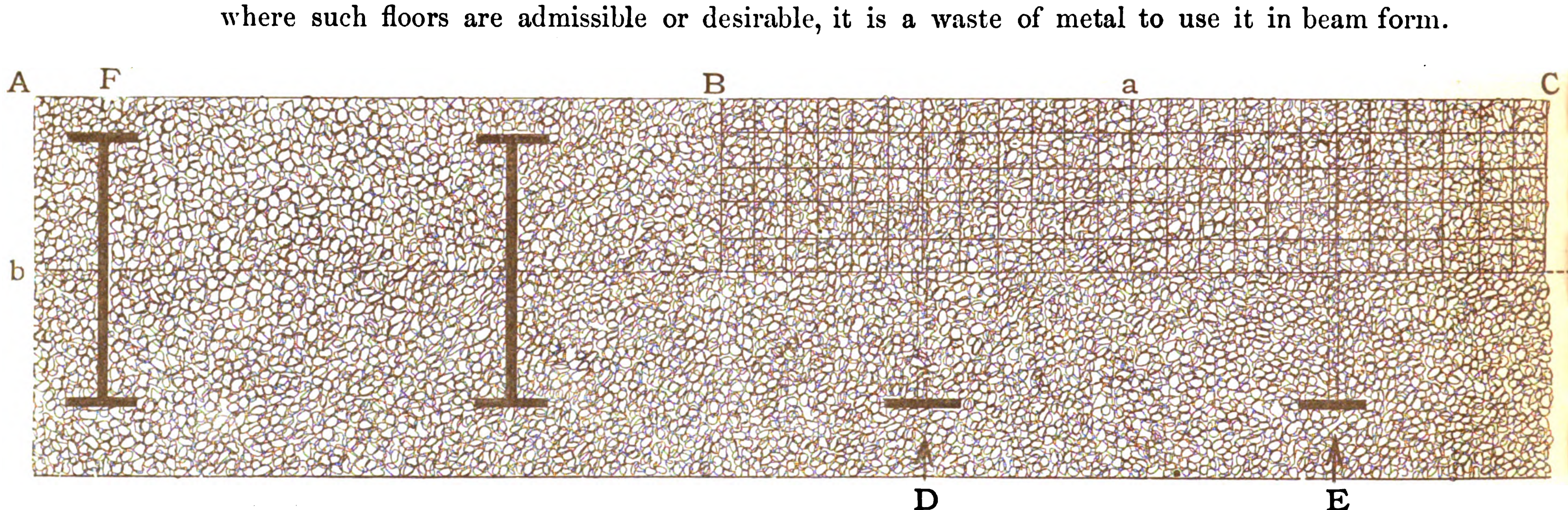


Fig. 23.

Fig. 23 represents at A B a solid floor of concrete and iron joists in cross section; the joists, placed 1 ft. apart, are 8 in. high, flanges 2 in. wide and ¼ in. thick. B C represents the same floor, but with no beams, only the bottom flanges or tie-metal of the beams being used, the web and top flanges being so to speak cut away.

For convenience of calculation, the compressive surface B C above the neutral axis, b c, is laid off by cross lines to represent 1 in. squares, and for easy calculation and comparison the

[1] The writer has assumed a carrying capacity for wrought-iron beams of 120 lbs. over 14 ft. span at an expense of 8 lbs. of metal to each foot of load carried. That this estimate is rather favourable than otherwise may be judged of from the following table of spans, weights, and depths of the joists used in the floor of the Louvre, the

metal tie in cross section has been taken at $\frac{1}{2}$ in. Now then, taking the metal ties D E to represent each $\frac{1}{2}$ in. of metal, and B a, above the neutral axis b c, to represent the compressive surface belonging to D, we find by counting the squares that we have 60 *square inches* of compressive concrete surface as the fulcrum for D to act against, in lieu of the $\frac{1}{2}$ in. of metal, F, in the top flange of the rolled joist; and the question is, can these 60 in. of concrete when brought into compression be made to do the duty of the $\frac{1}{2}$ in. of metal at the top of an iron joist? Let us see. If we take the compressive resistance of concrete at 2,000 lbs. per square inch,[1] we get a mean of 1,000 lbs. acting at $2\frac{1}{2}$ in. above the neutral axis b c; thus, $60 \times 1{,}000 \times 2\frac{1}{2} = 150{,}000$, or a resisting fulcrum equal to 150,000 lbs. Then if we take the metal tie, D $2 \times \frac{1}{4} = \frac{1}{2}$ square *in.* and assume the tensional power of the metal at 60,000 lbs. per square inch, the $\frac{1}{2}$ in. of metal in the tie represents 30,000 lbs., multiplied by the leverage of 4 in., which equals 120,000 lbs.

The compressive surface of the concrete is, therefore, in excess of the demands of the tie-metal. But this demonstration, although reasonable to the writer on account of the experiments he has made, may not be equally so to the reader, who may desire to know, first, as to the possibility of uniting metal to concrete as a bottom flange is held to its web in a rolled or riveted beam; and secondly, as to whether when under strain the two materials will act in concert. The answer to these queries is by reference to figs. 5,540, 5,541, 5,538, 5,539, and 5,543, Plate A, illustrated by figs. 17, 18, 19, Plate H, and figs. 15 and 16, Plate G, and analyzed on Table I. *continued*, Nos. 15, 16, 17, 18, 19. A study of these will show, from the breaking of the metal, first, that all the blades of iron were perfectly held while the beam was under strain; secondly, that the two materials worked in perfect harmony; and thirdly, that the proportionate

load being taken at 150 lbs. per square foot, and the condition maintained that the deflection at the middle of any beam shall not exceed $\frac{3}{4}$ in. A camber is given to the beams to prevent any deflection below a horizontal line.

Spans.	Weight of beams per yard.	Depth of beam.
6 ft. 7 in.	18 lbs.	4 in.
9 „ 10 „	22 „	$4\frac{3}{4}$ „
13 „ 2 „	40 „	$5\frac{1}{2}$ „
16 „ 5 „	50 „	$6\frac{1}{4}$ „
18 „ 1 „	54 „	$7\frac{1}{8}$ „
21 „ 5 „	60 „	$7\frac{7}{8}$ „
25 „ 0 „	76 „	$8\frac{3}{4}$ „

From the "New American Encyclopædia."

[1] The compressive strength of concrete may be anything from 500 lbs. to 5,000 lbs., according to the quality of the materials and the skill and fidelity of the workmen; but if anyone objects to the system on this ground, much more may he object to rolled beams. The making of concrete beams is in the hands of the builder and the engineer or architect, and may be whatever they choose to order it; but rolled beams have to be taken largely on faith. Whoever doubts this had better inspect Mr. Kirkaldy's museum of broken (wrought!) iron beams.

power of the metal increased regularly as it became tie-metal, the 2 in. blades of beam 5,540 exhibiting a greater tensile power in proportion to cross section than 5,543, where the blades were 5 in. in depth; or in other words, the higher the blades the more they lost as *tie*, and the more they gained as *compressive* material, the portion which came into compression being so much metal relatively lost, inasmuch as there was concrete enough to do this part of the work without it. These facts are still more strikingly confirmed by the tests 874, 844, and 845, Plate C, illustrated as fig. 24, Plate I, by fig. 27 on Plate J, and by fig. 29 on Plate K, the ties in all these concrete beams being *flat* metal, and in this respect more nearly resembling the bottom flanges of rolled beams. Deducting the $\frac{1}{2}$ in. of metal along the middle line of the flat bar occupied by the row of vertical bolts put there to fasten it to the compressive portion of the concrete, the tie may be computed at $\frac{1}{2}$ in. in cross section. The mean load of these three beams, as shown by Mr. Kirkaldy's report, was 18,812 lbs., and equal to what would have been borne by a web-and-flange beam of equal depth, having a bottom flange of the same area as the metal tie of the concrete beams, with the addition (note this) of a load equal to what the concrete itself, if acting alone, would have sustained. In proof of this it will be seen by referring to 5,537, Plate A (see also No. 2, Table I.), that a beam 12 × 8 in., and made of concrete only, broke under a strain of 1,484 lbs. upon a 5 ft. bearing; but inasmuch as the three beams now in question were 12 × 12 in., we have as 8^2 is to 12^2, so is 1,484 to 3,339 lbs., the breaking strength of a 12 × 12 in. concrete beam. Then to ascertain the ultimate strength of a wrought iron beam 10 in. deep, with the bottom flange 2 × $\frac{1}{4}$ in., the same as the iron tie, we take Fairbairn's formula $\frac{a \times d \times c}{l}$, where a equals the area of the bottom flange, d the depth in inches, c the constant multiplier of 80 tons (found by experiment), and l the length of bearing in inches, which then becomes $\frac{10 \times \frac{1}{2} \times (80 \times 2240)}{60} = 14{,}933$ lbs. breaking strength of the wrought-iron beam, and 14,933 lbs. wrought-iron beam added to 3,339 lbs. concrete beam, gives 18,272 lbs. total. Now, taking 18,272 lbs., the united breaking strength of a wrought-iron and concrete beam, and comparing this with 18,812 lbs., found by experiment to be the mean breaking strength of the three beams under consideration, who can doubt or who can question the feasibility of uniting tie-metal to concrete with a perfection equalling that of riveted or rolled beams?

To illustrate more forcibly the waste of metal produced by the use of iron beams in solid concrete floors, and how easy under such circumstances it is to save two-thirds of the metal, two sketches are given, Plate N and Plate O—the former representing a floor made of 7-in. rolled joists placed 1 ft. apart, the span being 15 ft. This floor, when filled in with concrete, will be

10 in. in thickness, viz., 2 in. of concrete below and 1 in. above the joist, and consequently be capable of resisting the fiercest fire during a period of six hours.[1] Weight of iron per foot super, 14 lbs.; weight of concrete, 100 lbs.; safe distributed gross load, 384 lbs., or 270 lbs. net. Plate O represents a floor of *tie*-metal, the weight of iron, 5 lbs. per foot super; span, 15 ft.; thickness of floor 14 in. when the concrete is put in; safe distributed gross load, 415 lbs., or 270 lbs. net. The difference in the thickness of the floors is seen by the cross-sections on the plates. To construct a floor no greater in thickness than the one made of rolled joists, skeleton beams as shown on Plate P are made use of. The iron at top and bottom of the skeletons is the same as the flanges of the rolled beams. A floor made in this way will be 10 in. thick; weight of iron, 9 lbs. per foot super; safe distributed gross load, 379 lbs., or 270 lbs. net; span, 15 ft. A floor constructed on this plan has all the advantage of diminished thickness, the same as where rolled joists are employed, and with a saving of 33 per cent. over the solid beams.

The examples here given will serve to illustrate in a general way the principles of floor construction advocated by the writer; and these together with the tables at the end of the work will show the *possibilities* of concrete and iron in combination. Not that all the things shown as possible to be done are the best, or would be recommended. For example, Table II. shows that a *solid* concrete floor 35 in. thick on a 40 ft. span may be made with 9·6 lbs. of iron capable of carrying a safe net load of 221 lbs. But it by no means follows that a *hollow* one would not be a great deal better, nor but that by an expenditure of double the amount of iron a cheaper, thinner, and lighter floor of concrete could be constructed.[2]

The *concrete* beams broken in Mr. Kirkaldy's testing-press were about 50 in number, and weighing from 200 lbs. to 900 lbs. each; and satisfactory as were the results, and instructing, there remained yet other points of equal importance. The fireproof qualities of Portland cement; the ratio of its expansion and contraction as compared with iron under like conditions; the effect of the two in combination when heated; difference between light and heavy metal in the combination; the heat-conducting powers of concrete, laws of its conduction; the compressibility and extensibility of cement as compared with iron;—all these, with some minor points, it seemed desirable to settle with as little delay as possible. In order to test the fireproof qualities of Portland cement, blocks of concrete were made of the kind already illustrated and described and

[1] See Thermal Chart, page 28.

[2] Table II. must not be regarded as rigidly accurate, but rather as an approximation or rough statement of the way the facts may be worked out in practice, it being the intention of the writer to follow up this work by an illustrated circular setting forth accurately and in detail the different methods he considers best to be adopted in applying combined concrete and iron to floor and roof constructions to secure lightness and strength with thorough fireproof protection, and at least cost.

subjected to a furnace heat for six hours with the results stated. To ascertain the length of time required for heat to penetrate concrete layers of different thicknesses, a furnace was built like the one represented by fig. 24 below.

The top of the furnace consisted of a slab of concrete of three different thicknesses, indicated on the drawing by the step-like form of the slab, a flat bar of iron being let into each step, with the effect of leaving 2 in. of concrete under one, 3 in. under another, and 4 in. under the

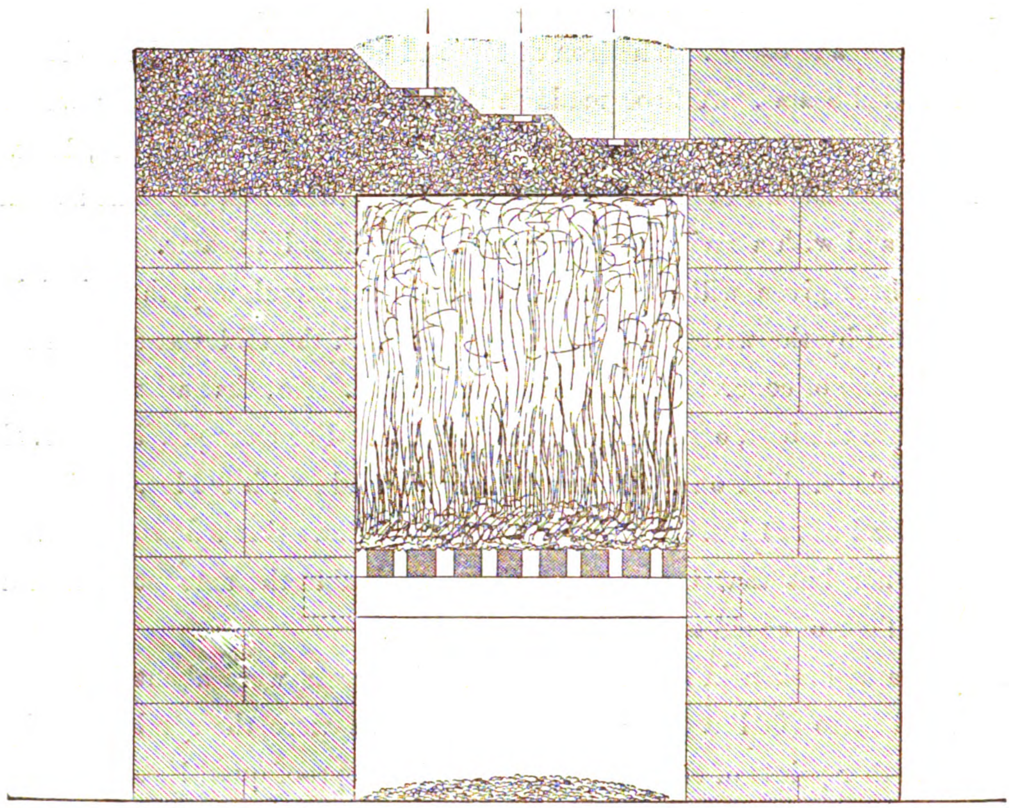


Fig. 24.

third. Two small squares of metals, one being tin, and the other lead, were let into each bar of iron; upon these, rods or needles were made to rest as shown in the drawing, the needles being connected with weights in such a way that on the melting of the metal the needle would sink, and thus indicate the exact degree of heat at the time. The preliminary degrees of heat, however, were taken with thermometers, and the final degree at the end of 12 hours, the close of the experiment, was ascertained by withdrawing the heated bars from the concrete bed and plunging them into vessels of water provided with thermometers, the rise of temperature of the water indicating the heat of the irons at the time of immersion. From these data the Thermal Chart, page 28, was constructed. It will be observed on examining the Chart that the thermal lines as they approach the boiling-point of water remain in that vicinity for some considerable time, the explanation of which is that this length of time was required for the evaporation of a certain amount of free moisture contained in the concrete, after which the temperature again continued to rise as before. It will be also noted that the thermal line of the 3-in. thickness of concrete is higher than a mean between the 2 in. and 4 in. thicknesses, which may be accounted for on the ground of its position at the centre of the top of the furnace.

To ascertain the limits of expansion and contraction of Portland cement within definite ranges of temperature trial sticks of cement were made and heated, the expansion of the same being ascertained by placing the tests between two fixed points, space being allowed between, the variations in which were ascertained by means of tapered pieces, which were then measured by Holtzapffel's Thousandths gauge; the result was found to be a lineal expansion of ·00137 for 180 degrees of heat as compared with ·0014 for wrought iron, a result so near that the expansion may be considered to be the same; but in order to prove the result practically, blocks of cement concrete 14 in. long and 4×3 in depth and breadth were made in which bars of iron were imbedded, the bars varying in size from $2 \times \frac{1}{32}$ of an inch to 2 in. square and 12 in. long. On testing these by fire no difference in effect was found to be produced on the concrete by the different masses of metal contained within them. As a final test bars of iron 2 ft. long by ½ in. thick were imbedded in blocks of concrete; these blocks on being exposed to the red heat of a furnace for six hours were found to be entirely sound and good when taken out; the synchronism existing between the expansion of the two materials, whatever the size of metal, was thus placed beyond question, and in respect to this in combining concrete with iron for building purposes the two materials may be regarded as practically homogeneous. These results, as may be supposed, were in the highest degree satisfactory and assuring.

The compressibility and extensibility of cement were investigated by experiments with a bar of cement ten days old. This bar was made sufficiently long to admit of the insertion therein of two fixed points 50 in. apart, one of the points being the bent end of a rod lying upon the outside of the bar of cement and parallel with it, and which rod extended to within a short distance of the other point, thus leaving a space sufficiently small for accurate measurement on the cement being subjected to pressure. To prevent bending, the cement bar was placed in a frame fitting loosely about it and yet sufficiently tight for the purpose. The load was then applied gradually by means of a lever, the actual compression from time to time being ascertained by tapering pieces, as before described, which were again measured by the gauge. In this way the compression was ascertained to amount to ·048 in. in 50 in. with a load of 1,000 lbs. per square inch, the bar returning to its original length on removal of the load. This gives the ratio of expansion as ·00096 of length for 1,000 lbs. per square inch, or say in round numbers the one-thousandth part of length; and if the ultimate compressive strength is taken at 2,000 lbs. per square inch (which is perhaps the safe figure considering that concrete in practice, and not neat cement will form the compressive member of the compound beam), the final compression will be the $\frac{1}{500}$th part of length. Now, as wrought iron is found to extend the $\frac{1}{10000}$th part of its length for each ton of strain per square inch, it follows that at 20 tons, or say prior to rupture, it will extend the $\frac{1}{500}$th part of its length, or about the same as the compressibility of cement; the effect of which in the compound beam is to keep the neutral axis at the centre line of the beam, the entire tensional strain being thus thrown upon the metal tie. The results of the Kirkaldy tests already alluded to confirm these conclusions.

The ratio of extension was measured by similar means, but as the range of tensile strength in cement is limited, it is not possible to determine the point with the same accuracy, the result being only ·000042 of length for 100 lbs. per square inch, or say the $\frac{1}{10000}$th part of length as final extension before rupture. This sample at the same age of ten days yielded at a tensile strain of 224 lbs. per square inch.

The fitness of Portland cement and its concretes to serve as web-and-top flange to a metal tie having been thus ascertained with reference to the questions of compression, extension, expansion, and contraction, and the mechanical perfection of the union between the two having been demonstrated by the results of Mr. Kirkaldy's testing machinery, it might seem that this should have been sufficient; but it was thought best to apply the test of fire and water to a real floor, or a section of one sufficiently large to leave no doubt as to the result of fire upon such a floor in actual use. Accordingly, a furnace was built as represented in the Frontispiece, Plate Q, the top being a slab or floor section 6 ft. long by 2 wide and 7½ in. thick. The tie metal in gridiron form was placed at the middle of the thickness, 3 in. of concrete being above, and 3 in. below the metal. The furnace was made with a range of air holes on either side, to insure perfect combustion and intense heat. Loose bricks were piled upon the furnace top until a load was obtained of 300 lbs. to the foot square over the whole surface, the deflection being with this load $\frac{1}{32}$ of an inch in a span of 5 ft. The fuel was arranged to form an incandescent bed 6 in. thick at 12 in. below the under face of the concrete slab. The fire being kindled at six o'clock in the morning, had by eleven become an intense heat perfectly uniform over the entire surface, and the bottom of the concrete was also at a glowing red heat all over. At this intensity the fire was kept up until 4 P.M., a period of ten hours from the lighting of it. During this time the slab had deflected $\frac{3}{8}$ths of an inch. A stream of cold water was now thrown forcibly against the bottom of the slab for a period of 15 or 20 minutes, by means of a garden force pump, and the load then removed. On examining the underside of the section it was found uninjured; and the next morning, being then entirely cold, the deflection had disappeared, the slab having returned to its former level. In order to confirm these results, a second trial was made; this time the load was left upon the slab, which during the firing deflected as before, but upon cooling returned to its original level, *lifting the load with it.* In proof of the heat of the furnace it may be mentioned that in the course of this experiment the faces of all the side bricks in actual contact with the fire were melted.

In addition to the experiments described, others of less moment were made, as to the non-conducting power of various substances, such as plaster of Paris of different densities, and concretes more or less porous, also air spaces; the result of all being that the best material to protect the metal against heat was found to be that which was strongest in compression, viz., Portland cement concrete of best quality, no advantage for any purpose being found from *fibres* of any kind, not even *asbestos.*

Plates A, B, C are Mr. Kirkaldy's Reports of the beams tested by him. Plates D to M, inclusive, show the interior construction and external shape and proportions of the beams, which are numbered consecutively and likewise indicated by the same numbers used in Mr. Kirkaldy's Reports, A, B, C. Tables I. and I. *continued* explain the kind and weight of materials of which the beams were made, and their relative proportions, together with a comparative analysis of values as derived from the breaking strains applied to them; while Table II. is intended to show about the quantities and weights of materials required in beam or floor construction of the kind herein described for given spans, with the carrying capacity of the same.

The tubular and brick beams indicated on the plates have been passed over in silence by the writer, as he has long since become convinced of the greater practical value of concrete for floor and roof constructions. The brick beams tested were made of fire-brick in the year 1874. The fractures in these beams, as seen in Plates D and E, appear to be on one side of the centre, owing to a portion only of the length being shown. The tubular beams of iron and concrete were made in 1870, and the concrete beams during the latter part of 1876 and the early part of 1877. The first brick beam made by the writer was in the year 1855, and resembled the brick beams of 1874, shown on the plates. This beam was made of flat bricks about 9 in. square and 1 in. thick, confined by a tie-rod near the bottom of the bricks, which passed through holes made for the purpose in them. The beam, 5 ft. long, was tested in the hydraulic press of R. G. Hatfield, Esq., of New York.[1] Allusion is made to it here and the letter below introduced for the purpose of showing how long ago the writer began his labours.

[1] Having preserved no memoranda concerning this and some others made at the time, the writer in the early part of the present year wrote to Mr. H. for particulars of them, and received from that gentleman the following reply:—

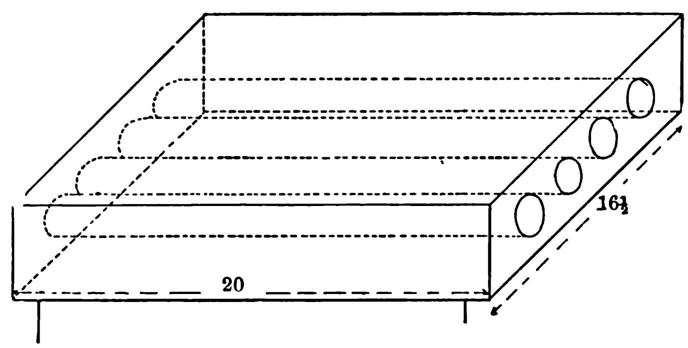
"New York, 31, Pine Street,
"*April* 24*th*, 1877.

"Mr. Thaddeus Hyatt,

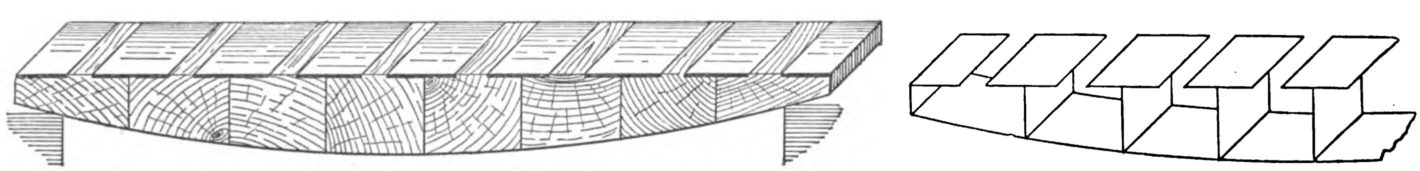
. . . . "I have no record of the results of the experiment on the *brick beam.* Looking in my diary for "1855, I find at September 12th: 'Mr. Hyatt's men busy testing brick beams.' And at other days previous to this

The metal ties employed in the experiments herein described were of two kinds, viz., *round* rods and *flat* bars; the latter being placed edgewise in seven of the beams (13 to 19, Table I. *continued*), and flatwise in 12 others (20 to 31, Table I. *continued*), and placed flatwise also in 22 others (Plates B, L, and M). The 6 beams illustrated on L and M represent 18 beams on

"I find mem. of being at your shop, and observing your men at work on brick beam. From these mem. I judge, and "also have some recollection, that I, being busy, left the testing to your men, and so preserved no record of the "experiment. In my experiment book, under date June 2, 1855, I find a record of tests of tin tubes. Of these "No. 79 was a test upon a plate of plaster of Paris, $16\frac{1}{2}$ by 20 in., 4 in. thick. This plate had imbedded in it four "hollow tin tubes, 2 in. diameter and 20 in. long, placed at regular intervals of 4 in. from centres, thus—



"This plate was laid on chairs set with a clear span of 18 in. A pressure of 2,740 lbs. at middle cracked the plate "on the underside, and at 2,940 lbs. the tubes collapsed. Following this account there are tests upon simple tubes "of tin, like the above. No. 80, empty tube, bore 80 lbs. at middle, seam down. No. 81, seam up, 110 lbs. at "middle, top crushed, bottom straight. June 8. Another of the tin tubes filled with mortar, two days before, ends "sealed up, 18 in. clear bearing, seam up, bore 190 lbs. This weight puckered the sides. Another tube, filled two "days since with plaster of Paris, ends soldered tight, 18 in. clear bearing, load at middle. This bore 590 lbs. (gradually "put on 10 lbs. at a time) without apparent injury. It deflected $\frac{1}{4}$ in., 630 lbs. caused it to pucker across the top, and "soon after the bottom parted, showing signs of extension for 6 in. in length at the break. . . . . On the 25th April, "1855, I tested a model of beam for you made of blocks of wood, held together by a tin band, thus—



"band turned over at the ends and nailed. The uprights passed up the joints between the blocks, and by the top "flange held on to the blocks. One of the uprights parted at a soldered joint, with 260 lbs. laid on at middle. The "beam was 17 in. long, $1\frac{1}{2}$ in. high, and 2 in. broad. The clear bearing upon the chair was 15 in. I am just com- "pleting a new book, 'Transverse Strain.' It will interest you, I dare say.

"I wish you success in your undertakings.

"Yours truly,

"R. G. Hatfield."

Plate B. These beams having been made three of each in order to obtain in each instance an average of three tests. Plate B describes four others, not illustrated; but they were similar in all respects, differing only in length, with the exception of 2,241 on Plate B, which contained two ties, and was therefore relatively weak in compressive power, as indicated by the results of the test. In this respect indeed all the beams of this series were weak, for which reason no deductions have been made from them, Table II. being based on beams where the ties broke. The flat ties placed edgewise are illustrated on Plates G and H, and the flat ties placed flatwise are illustrated on Plates I, J, and K, one of them being on H, these latter were held by bolts at varying distances apart, as shown on the illustrations. Some of the ties were bent, but with no advantage. The bolts in all cases were made long enough to extend upward into the compressive part of the beam, and all were furnished with washers at the heads to take a broad bearing in the concrete. The flat ties illustrated on Plates L and M differ from the preceding only in the form of the washers, having in place of a washer to each bolt one continuous washer in arched form for the whole, giving to the metal tie the appearance somewhat of a bow-string girder. But all these contrivances for holding a metal tie to the concrete were devised under a misapprehension of the real nature of the strains that take place in a beam under stress, no such connections being required. Whether the web of a beam or of a bridge be solid or open, the tie requires no attachment to it other than one that will *prevent it from sliding* upon the web. A mere row of pegs or pins in a flat tie, whether placed edgewise or flatwise in the concrete, is all sufficient, as may be seen by the beams on Plates G and H, where the blades of metal placed edgewise were threaded upon wires that served as *stops*, and prevented all tendency to slide, the blades of No. 19, only 2 in. deep, being held perfectly to the concrete, and finally breaking *short* like a piece of cast-iron, showing the perfection of the union. When a beam is subjected to a bending stress it becomes more or less curved, by virtue of which the outer or lower portion is lengthened, and the inner or upper portion shortened, in proportion to the depth of the beam or the difference of length between the radii of the curves. Were the beam made up of horizontal layers, the effect of the stress would be to cause these to slide one upon another; but the beam being solid, the particles are held together by their own cohesion, the shearing strains being thus opposed by cohesive force. The primary strains in the beam or the lines of compression and extension being upon curved lines, the disturbed particles must of necessity tend to arrange themselves in harmony with the radial lines of the circles, all below the neutral axis seeking extension, and all above, compression. How slight are the duties of the web of a beam under these circumstances may be seen from the exceeding thinness to which it is possible to reduce it; which fact seems to confirm the view that when the web of a beam possesses cohesive power sufficient to resist the shearing strains resulting from a bending stress, it is equal to all the duties required of it, all other strains upon it being secondary and inferior. If these views are correct it is not difficult to understand how a metal tie is held in the embrace of a concrete web, nor how a web of concrete four or five times as thick as metal webs are usually made should be quite able to perform its part and become equally as serviceable.

A flat tie, on account of the large holding surface presented for the concrete, is probably the best form in which the iron can be used; when placed edgewise, as in the floor construction already illustrated, it makes the cheapest and most convenient tie that can be employed; the wires that connect the bars also serve as stops to prevent the metal from sliding when the beam is under strain. By employing the metal in gridiron form for the top flange, and the same for the bottom, the two being connected by concrete webs, hollow floors of great span may be made; one of 40 ft. requiring to be no more than 2 ft. thick, the concrete and iron together weighing only 173 lbs. to the square foot; gross load, 396 lbs.; net, 223 lbs., and at an expense of but 20 lbs. of iron per square foot. The gridiron top flange would be composed of ¼ bars 2 in. deep at 2 in. apart, thus representing in quantity at the floor-line an amount equal to a continuous or solid flat plate of iron a quarter of an inch thick, and an equal quantity at the ceiling-line. A cellular iron floor made like the bottom of a tubular bridge would require all this and as much more iron as would be needed to make the webs of, besides costing vastly more for labour, and when finished would not be fireproof—flat, plain surfaces of iron being impossible to overlay. The iron in a gridiron top and bottom construction amounts to the same thing as though the continuous or solid flat plate spoken of were cut into strips of 2 in. width and placed edgewise 2 in. apart. By this arrangement the metal does its work equally well, and is better shaped for being held by the concrete and protected by it.

As between solid and hollow concrete floors the circumstances of each case must determine which is best. In general, the hollow is to be preferred, although requiring top-metal as well as tie, as illustrated on Plate P: the most convenient method, however, of making such floors, especially where the span is great, is to use the metal in gridiron form, concentrated upon lines at top after the manner of the upper flanges of beams, and spread out below as a continuous tie over the whole ceiling surface. Floors made in this way, when finished, will have the appearance of the construction illustrated by figs. 18, 19, and 20, on page 12, and be but little more than half the weight of solid ones. The objections to metal in beam form for house-building purposes are many. The difficulty of getting beams that are light enough to admit of being placed sufficiently near together to make good work without cross-metals, and the waste of material when this is done, the inter-beam filling material being dead weight or load upon the floor; the wide margin required on account of the variable quality of the material of which beams are made and the cost and trouble of testing them; the labour and expense of getting heavy beams into position; besides many other disadvantages not necessary to mention. On the other hand, by the method of construction illustrated in these pages, we may be certain of our material, the use of *steel* even being possible where desirable; while hoop and bar iron of reliable quality can be always had in the open market, and may be tested at any time with ease and cheaply. For floors and roofs of any span and strength, the material may be had in light and convenient sections for handling and carriage, so as to be readily placed, thus affording facilities for distributing the metal through the concrete in lines of compressive and tensional strength to the greatest advantage—no portion of the structure being dead weight; and finally, the convenience which this mode of obtaining beam strength affords the architect under circumstances where metal beams are both troublesome and expensive. Take an example like the following: An architect requires a support for a dwarf wall between piers, and a beam with a broad flange is needed; but none can be had with the convenient flange except by using a beam three times as strong as there is any need of. For such a case the concrete beam comes in admirably,[1] and for many others of a similar character; in fact, it is difficult to conceive of any circumstances connected with house-building where the concrete-beam method is not more convenient, cheaper, and safer than the employment of metal in beam form.

If the conclusions of the writer are correct, and if the advantages to be derived from judicious combinations of iron and steel with concrete are as great as he believes, the method (within certain limits) should be applicable also to bridge construction; and a bridge made of combined concrete and metal should be weather-proof and need no paint, besides (probably) costing less for repairs. If we may reason from a sample to the whole piece, from a small structure to a large one, the following may help to illustrate the value of combined iron and concrete. Two grid-iron ties, each 1 ft. wide and 5 ft. 6 in. long, were made of five blades each, one being a duplicate of the other; the blades of one were prevented from buckling by thimbles placed between them; the other was overlaid with concrete, and at the same time set with glasses, becoming a

[1] A case in point has just occurred which illustrates the above. There were seven openings to be closed, each 2 ft. 4 in. × 7 ft. between piers under windows, and beams with broad flanges were needed to carry the dwarf walls; but no light beams of this description could be had, and heavy ones, three times as strong as were necessary, had to be decided on. The writer brought his new methods to the notice of the architect; the beams were dispensed with; and for but little more than their cost, not only are the dwarf walls furnished with convenient foundations, but the entire openings, 2 ft. 4 in. wide, are closed by *illuminating* concrete slabs possessing beam strength, which, besides transmitting light to the space below, make a handsome finish under the windows on a level with the court, which is also to be entirely covered by the New Stone Light, making an Illuminating Roof of nearly 600 square feet to a work place below.

"*stone light.*" On being placed upon chairs leaving a clear span of 5 ft., the naked iron deflected an inch under 1,400 lbs., and sunk to 5 in. with 2,200, which crippled it. The other, upon the same bearing, deflected just one inch under a load of 30 cwt., and when the load was removed returned to its former level within a fraction; not a glass was fractured, and the concrete showed no signs of flaw in any part.[1] The writer may say in passing that he is now prepared to undertake the construction of domes of any span from 2 feet to 200, according to the general methods herein set forth. Such domes when set with glass may be underlined with bent or curved glass stained or coloured with any design, the effects of such combination being singularly beautiful and unique, and for the roofs of churches particularly applicable. The plain stone light roofs may be curved to any pattern, either as dome or arch; and when made with glasses having a stepped lens-face (the steps being ground) transmit and diffuse a light of remarkable softness and clearness suitable for picture galleries and other places requiring a particularly good light. By the use of the New Portland Cement[2] in making these structures the illuminating roofs, even when set with glass, are made thoroughly fireproof—a great desideratum for a gallery containing treasures of art. But the combined fireproof concrete and iron has other uses besides the ones thus far treated of. For chimney shafts of great height for manufacturing purposes, this combination of metal blades and concrete seems admirably adapted, the metals, like roots of a tree deep planted in the ground, extending upward through the concrete mass, and threaded upon strong wires forming circles, give to such a monolithic construction the strength of a hollow metallic cylinder, at once lighter, cheaper, and stronger than one made of brick. And if serviceable for such purposes, equally applicable for *lighthouses*, needing coherence as well above as below the waves. Such lighthouses also, when set with glass, being capable of transmitting light from base to summit like a column of flame. One of the first things in a dwelling-house that fails in the midst of the flames is *the stone stairway;* but stairways perfectly fireproof may now be made from the new material, the concrete being moulded into any desired pattern and made with beam strength upon a metallic core. The writer is also preparing to manufacture safe-walking open stone gratings, somewhat similar to the stone lights, but with the glasses left out; the design being to form a safe footway of open gratings. The principle of this invention makes it equally applicable for area railings and other similar purposes, the advantages here being cheapness, protection from the weather, and a greater variety of tasteful and ornamental

[1] This stone light may be seen at Farringdon Road.

[2] The undersigned is gratified to be able to announce that after many experiments he has at length succeeded in producing the new cement at no greater cost than ordinary Portland. This cement will not be on the market for sale until a company can be formed for its manufacture, which the writer hopes to see shortly accomplished. Meanwhile, however, he has facilities for executing with it all orders that may be received.—T. H.

designs. The principle admits of development also in other directions not necessary to be enumerated.

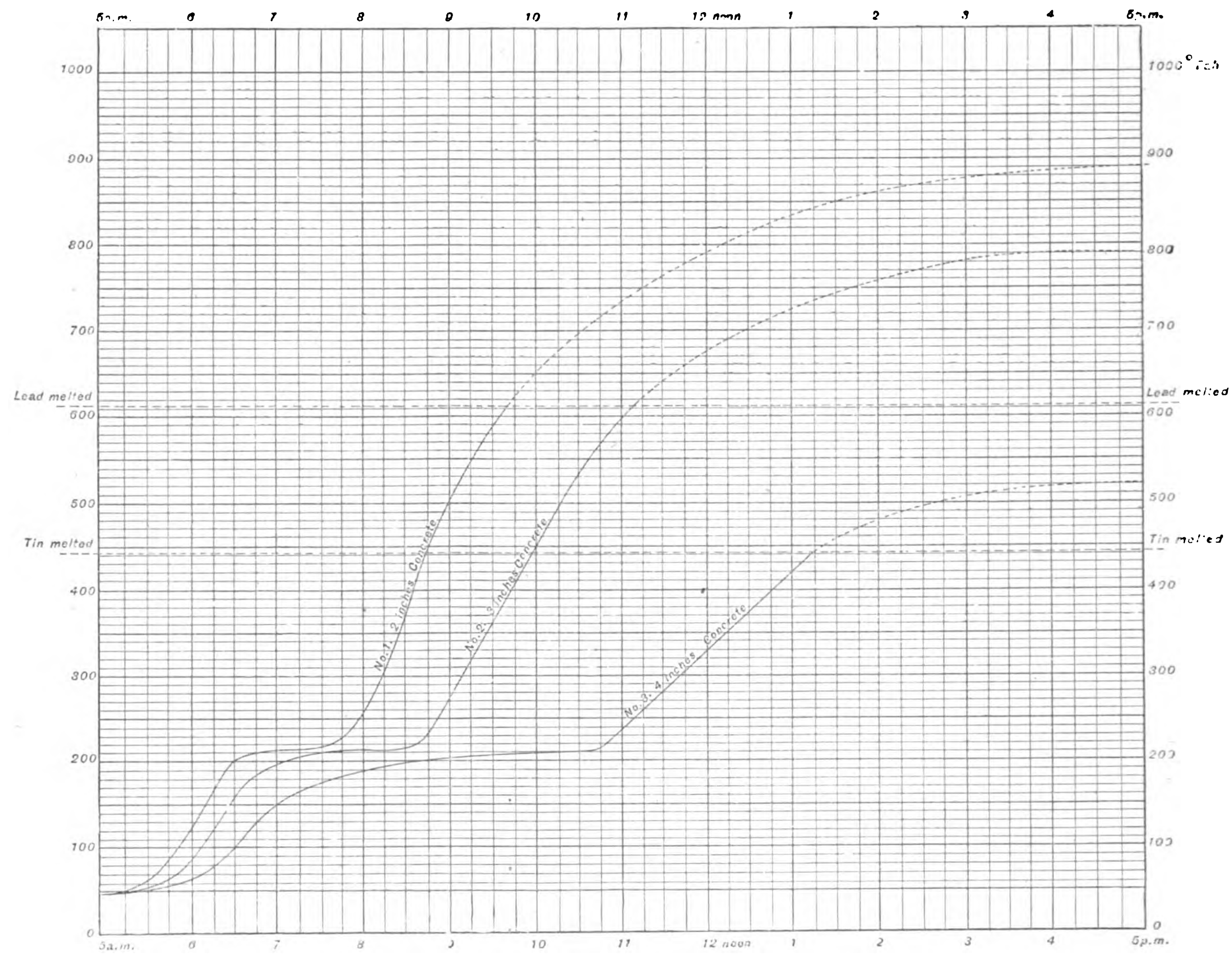
In conclusion, the writer desires to acknowledge his great indebtedness to Mr. Thomas Rickett, of Birmingham, formerly and for ten years in the employ of the London and North-Western Railway Company, an inventor and engineer of ripe experience and judgment. To his ingenuity, talent, and skill the writer is largely indebted for the successful working out of the various problems herein mentioned, and for valuable assistance rendered in getting up this report of the work done. The undersigned is also happy to be able to announce that he has effected an arrangement by which the fireproof constructions described in these pages, and which it is the intention of the writer to carry into practice as occasion may arise, will be under the immediate care and supervision of Mr. Rickett.

Finally, some further experiments of an interesting character connected with the subject-matter of this work are now in hand, and will be made known hereafter.

THADDEUS HYATT.

November, 1877.

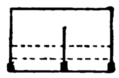
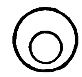
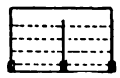
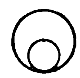
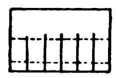
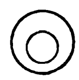
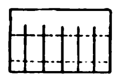
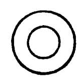
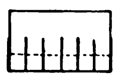
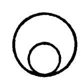
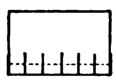
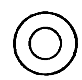
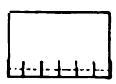
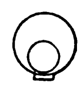
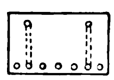
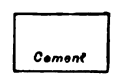
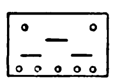
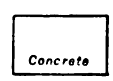
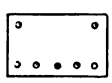
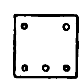
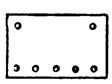
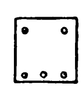
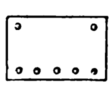
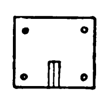
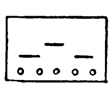
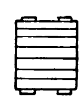
Thermal Diagram, showing the heat imparted to iron bars when protected by 2, 3, and 4 inches of Concrete, placed in the arch of a furnace and heated for 12 hours, the underside of Concrete being red hot in $2\frac{1}{2}$ hours after fire lighted.



From the above it will be seen that in 3 hours after the fire was lighted, or at 8 a.m., the temperature of iron protected by 2 in. of concrete was 250°; in 5 hours, or at 10 a.m., it was 650°; and finally, at the end of 12 hours, 900°, or red hot in the dark; while the iron protected by 4 in. of concrete for $5\frac{1}{2}$ hours did not exceed 212°; in $8\frac{1}{2}$ hours the temperature was 450°, and at the end of 12 hours, 550°, or less than the melting heat of lead, an intense heat being maintained the whole time, and the temperature noted every few minutes.

Plate A.

Results of Experiments to ascertain the resistance to a gradually increased bending strain of Composite Beams, received from Thaddeus Hyatt. Load applied at centre.

K. 5545		lbs 29,628	at 5ft span	K 6553		lbs 27,482	at 6ft span
K 5546		lbs 28,022	at 6ft. ,,	K 5553		lbs 26,392	at 6ft. ,,
K 5543		lbs 25.868	at 5ft. ,,	K 5556		lbs 25,174	at 6ft. ,,
K 5539		lbs 25,148	at 5ft. ,,	K. 5552		lbs 23,468	at 6ft. ,,
K 5538		lbs 23,884	at 5ft. ,,	K 5554		lbs 22.172	at 6ft. ,,
K 5541		lbs 21,222	at 5ft. ,,	K. 5551		lbs 21,238	at 6ft. ,,
K 5540		lbs 16,418	at 5ft. ,,	K 5557		lbs 17,918	at 6ft. ,,
K 5549		lbs 15,478	at 5ft. ,,	K. 5544		lbs 3,192	at 5ft. ,,
K 5536		lbs 14,496	at 5ft. ,,	K 5537		lbs 1,484	at 5ft. ,,
K. 5547		lbs 13,583	at 5ft. ,,	K 5559		lbs 13,512	at 8ft. ,,
K 5542		lbs 12,348	at 5ft. ,,	K 5560		lbs 11,983	at 8ft. ,,
K. 5550		lbs 12,178	at 5ft. ,,	K 5558		lbs. 10,513	at 8ft.
K. 5548		lbs 9,274	at 5ft ,,	K. 5561		lbs 9,084	at 8ft. ,,

(*Signed*) DAVID KIRKALDY,

99, Southwark Street, London.

Feb. 26th, 1877.

PLATE B.

RESULTS OF EXPERIMENTS TO ASCERTAIN THE RESISTANCE TO A GRADUALLY INCREASED BENDING STRESS OF COMPOSITE BEAMS, RECEIVED FROM THADDEUS HYATT.

LOAD APPLIED AT CENTRE.

Test No.	Dimensions. Breadth. Depth.	Stress, Cracked.		Deflection.		Stress, Ultimate.		Span.
L.		lbs.	lbs.					
2,222	9¼ × 4⅜	3,168		·51		3,472		
2,221	9⅛ × 4¼	2,644	2,794	·57	·54	2,891	2,978	5 ft.
2,220	9⅛ × 4¾	2,572		·54		2,572		
2,223	9 × 5½	4,032		·28		5,288		
2,225	9 × 5½	3,968	3,911	·28	·28	5208	5,023	5 ft.
2,224	9½ × 5¾	3,734		·29		4,574		
2,228	9 × 6⅜	5,568		·27		6,377		
2,226	9⅛ × 6¼	6,232	5,580	·39	·31	6,232	6,027	5 ft.
2,227	9⅜ × 6¼	4,942		·27		5,472		
2,230	9⅛ × 7¾	7,241		·24		8,824		
2,229	9¾ × 7⅜	7,509	7,333	·28	·25	8,739	8,600	5 ft.
2,231	9⅛ × 7¾	7,249		·24		8,237		
2,233	9 × 8½	8,362		·20		11,211		
2,232	9¾ × 8½	7,832	8,153	·21	·22	10,684	10,441	5 ft.
2,234	9¼ × 8½	8,266		·26		9,428		
2,236	9⅛ × 9½	10,386		·29		11,731		
2,235	9⅜ × 9¾	10,434	10,277	·25	·26	11,462	11,336	5 ft.
2,237	9½ × 9¾	10,012		·26		10,816		
2,238	9¼ × 9¼	6,044		·58		7,747		
2,239	9½ × 9⅜	5,868	5,642	·60	·63	7,216	7,117	10ft.
2,240	10⅜ × 9½	5,014		·72		6,389		
2,241	12½ × 9		7,572		·41		8,588	10ft.

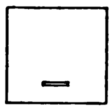
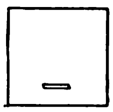
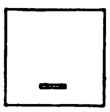
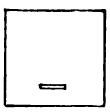
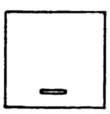
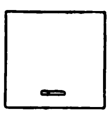
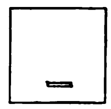
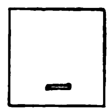
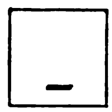
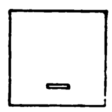
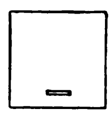
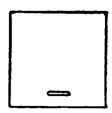
(Signed) DAVID KIRKALDY,

99, Southwark Street, London.

July 21*st*, 1877.

Plate C.

Results of Experiments to ascertain the resistance to a gradually increased bending stress of Composite Beams, received from Thaddeus Hyatt. Load applied at centre.

L. 841		lbs. 15,938	at	5 ft. span	
L. 842		lbs. 16,386	at	5 ft.	,,
L. 843		lbs. 16,344	at	5 ft.	,,
L. 844		lbs. 18,084	at	5 ft.	,,
L. 845		lbs. 19,024	at	5 ft.	,,
L. 846		lbs. 21,592	at	5 ft.	
L. 872		lbs. 20,346	at	5 ft. span	
L. 873		lbs. 18,066	at	5 ft.	,,
L. 874		lbs. 19,328	at	5 ft.	,,
L. 875		lbs. 17,110	at	5 ft.	,,
L. 876		lbs. 19,584	at	5 ft.	,,
L. 877		lbs. 18,866	at	5 ft.	

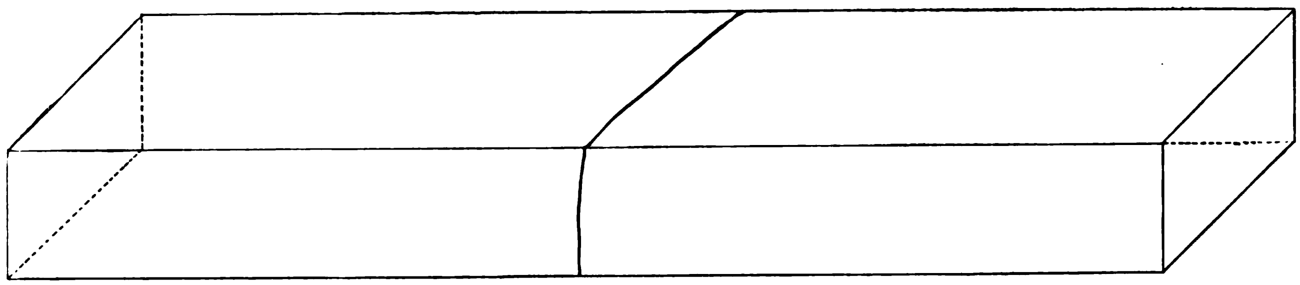
(*Signed*) DAVID KIRKALDY,

99, Southwark Street, London.

August 17*th*, 1877.

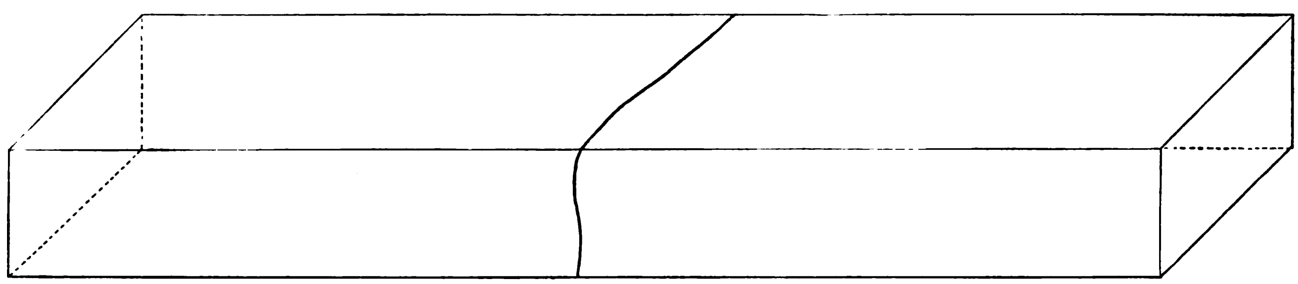
Plate D.

No. 1.



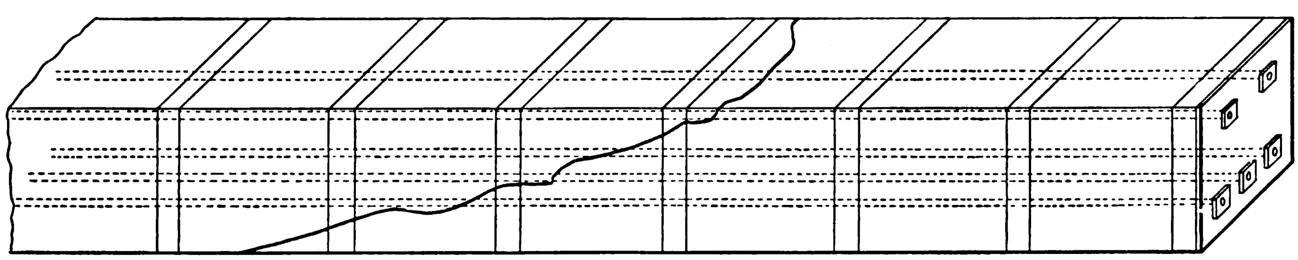
Kirkaldy's No. "K 5544." Plate A.

No. 2.



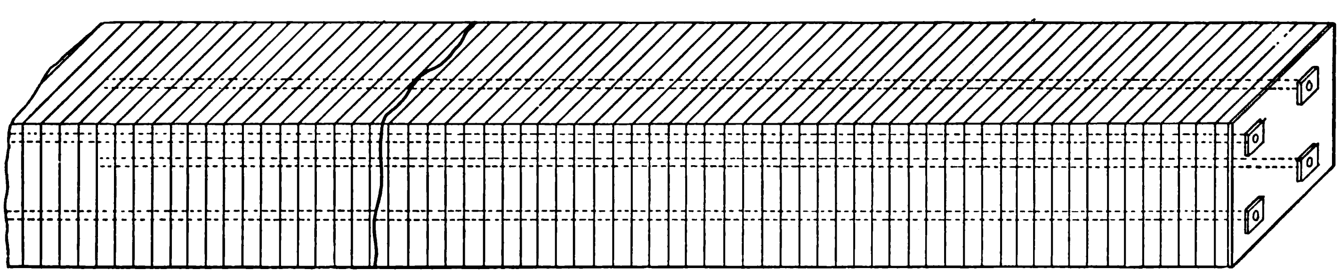
Kirk. No. "K 5537." Pl. A.

No. 3.



Kirk. No. "K 5559." Pl. A.

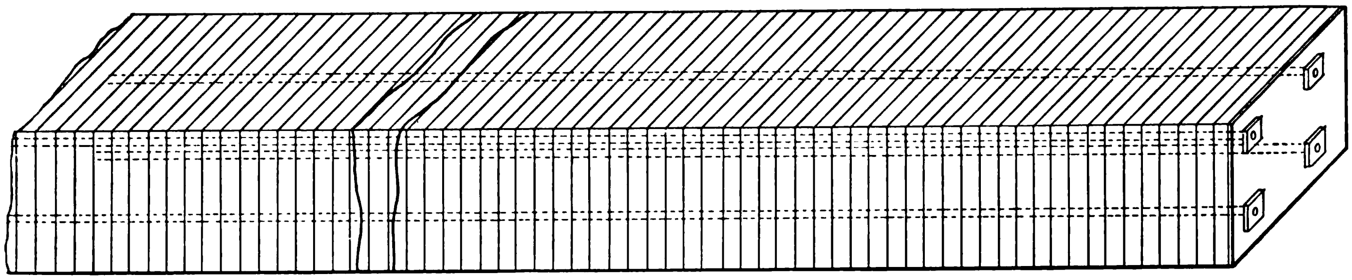
No. 4.



Kirk. No. "K 5558." Pl. A.

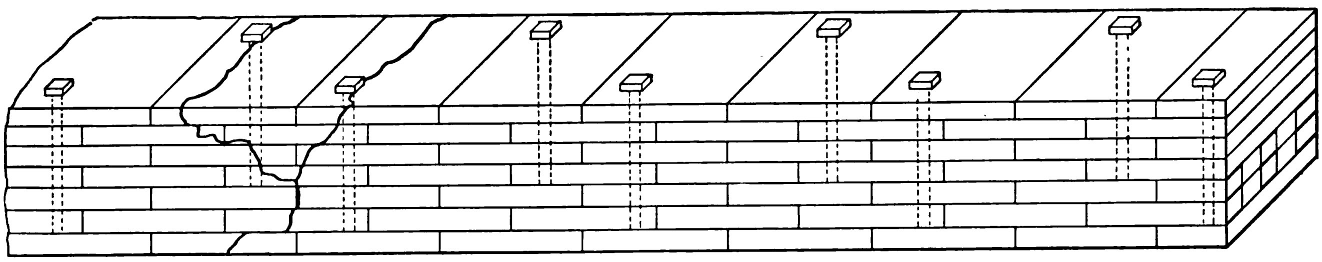
Plate E.

No. 5.



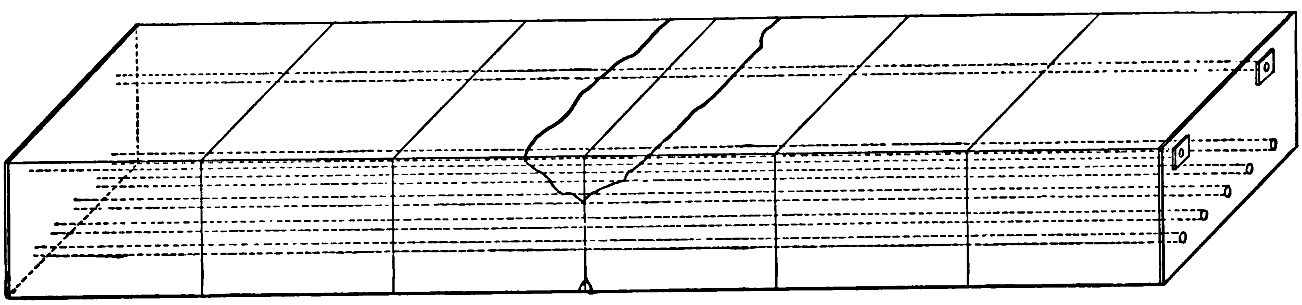
Kirkaldy's No. "K 5560." Plate A.

No. 6.



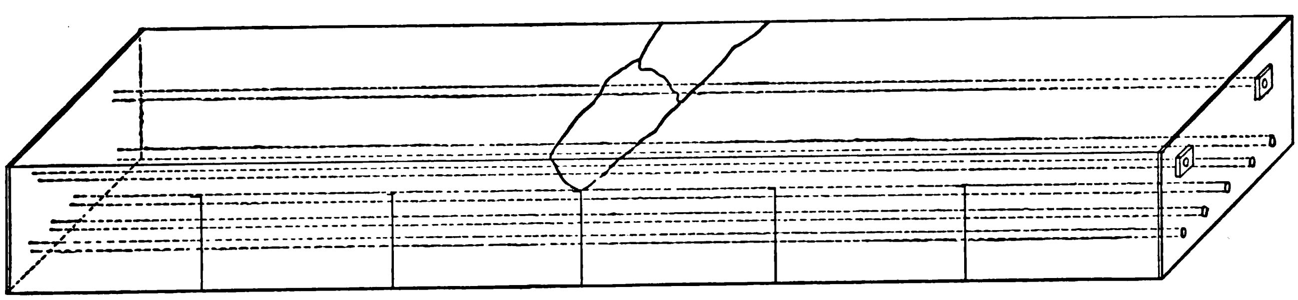
Kirk. No. "K 5561." Pl. A.

No. 7.



Kirk. No. "K 5542." Pl. A.

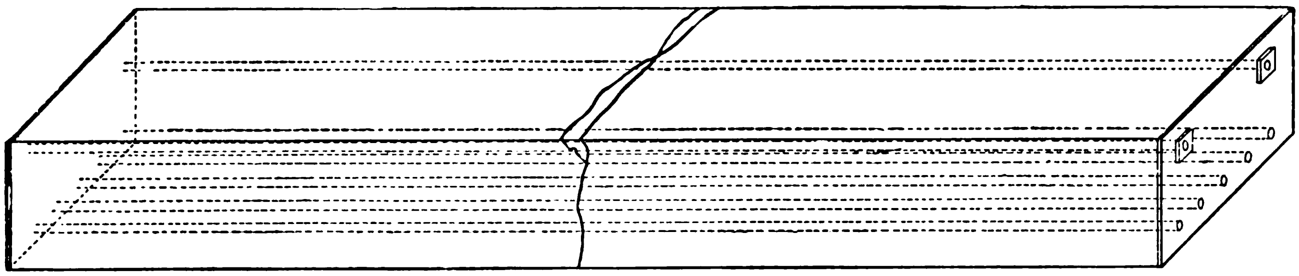
No. 8.



Kirk. No. "K 5536." Pl. A.

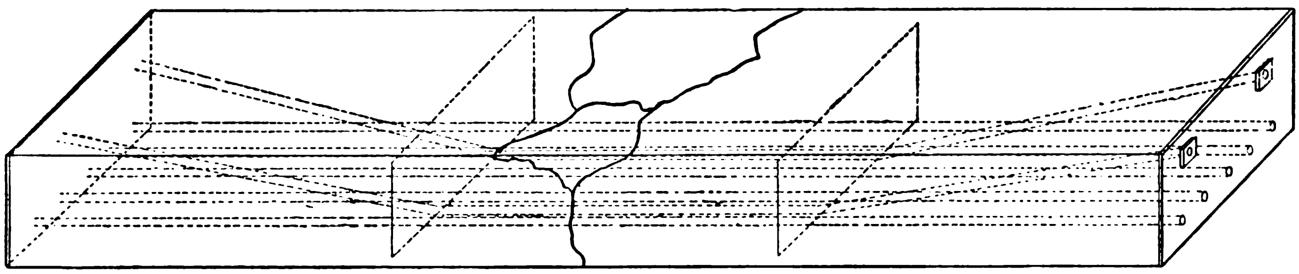
Plate F.

No. 9.



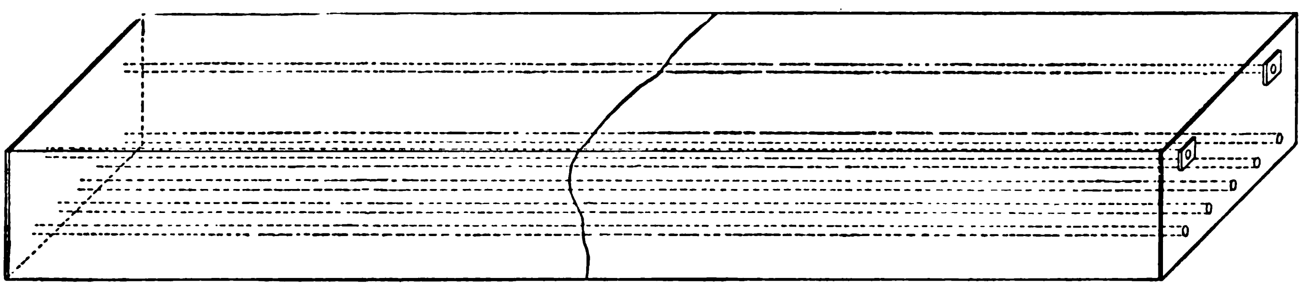
Kirkaldy's No. "K 5547." Plate A.

No. 10.



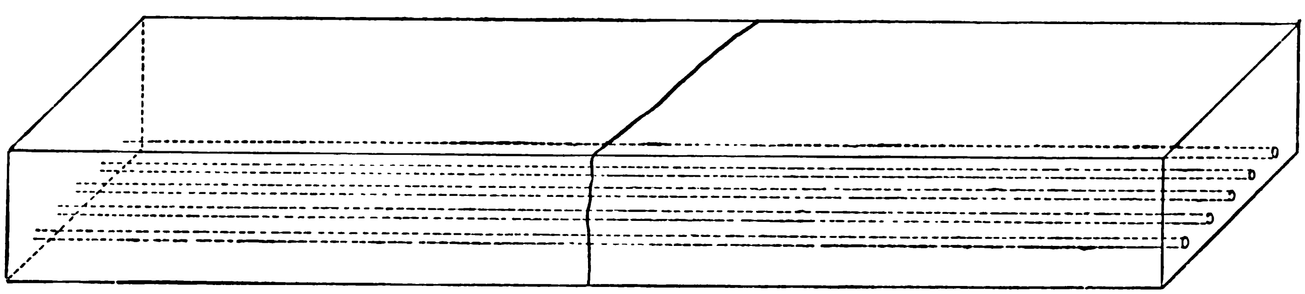
Kirk. No. "K 5549." Pl. A.

No. 11.



Kirk. No. "K 5550." Pl. A.

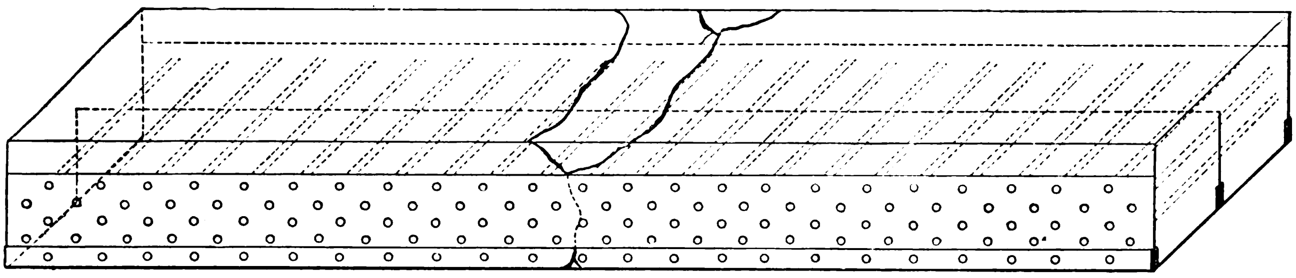
No. 12.



Kirk. No. "K 5548." Pl. A.

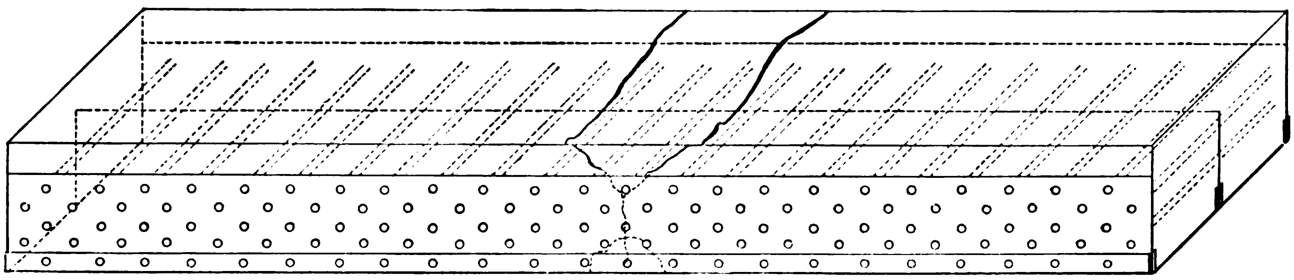
Plate G.

No. 13.



Kirkaldy's No. "K 5545." Plate A.

No. 14.



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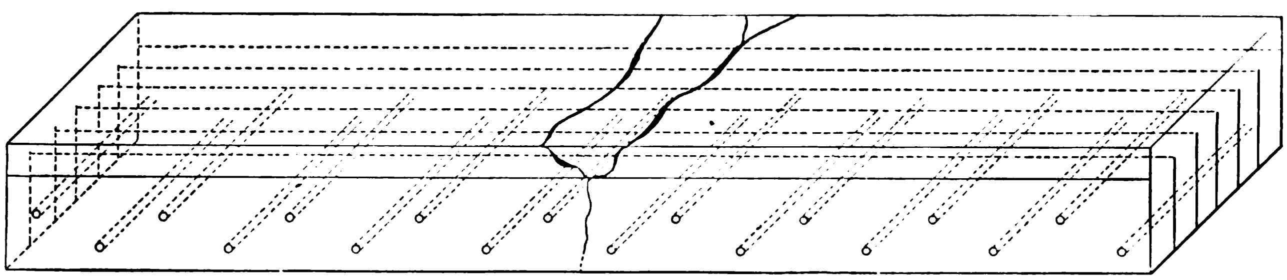
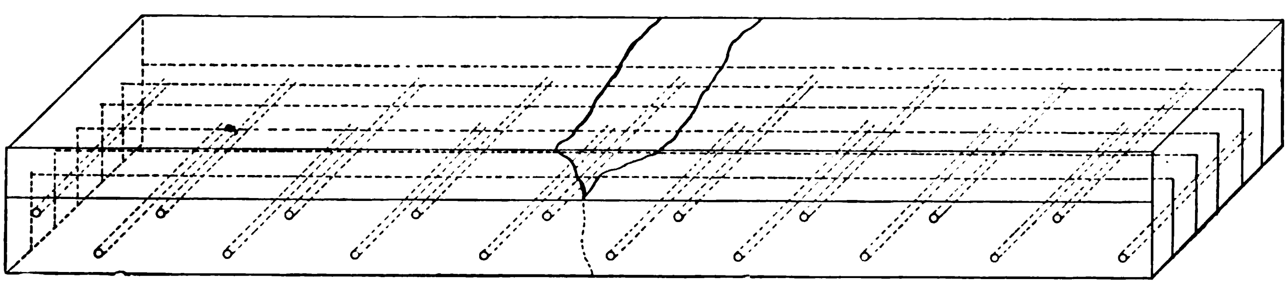
No. 15.



Kirk. No. "K 5549." Pl. A.

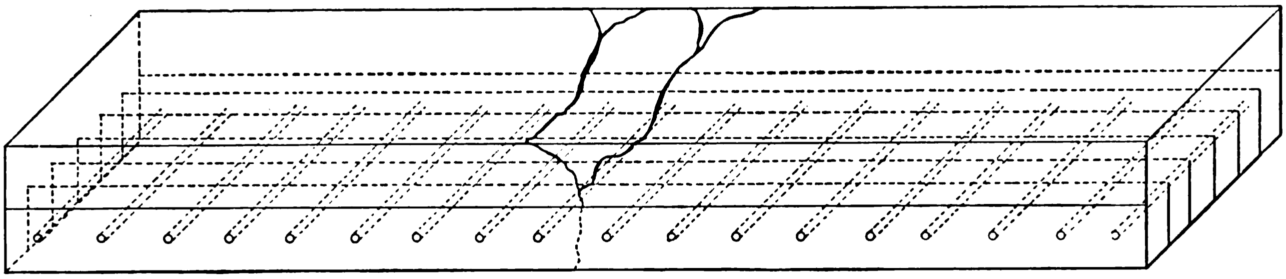
No. 16.



Kirk. No. "K 5543." Pl. A.

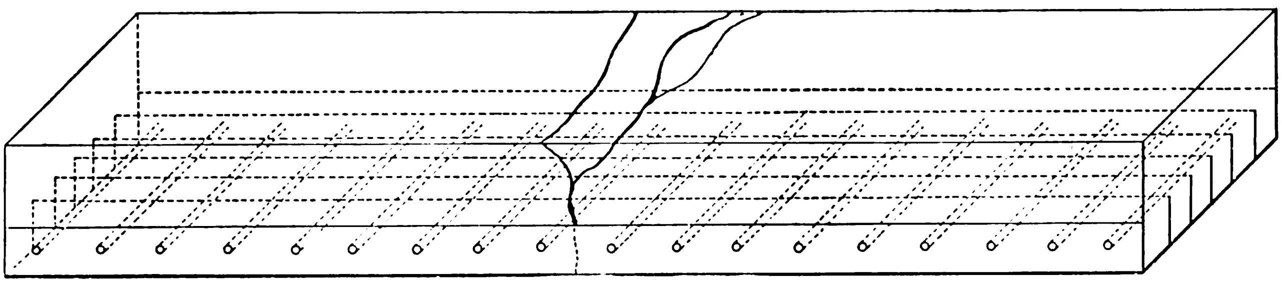
Plate II.

No. 17.



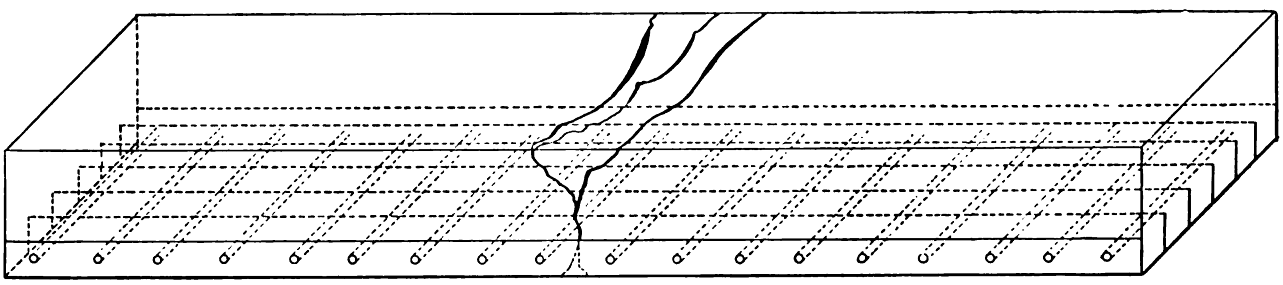
Kirkaldy's No. "K 55[illegible]8." Plate A.

No. 18.



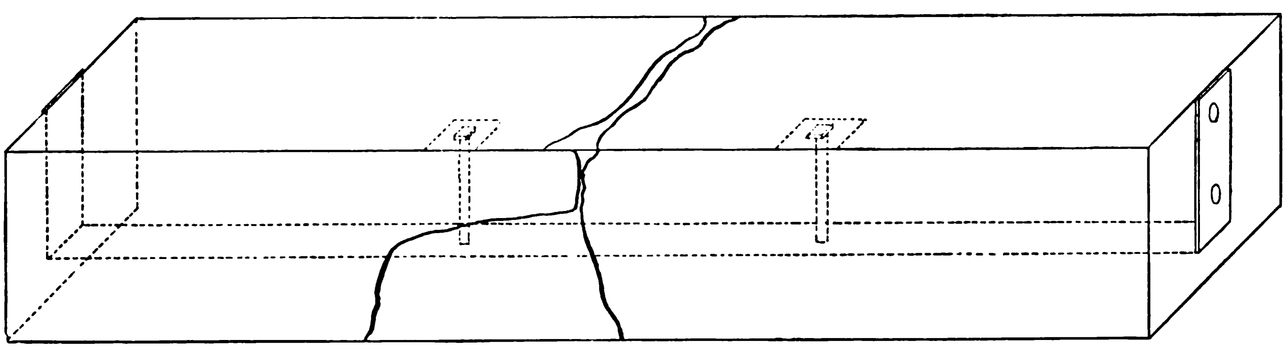
Kirk. No. "K 5541." Pl. A.

No. 19.



Kirk. No. "K. 5540." Pl. A.

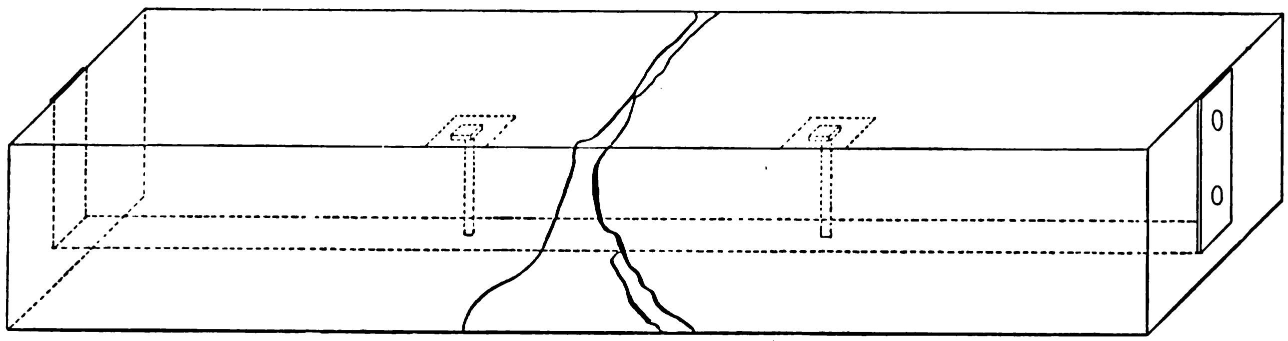
No. 20.



Kirk. No. "L 841." Plate C.

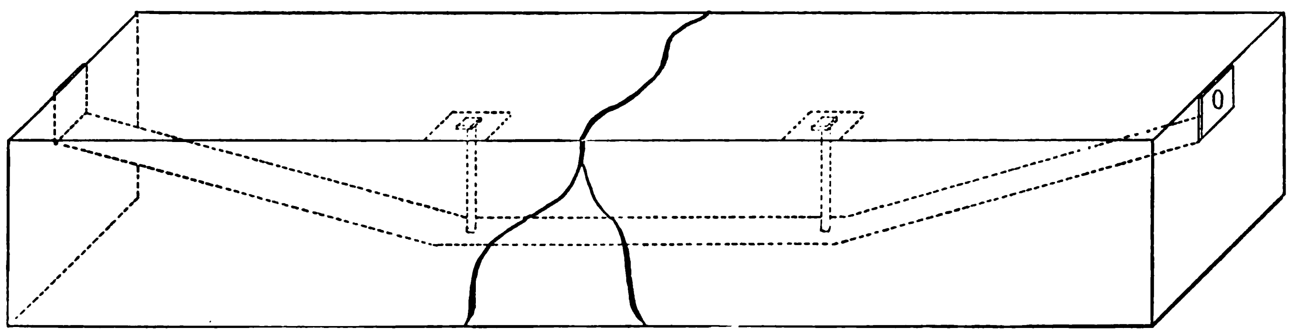
Plate I.

No. 21.



Kirkaldy's No. "L 872." Plate C.

No. 22.



Kirk. No. "L 842." Pl. C.

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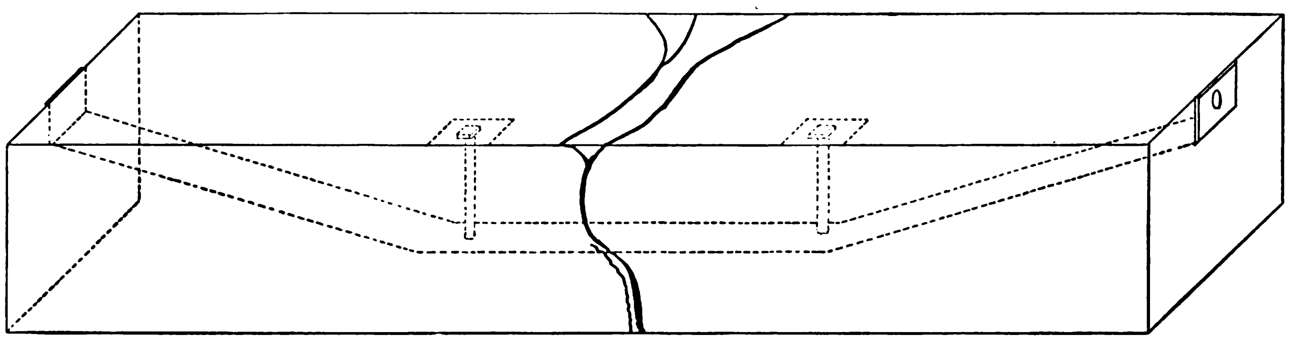

Kirk. No. "L 873." Pl. C.

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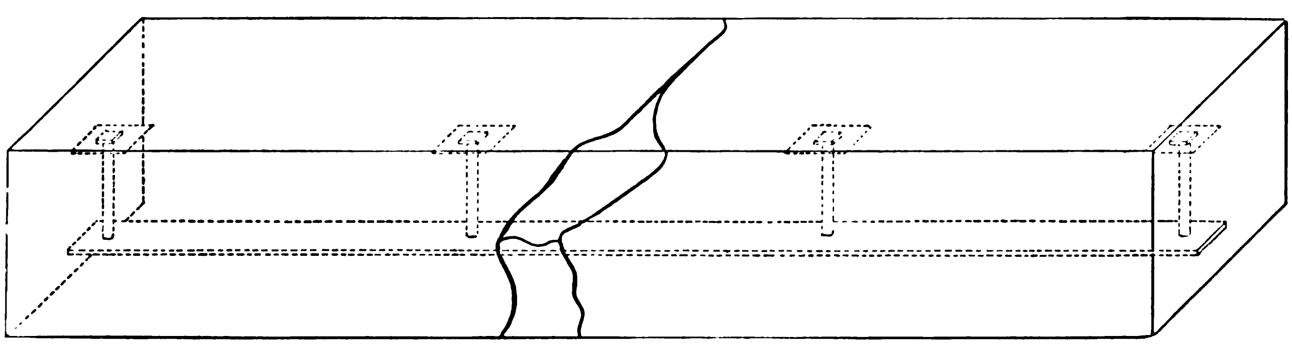
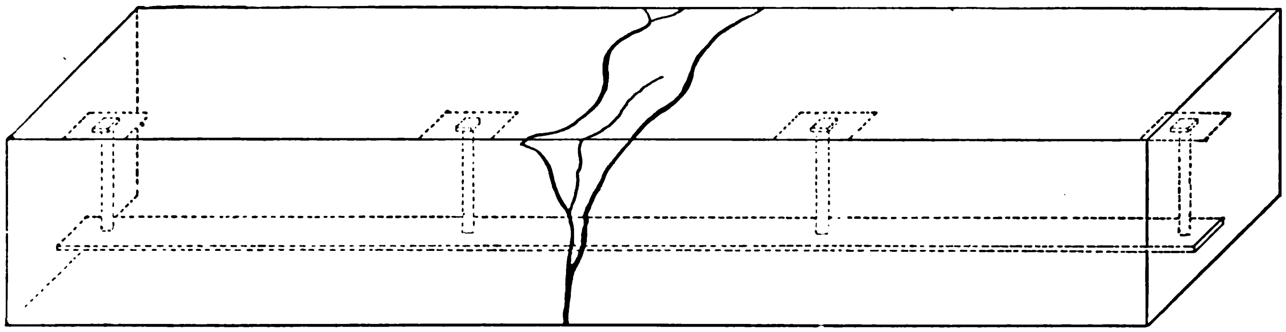


Kirk. No. "L 843." Pl. C.

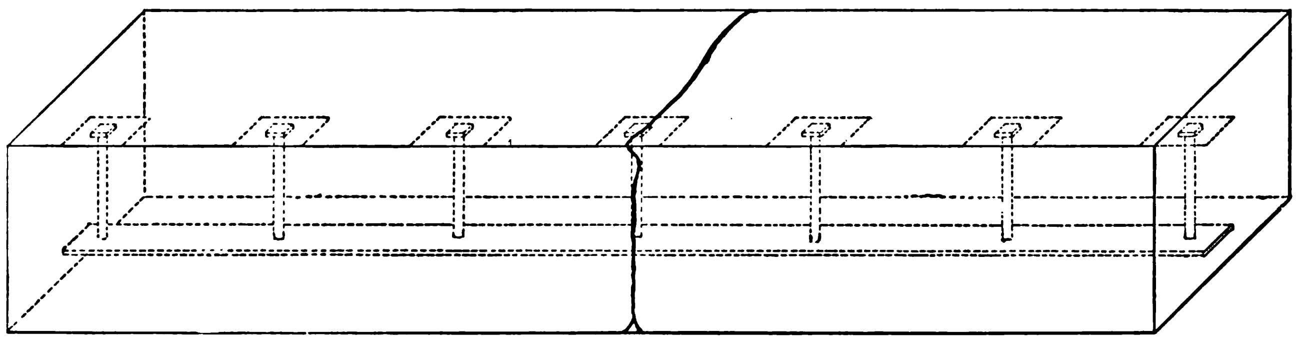
Plate J.

No. 25.



Kirkaldy's No. "L 874." Plate C.

No. 26.



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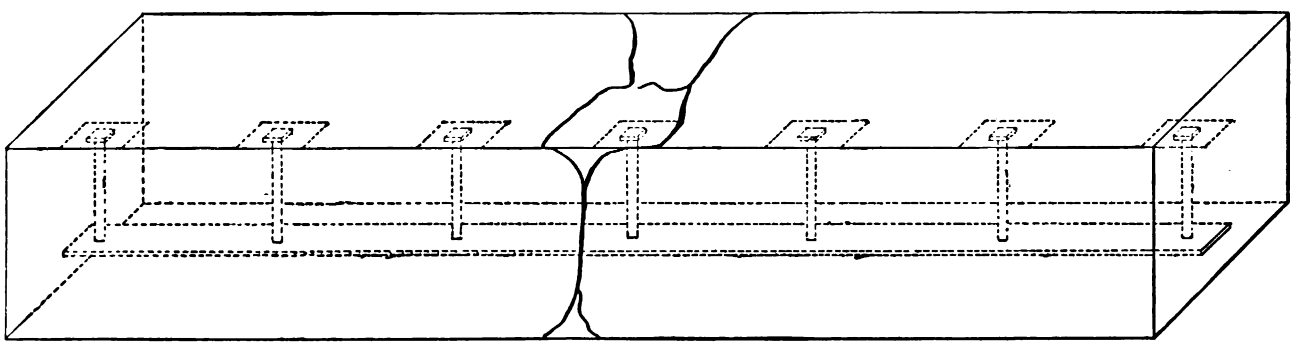
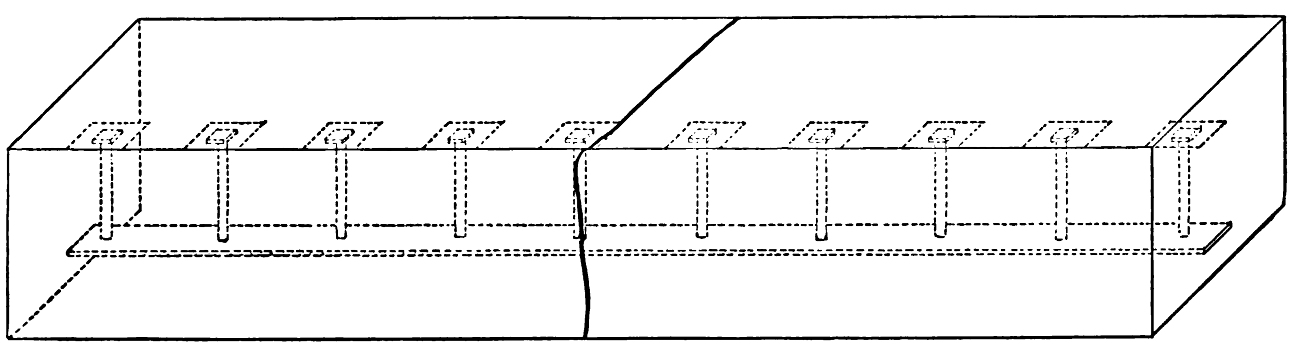


Kirk. No. "L 875." Pl. C.

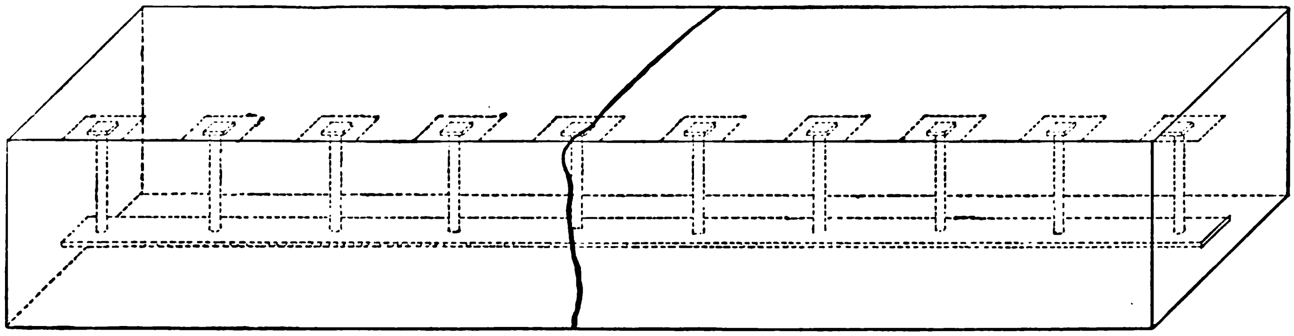
No. 28.



Kirk. No. "L 845." Pl. C.

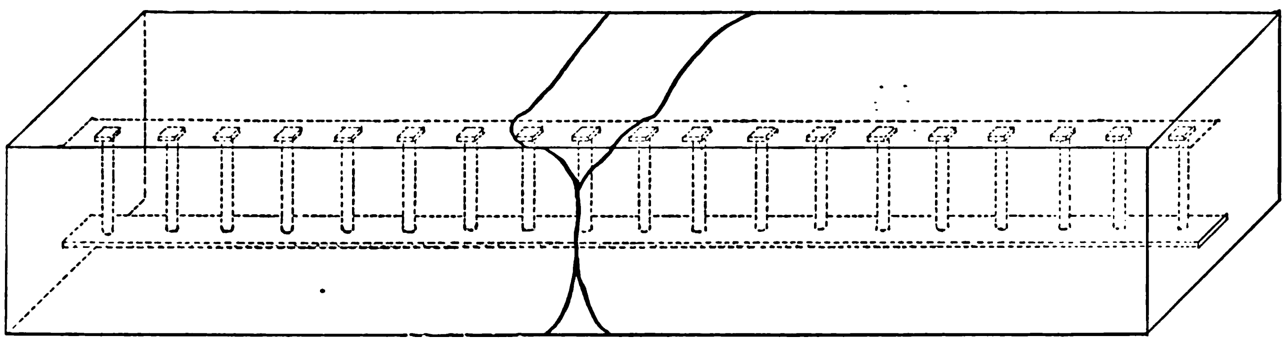
Plate K.

No. 29.



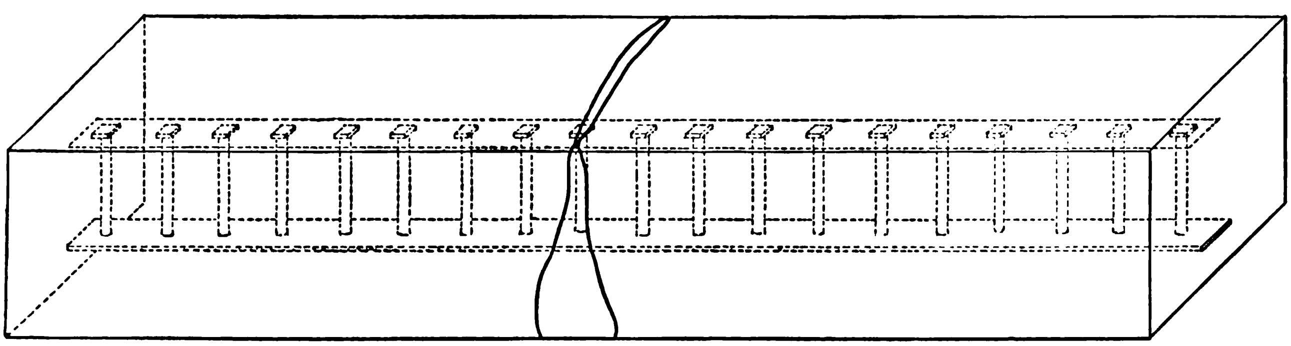
Kirkaldy's No. "L 876." Plate C.

No. 30.



Kirk. No. "L 846." Pl. C.

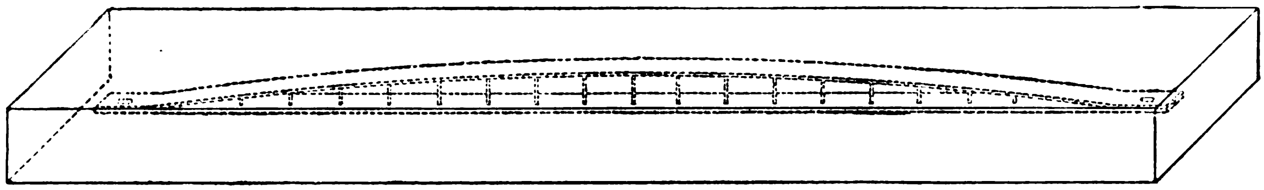
No. 31.



Kirk. No. "L 877." Pl. C.

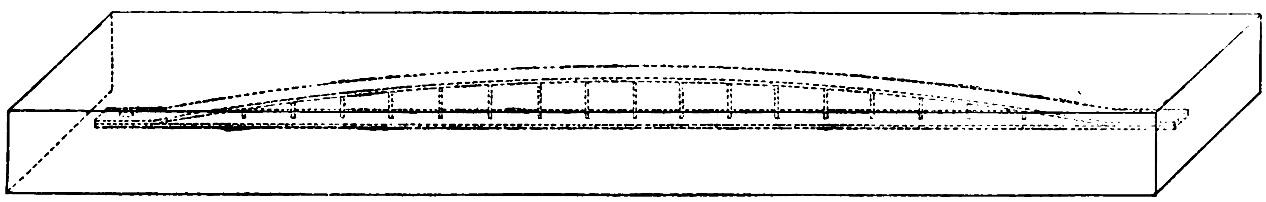
Plate L.

No. 32.



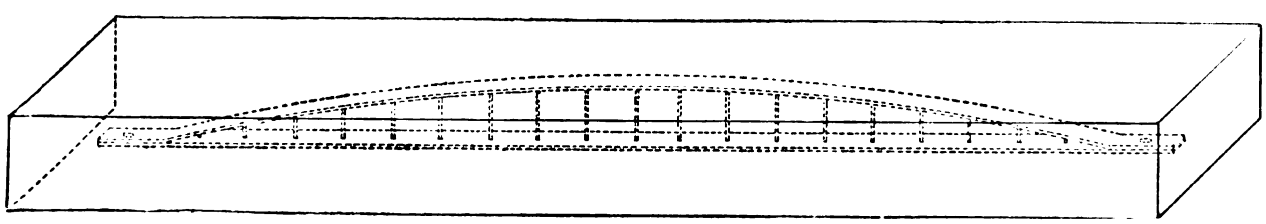
Kirkaldy's Nos. "L 2222, 2221, 2220." Plate B.

No. 33.



Kirk. Nos. "L 2223, 2225, 2224." Pl. B.

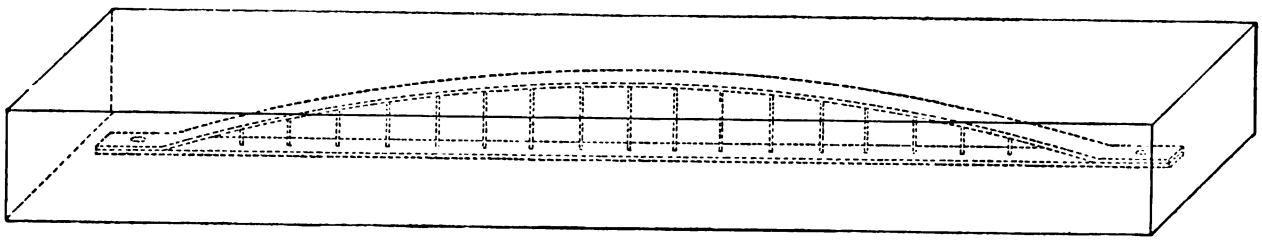
No. 34.



Kirk. Nos. "L 2228, 2226, 2227." Pl. B.

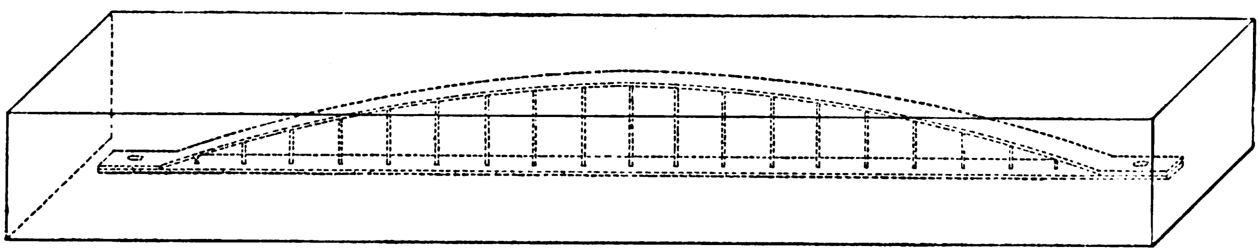
Plate M.

No. 35.



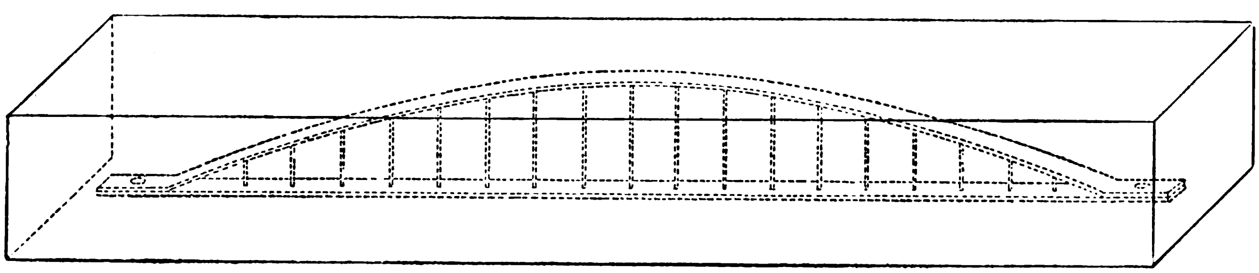
Kirkaldy's Nos. "L 2230, 2229, 2231." Plate B.

No. 36.



Kirk. Nos. "L 2233, 2232, 2234." Pl. B.

No. 37.



Kirk. Nos. "L 2236, 2235, 2237." Pl. B.

ROLLED BEAM CONSTRUCTION.

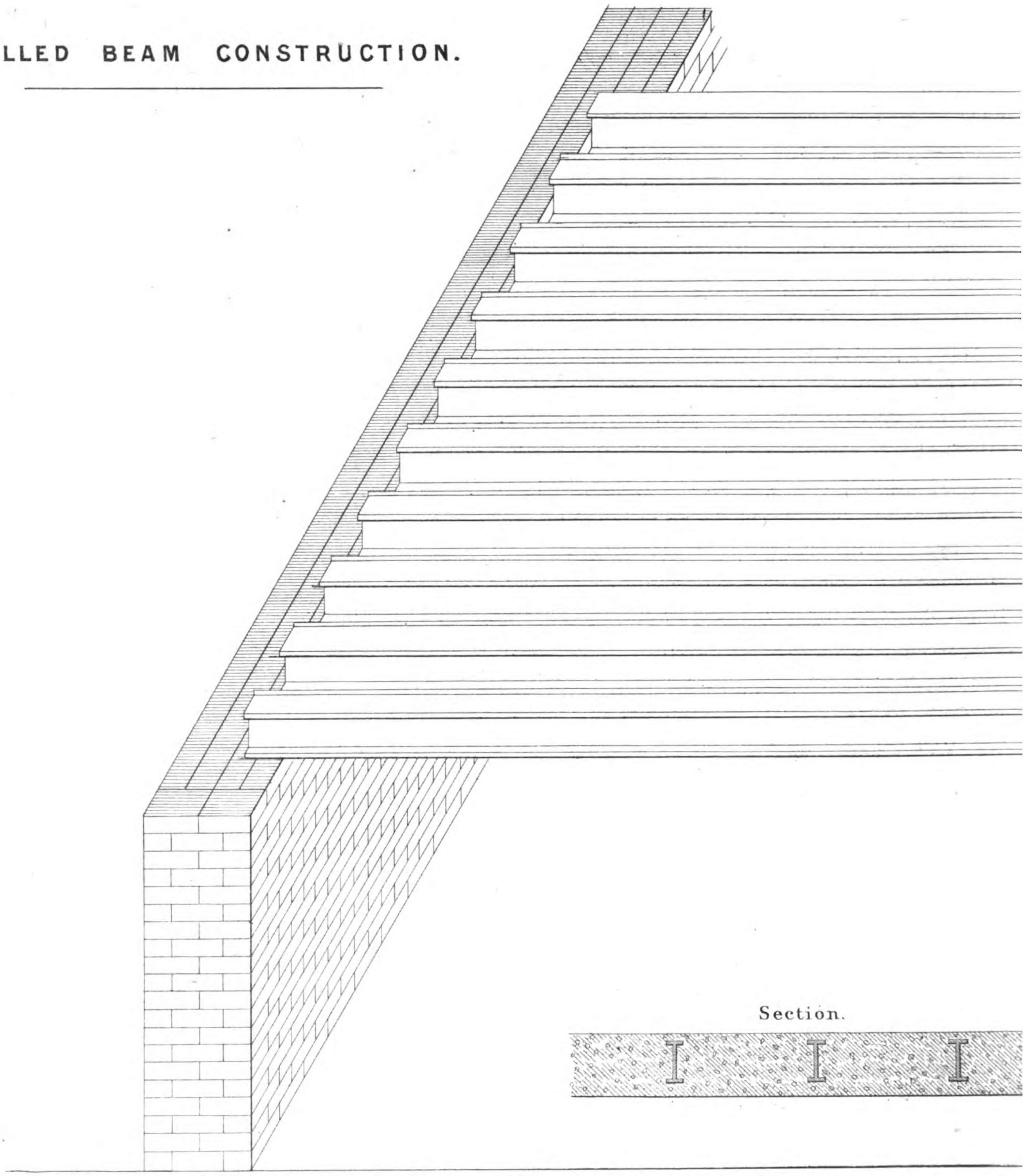
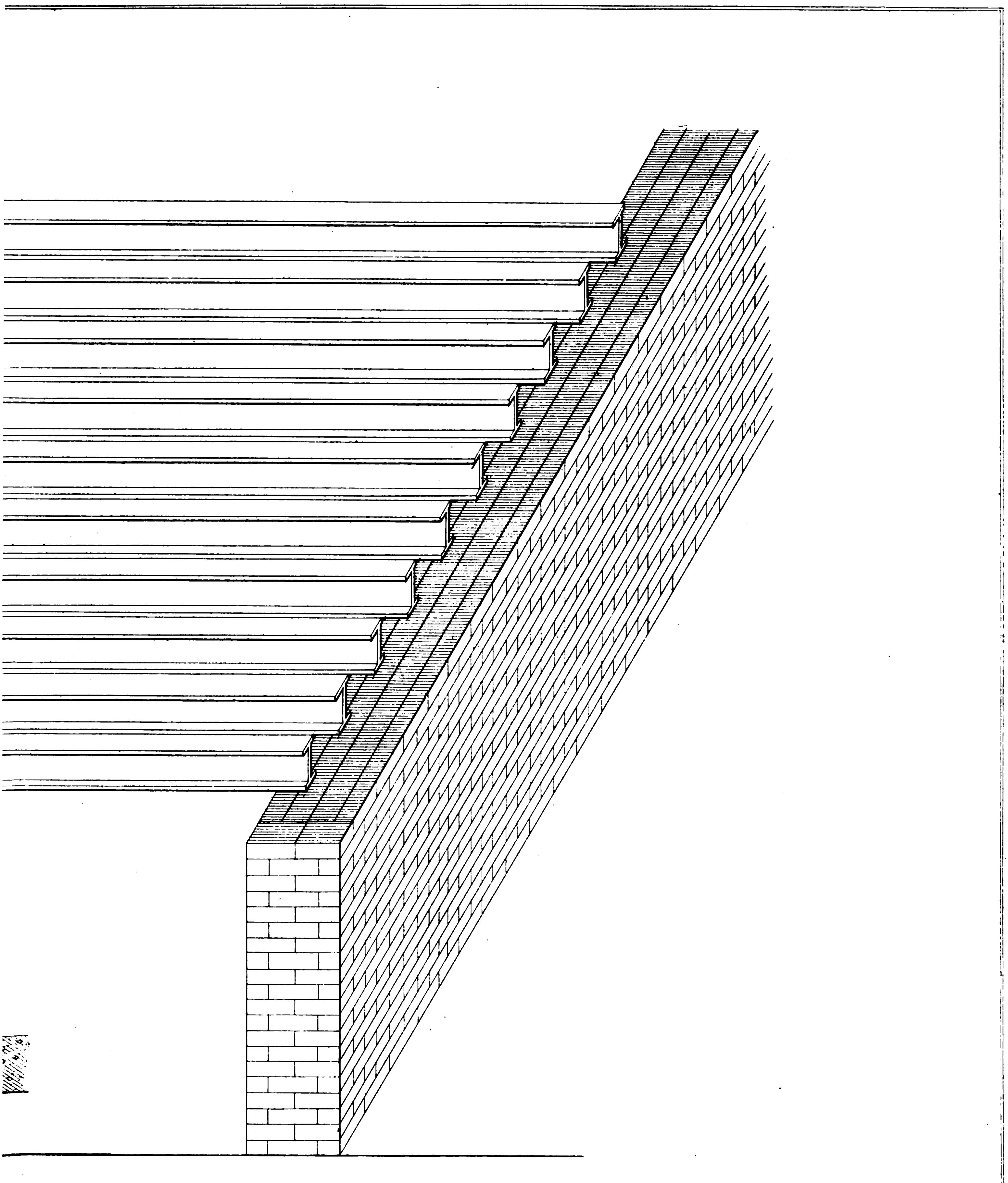


PLATE N.



GRIDIRON—TIE CONSTRUCTION.

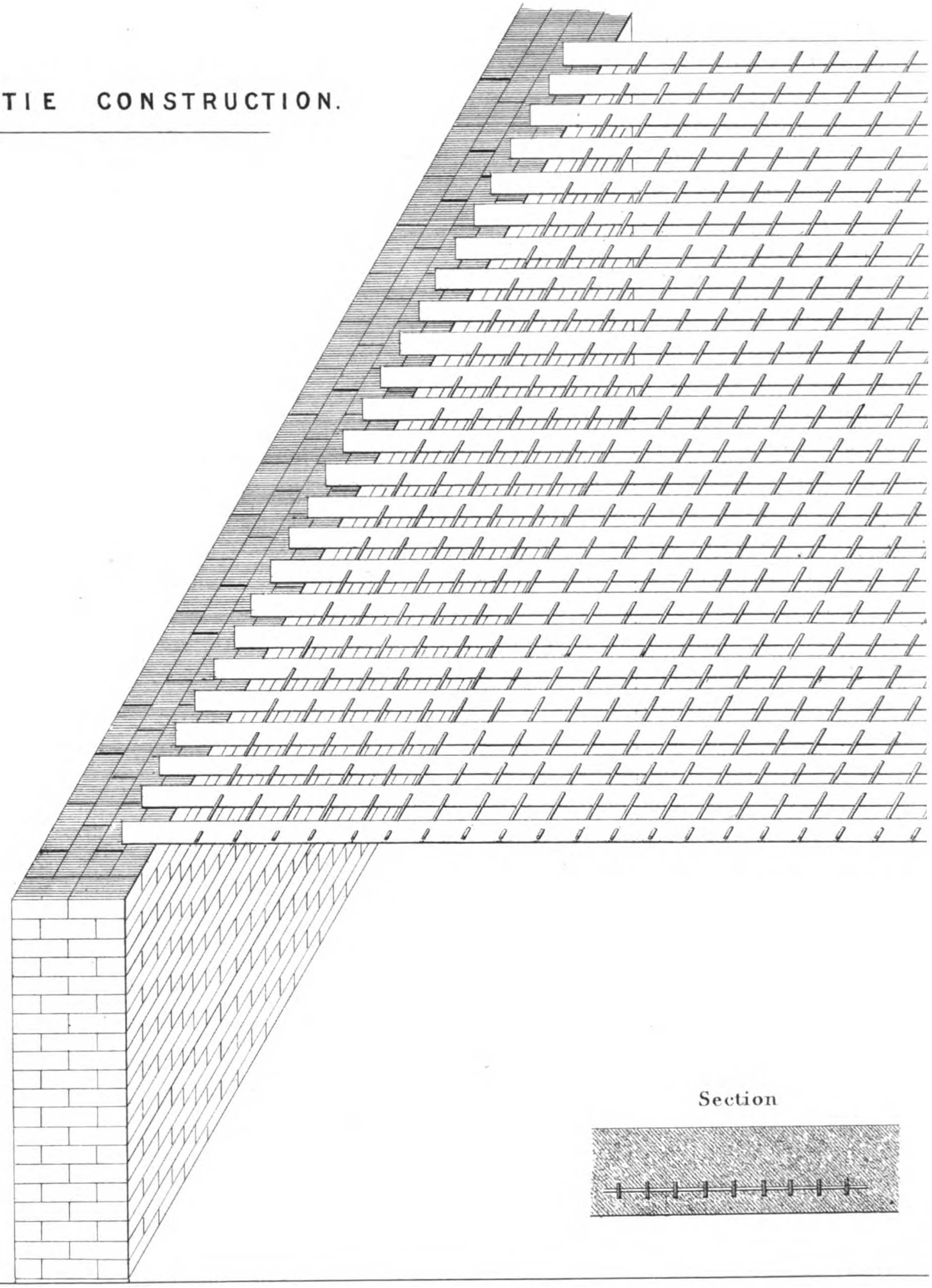
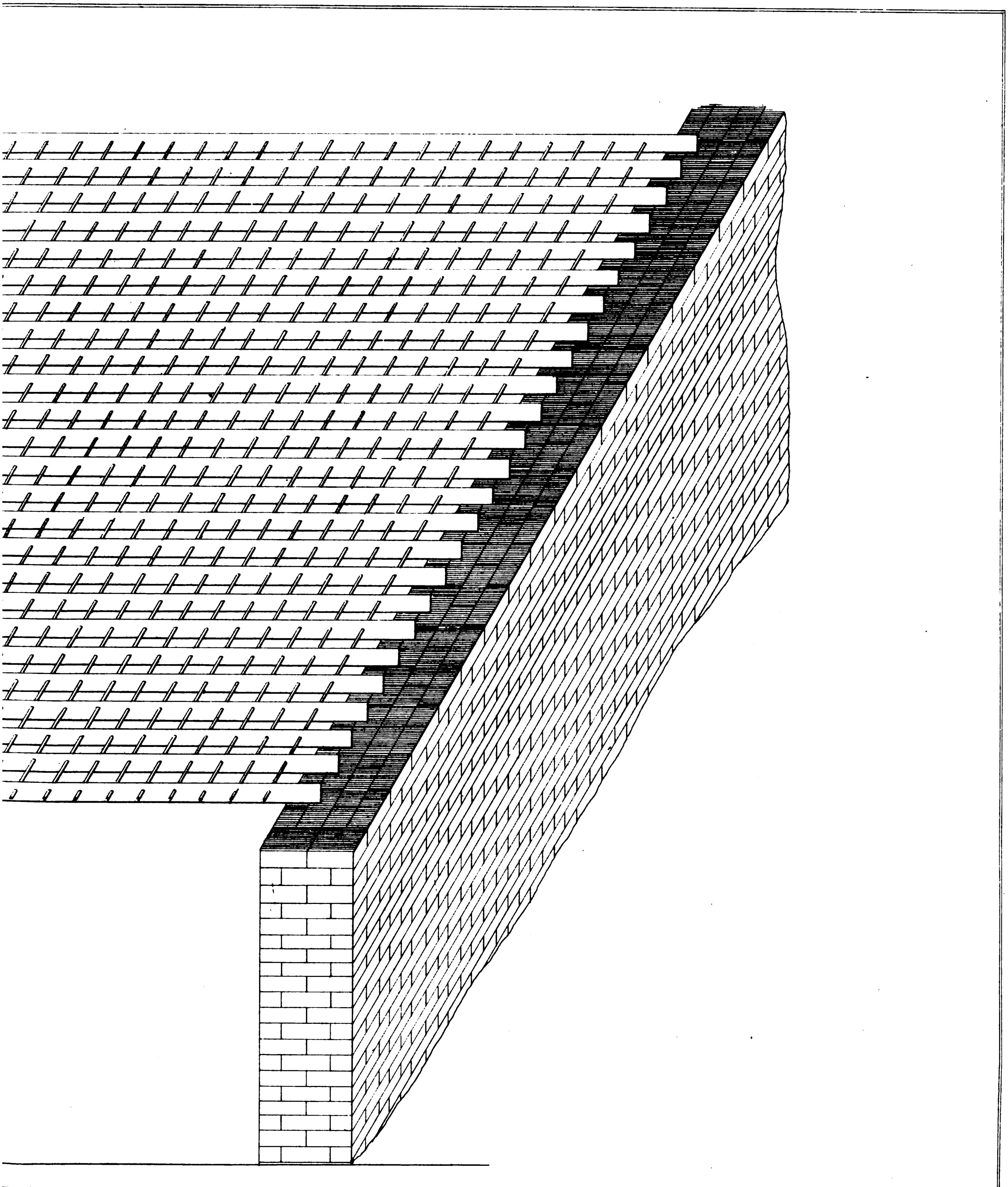
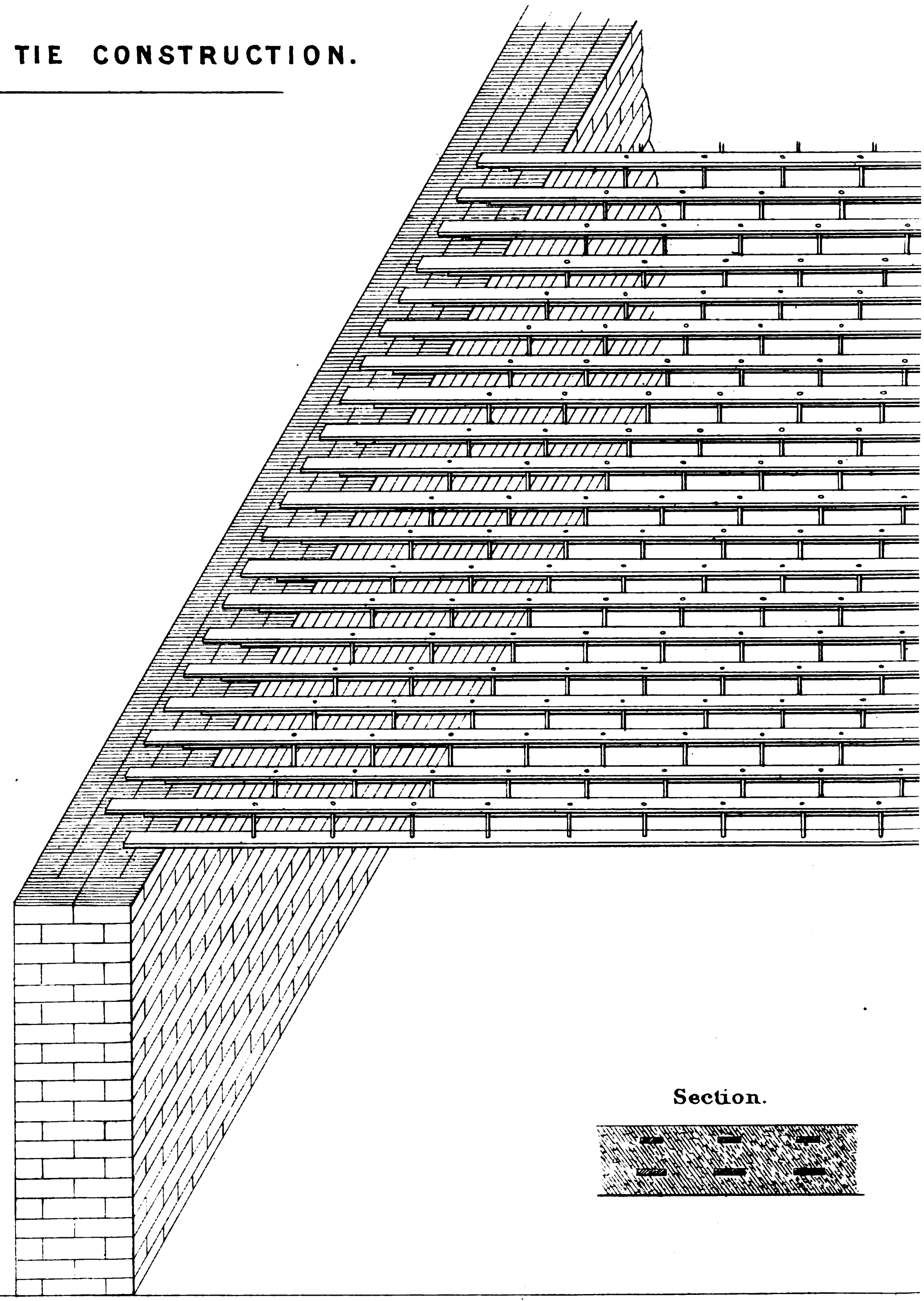


PLATE O.



TOP-FLANGE AND TIE CONSTRUCTION.



Section.

PLATE P.

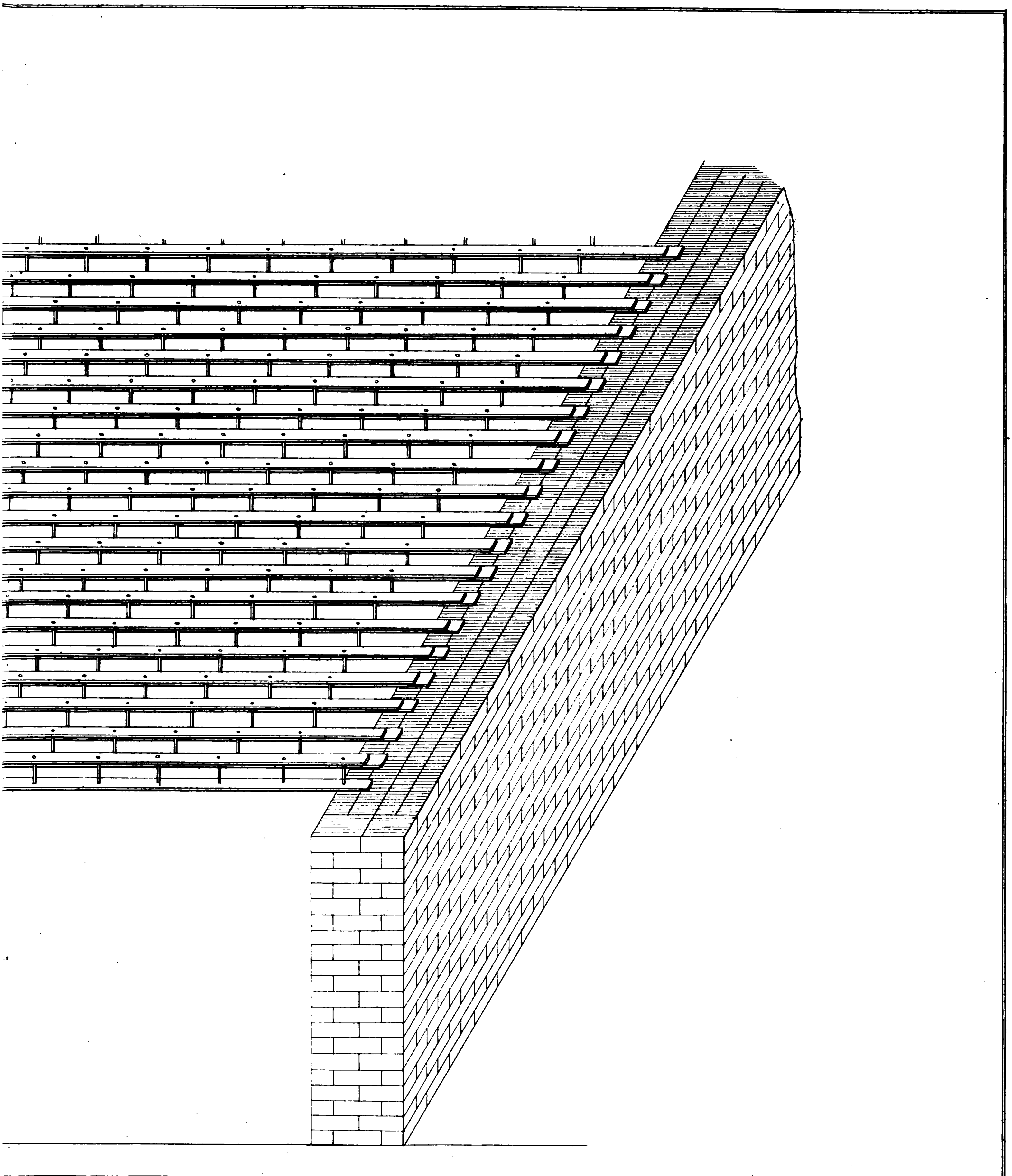


TABLE I.

ANALYSIS OF BEAM-TESTS, CONSTRUCTION, AND MATERIALS.

EXPERIMENTAL BEAMS, TESTED BY D. KIRKALDY, FOR THADDEUS HYATT.

In all these Beams the best London Portland Cement was used, and the Beams (except as mentioned on page 21) were made from 2 to 3 months before being tested.

No.	Testing Mark.	Description.	Iron used.	Dimensions. Length.	Dimensions. Width.	Dimensions. Depth.	Test. Bearing.	Test. Load.	Unit of beam strength.	Remarks.
			Lbs.	Ft.	In.	In.	Ft.	Lbs.	Lbs.	
1	K 5544	Cement only	—	6	12	8	5	3,192	20·7	
2	K 5537	Concrete only; two of crushed stock bricks and one of cement	—	6	12	8	5	1,484	9·7	
3	K 5559	Concrete as above, with firebrick slabs across, 2 in. thick and 11 in. apart, three $\frac{5}{8}$ rods through lower side, and two $\frac{3}{8}$ rods through upper side	31	9	8	9	8	13,512	211·1	Concrete crushed, rods not broken.
4	K 5558	Firebrick tiles 1 in. thick, with $\frac{1}{8}$ in. cement between each; two $\frac{5}{8}$ rods through lower side, and two through upper side	33	9	$10\frac{1}{2}$	9	8	10,513	120·5	Bricks parted, rods not broken.
5	K 5560	Firebrick tiles 1 in. thick with $\frac{1}{8}$ in. cement between each; two $\frac{5}{8}$ rods through lower side, and two through upper side	33	9	8	9	8	11,983	183·2	Broke through tile, rods not broken.
6	K 5561	Firebrick tiles, flatwise; seven courses, three lengths of hoop-iron $1\frac{1}{4}$ in. × $\frac{1}{16}$ in. between each of the two bottom courses, and vertical bolts through each tile	24	9	8	9	8	9,084	142·2	Bricks crushed, one tie out of six broken.
7	K 5542	Concrete beam, with five $\frac{3}{8}$ round iron ties at bottom, riveted to heel-plates, and two $\frac{3}{8}$ rods at top, five cross plates of sheet iron 12 in. × 6 in.	$26\frac{1}{2}$	6	12	8	5	12,348	105·0	Parted at sheet iron, ties not broken but pulled through.
8	K 5536	Cement beam, with five $\frac{3}{8}$ round iron ties at bottom riveted to heel-plates and two $\frac{3}{8}$ rods at top, five cross plates of sheet iron 6 in. deep.	$26\frac{1}{2}$	6	12	8	5	14,496	123·3	Parted at sheet iron, ties not broken, [pulled through.
9	K 5547	Concrete beam, same construction as No. 8 .	$26\frac{1}{2}$	6	12	8	5	13,583	116·3	Ties not broken, pulled through.
10	K 5549	Concrete beam, with five $\frac{3}{8}$ round iron ties at bottom, riveted to heel-plates; the two upper rods in the form of bent ties coming down between the bottom ties in the middle, and two plates across 12 in. × 6 in.	$22\frac{1}{2}$	6	12	8	5	15,478	131·6	Ties not broken; strength due to the bent ties furnished with threaded ends and nuts.
11	K 5550	Concrete beam, with five $\frac{3}{8}$ round iron ties at bottom riveted to heel-plates, and two $\frac{3}{8}$ rods at top, five cross plates of sheet iron 12 in. × 6 in.	$26\frac{1}{2}$	6	12	8	5	12,178	103·5	Ties not broken, very faulty, pulled through.
12	K 5548	Concrete beam, with five $\frac{3}{8}$ round iron ties at bottom, but no top rods and no heel-plates; rods upset only	10	6	12	8	5	9,274	—	Ties not broken, pulled through.

TABLE I. (*continued*).

13	K 5545	Concrete beam, with three plates of iron 6 in. × $\frac{1}{16}$ in., and 1 in. × $\frac{1}{4}$-in. ties riveted on both sides of each plate at bottom, the iron plates crossed by five ranges of $\frac{1}{4}$ wire 3 inches apart	$67\frac{1}{2}$	6	12	8	5	29,628	192·8	Concrete crushed, iron ties buckled but not broken.
14	K 5546	Concrete beam, same as No. 13, but wires 6 inches apart	60	6	12	8	5	28,022	182·4	Concrete crushed, iron ties buckled but not broken.
15	K 5539	Concrete beam, with seven plates of iron 6 in. × $\frac{1}{16}$ in. crossed by eighteen wire rods $\frac{1}{4}$ in. diameter	62	6	12	8	5	25,148	163·7	Iron broken at rivet holes.
16	K 5543	Concrete beam, with seven plates of iron 5 in. × $\frac{1}{16}$ in. crossed by eighteen wire rods $\frac{1}{4}$ in. diameter	52	6	12	8	5	25,868	168·4	Iron broken at rivet holes.
17	K 5538	Concrete beam, with seven plates of iron 4 in. × $\frac{1}{16}$ in. crossed by eighteen wire rods $\frac{1}{4}$ in. diameter	41	6	12	8	5	23,884	155·4	Iron broken at rivet holes.
18	K 5541	Concrete beam, with seven plates of iron 3 in. × $\frac{1}{16}$ in. crossed by eighteen wire rods $\frac{1}{4}$ in. diameter	31	6	12	8	5	21,222	138·1	Iron broken at rivet holes.
19	K 5540	Concrete beam, with seven plates of iron 2 in. × $\frac{1}{16}$ in. crossed by eighteen wire rods $\frac{1}{4}$ in. diameter	21	6	12	8	5	16,418	106·8	Iron broken at rivet holes.
20	L 841	Concrete beam, with flat iron tie $2\frac{1}{2}$ in. × $\frac{1}{4}$ in. placed 2 in. from bottom, ends turned up and riveted to heel-plates, and tie also supported by two $\frac{1}{2}$-in. bolts, $8\frac{1}{2}$ in. long and 23 in. apart	35	6	12	12	5	15,938	66·4	Concrete given way, tie moved in concrete but not broken.
21	L 872	Concrete beam, same as No. 20	35	6	12	12	5	20,346	84·8	Concrete given way, tie moved in concrete but not broken.
22	L 842	Concrete beam, same as No. 20, but with bent in place of straight tie	35	6	12	12	5	16,386	75·3	Concrete given way, tie not broken.
23	L 873	Concrete beam, same as No. 22	35	6	12	12	5	18,066	68·3	Concrete parted, tie not broken.
24	L 843	Concrete beam, with flat iron tie $2\frac{1}{2}$ in. × $\frac{1}{4}$ in. placed 2 in. from bottom, and supported by four $\frac{1}{2}$-in. bolts 23 in. apart; no heel-plates	38	6	12	12	5	16,344	68·1	Concrete crushed, tie drawn out.
25	L 874	Concrete beam, same as No. 24	28	6	12	12	5	19,328	80·5	Iron tie broken at bolt hole.
26	L 844	Concrete beam, with flat iron tie $2\frac{1}{2}$ in. × $\frac{1}{4}$ in. placed 2 in. from bottom, and supported by seven $\frac{1}{2}$-in. bolts, $11\frac{1}{2}$ in. apart	31	6	12	12	5	18,084	75·4	Tie broken at bolt hole.
27	L 875	Concrete beam, same as No. 26	31	6	12	12	5	17,110	71·3	Tie broken at bolt hole.
28	L 845	Concrete beam, with flat iron tie $2\frac{1}{2}$ in. × $\frac{1}{4}$ in. placed 2 in. from bottom, and supported by ten $\frac{1}{2}$-in. bolts 8 in. apart	33	6	12	12	5	19,024	81·6	Tie broken at bolt hole.
29	L 876	Concrete beam, same as No. 28	33	6	12	12	5	19,584	81·6	Tie broken at bolt hole.
30	L 846	Concrete beam, with flat iron tie $2\frac{1}{2}$ in. × $\frac{1}{4}$ in. placed 2 in. from bottom, and supported by nineteen $\frac{1}{2}$-in. bolts 4 in. apart	40	6	12	12	5	21,592	89·4	Tie broken at bolt hole.
31	L 877	Concrete beam, same as No. 30	40	6	12	12	5	18,866	78·6	Concrete crushed, tie not broken.

NOTE.—Concrete below the iron ties is not entered into the calculations of strength, but is considered as part of the load.

TABLE II.

APPLICATION OF PRINCIPLES OF NEW CONSTRUCTION TO FIREPROOF FLOORS AND ROOFS.

TABLES SHOWING THE STRENGTH AND DEPTH OF FLOORS FOR SPANS FROM 10 TO 40 FEET.

Standard Beams 12 *in. wide by* 10 *in. deep, to iron tie with iron* $2\frac{1}{2}$ *in. by* $\frac{1}{4}$ *in. placed flatwise; mean of three Beams, Nos.* 874, 844, 845, *broke with* 18,812 *lbs. at* 5 *ft. bearings; unit of Beam strength,* 78 *lbs.*

Spans of	10 Feet.		15 Feet.		20 Feet.		25 Feet.		30 Feet.		35 Feet.		40 Feet.	
Depth to bottom of iron ties . . . . in.	6	8	9	11	12	15	15	19	18	23	21	27	24	32
Total depth, giving 3 in. for protection ,,	9	11	12	14	15	18	18	22	21	26	24	30	27	35
Iron used per square foot . . . . . lbs.	1·8	2·4	2·7	3·3	3·6	4·5	4·5	5·7	5·4	6·9	6·3	8·1	7·2	9·6
Weight of Concrete per square foot . ,,	81	99	108	126	135	162	162	198	189	234	216	270	243	315
Ultimate strength in centre of 1 ft. width ,,	3,369	5,990	5,054	7,550	6,739	10,530	8,424	13,515	10,108	16,505	11,793	19,495	13,638	23,961
,, ,, distributed ,, ,, ,,	6,739	11,980	10,108	15,100	13,478	21,060	16,848	27,030	20,216	33,010	23,586	38,990	27,276	47,922
,, ,, per square foot gross ,,	674	1,198	673	1,006	674	1,053	674	1,081	673	1,100	673	1,114	682	1,198
,, ,, per square foot net . ,,	593	1,099	565	880	539	891	511	883	484	866	457	844	439	883
Safe net load at $\frac{1}{4}$ of ultimate strength ,,	148	275	141	220	135	223	128	221	121	216	114	211	110	221

Standard Beam 12 *in. wide by* 8 *in. deep, with* 7 *blades of iron* $2\frac{1}{4}$ *in. by* $\frac{1}{16}$ *in. placed vertically; No.* 5,540 *broke with* 16,418 *lbs. at* 5 *ft. bearings; unit of Beam strength,* 107 *lbs.*

Spans of	10 Feet.		15 Feet.		20 Feet.		25 Feet.		30 Feet.		35 Feet.		40 Feet.	
Depth to bottom of iron ties . . . . in.	5	6	7	10	10	14	12	17	15	20	18	24	21	28
Total depth, giving 3 in. for protection ,,	8	9	10	13	13	17	15	20	18	23	21	27	24	31
Iron used per square foot . . . . . lbs.	2·2	2·7	3	4·4	4·4	6·2	5·4	7·5	6·6	8·8	7·9	10·6	9·2	12·3
Weight of Concrete per square foot . ,,	72	81	90	117	117	153	135	180	162	207	189	243	216	279
Ultimate strength in centre of 1 ft. width ,,	3,210	4,622	4,194	8,560	6,420	12,583	7,395	14,842	9,630	17,120	11,886	21,132	14,156	25,166
,, ,, distributed ,, ,, ,,	6,420	9,244	8,388	17,120	12,840	25,166	14,790	29,684	19,260	34,240	23,772	42,264	28,312	50,332
,, ,, per square foot gross ,,	642	924	559	1,141	642	1,258	591	1,147	641	1,141	708	1,207	708	1,258
,, ,, per square foot net . ,,	570	843	469	1,024	525	1,105	456	967	479	934	519	964	492	965
Safe net load at $\frac{1}{4}$ of ultimate strength ,,	142	211	117	256	131	276	114	242	120	233	129	241	123	241

NOTE.—Concrete below the Iron Ties is not entered into the calculations of Strength, but is considered as part of the Load.

EXPERIMENTS WITH IRON AND CONCRETE.

From THE BUILDER, *March* 9, 1878.

SOME of those who took part in the first Architectural Conference in 1871 may remember that the subject of fireproof materials and construction was then discussed in a very practical manner, and it was, perhaps, on that occasion that several materials commonly called "fireproof" were first openly discredited in regard to that pretension. On the same occasion, also, a method of construction was advocated as alone deserving to be called really fireproof. Our note at the time (*Builder*, June 3, 1871) records it thus:—

"Mr. Fowler brought forward, also, a specimen of new fire-resisting construction for beams and bearers, manufactured by Messrs. Allen & Sons. This consisted of a cement concrete formed of a small proportion of Portland cement and a considerably larger quantity of breeze (foundry refuse) worked up into the shape of a kind of concrete joist, with a stiffener of thin plate-iron in the centre. From the effect of the concrete in always keeping the plate of iron precisely on edge in the direction of its greatest strength, a very thin piece of iron might be depended upon for giving a great amount of stiffness. Only 10 ft. or 12 ft., however, was named as the maximum bearing for joists of this kind, and as the ends of these must rest on some larger (probably iron) beam, the question of stability of the construction against fire seemed, after all, to turn on the manner in which the main beam behaved."

Remembering, however, our impression at the time as to the really fireproof character of the method of construction referred to, and our doubt as to how far it would be practically taken up (for improvements of this kind are so often just mentioned and then forgotten), it is with some interest that we notice a small, thin, quarto volume, very [illegible] shows the results of a systematic examination of and experiment upon this very principle, only carried further and with important additions in regard to detail. The book referred to, which is printed for private circulation,* is by Mr. Thaddeus Hyatt, who has been for more than twenty years engaged in investigating the subject of fireproof flooring. Mr. Hyatt calls attention to the radical error which has long pervaded attempts at fireproof flooring, of leaving the main iron bearers or beams more or less exposed, so that the very main portion of the construction is liable to injury from fire; and it is in consequence of this that firemen have, as he assures us, and as we believe is the case, a dread of so-called fireproof structures more than of those which are not called so. That neither iron nor stone can rank as a fireproof material is, indeed, becoming a commonplace with constructors now; and it has been laid down by some of those most conversant with the subject practically that no material can be called fire-*proof*, only fire-*resisting*. Mr. Hyatt, however, seems to have actually solved the problem of a fireproof material. The question remains as to its suitability for extensive adaptation from an architectural point of view.

The chief specialities of the method laid down in Mr. Hyatt's pages are threefold: first, the *entire* encasing of the iron which forms the pith of the construction in concrete; both the main beams and the thin slips of iron which take the place of joists being completely imbedded; second, the employment of a new and professedly superior Portland cement, the systematic manufacture of which awaits at present the formation of a company to work it, but which is stated experimentally to be more unaffected by fire than any existing cement; and lastly, and by far the most important point in the book, the discovery that the iron can be used in combination with concrete as a *tie* only, and in tension, and that the concrete itself is sufficient to form the web and compressile part of the compound beam. This is a most important advance on the mere idea of a central iron core giving bearing power, and stiffened against buckling by the action of the concrete. Without reproducing some of Mr. Hyatt's diagrams, it would be difficult to render precisely intelligible the details of his experiments, and the reasoning deduced from them. It must suffice to say that he shows that, in theory, the compressive resistance of the amount of concrete which can [illegible]on packed around and above a piece of [illegible] iron representing the lower flange only of [illegible]pressive beam, is rather greater than the [illegible]ange of the resistance of the web and upper [illegible] proportions of beam would be, in the ordin[illegible] sectional area; that, theref[illegible]e, when the beam is thus imbedded, the up[illegible] portion, which is in compression, is waste [illegible]ength, and can be dispensed with, the co[illegible]crete doing its work. The advantage in economy of material and in fireproof character is of course obvious; and that the facts bear out the theory is shown by the statement, in diagrams and figures, of the results of a number of tests carried out for the author by Mr. Kirkaldy; the composition of the various beams, and the relative proportions of iron and concrete, are shown in good-sized diagrams, with the results of the tests, from which it is evident that the iron coring is proportionately stronger the more it is concentrated at the lower edge of the beam; in other words, the more completely it is in the position of *tie* iron. The most satis- [illegible] amount of material and results, seems to have been one in which the iron appears in the shape of a few thin slips 2 in. deep laid parallel at a distance of 2 in. from one another, on edge, the lower edges coinciding with the soffit of the cement beam, which is 8 in. or 9 in. thick. An increased depth in the iron raises the breaking load of the beam, but by no means in proportion to the increase of scantling in the iron. The concrete is held in position in the first instance by a series of transverse wires passing through and connecting the iron slips at right angles; and these wires also serve the very important purpose of mechanically connecting the metal and the concrete so as to incorporate them in one system, and prevent any sliding the one over the other when the beam is loaded so as to produce a sensible deflection. But will the two materials, thus forced into mechanical connexion, work together harmoniously under the influence of heavy strains producing extreme tension and compression? This question naturally occurs; and this is Mr. Hyatt's answer:—

"The compressibility and extensibility of cement were investigated by experiments with a bar of hard cement ten days old. This bar was made sufficiently long to admit of the insertion therein of two fixed points 50 in. apart, one of the points being the bent end of a rod lying upon the outside of the bar of cement and parallel with it, and which rod extended to within a short distance of the other point, thus leaving a space sufficiently small for accurate measurement on the cement being subjected to pressure. To prevent bending, the cement bar was placed in a frame fitting loosely about it, and yet sufficiently tight for the purpose. The load was then applied gradually by means of a lever, the actual compression from time to time being ascertained by tapering pieces, which were measured by Holtzapffel's thousandths gauge. In this way the compression was ascertained to amount to ·048 in 50 in. with a load of 1,000 lb. per square inch, the bar returning to its original

[illegible]s the length on removal of the load. Thi[illegible]gth for ratio of expansion as ·00096 o[illegible] in round 1,000 lb. per square inch, o[illegible]t of length; numbers, the one-thousandt[illegible]sive strength is and if the ultimate co[illegible] inch (which is pertaken at 2,000 lb. per [illegible]sidering that concrete haps the safe figur[illegible]at cement, will form the in practice, and [illegible]r of the compound beam) compressive [illegible]ession will be the $\frac{1}{500}$ part of the final [illegible]ow, as wrought iron is found to its lengt[illegible] $\frac{1}{10000}$ part of its length for each ton of exten[illegible]r square inch, it follows that at 20 tons, st[illegible]y prior to rupture, it will extend the $\frac{1}{500}$ [illegible]art of its length, or about the same compressibility as cement; the effect of which in the compound beam is to keep the neutral axis at the centre line of the beam, the entire tensional strain being thus thrown upon the metal tie. The results of the Kirkaldy tests already alluded to confirm these conclusions."

There is another form of combination which Mr. Hyatt shows in some of his sections, in which the iron is arranged in two flat layers one over the other, as if the two flanges of the iron beam were left and the web removed, the concrete taking its place. This has advantages in certain positions, where it is desired to keep the thickness of the floor at a minimum. There are diagrams also of brick beams formed by square flat bricks placed on edge with their flat sides in contact, and the whole connected by iron tie-rods run through and bolted at either end, and taking the tensile strain, the upper edges of the bricks taking the compression. These do not appear to have behaved satisfactorily under tests, nor should we have expected it.

We can only quote one more passage as to the resistance of the Portland cement concrete to [illegible] we presume the experiment refers to the new Portland cement mentioned by the author; the test is certainly severe. A tie-metal and cement floor, in gridiron form, was laid down, and a furnace formed under it; the floor loaded to the extent of about 300 lb. to the square foot over the surface, which caused a deflexion of about $\frac{1}{16}$ in. in a span of 12 ft. "The fuel was arranged to form an incandescent bed 6 in. thick at 12 in. below the under-surface of the concrete slab. The fire being kindled at six o'clock in the morning, had by eleven become an intense heat perfectly uniform over the entire surface, and the bottom of the concrete was also at a glowing red heat all over. At this intensity the fire was kept up until four p.m., a period of ten hours from the lighting of it. During this time the slab had deflected $\frac{3}{8}$ in. A stream of cold water was now thrown forcibly against the bottom of the slab for a period of fifteen or twenty minutes, by means of a garden force-pump, and the load then removed. On examining the underside of the section it was found uninjured; and the next morning, being then entirely cold, the deflexion had disappeared, the slab having returned to its former level. In order to confirm these results, a second trial was made; this time the load was left upon the slab, which, during the firing, deflected as before, but upon cooling returned to its original level, *lifting the load with it*. In proof of the heat of the furnace it may be mentioned that in the course of this experiment the faces of all the side bricks in actual contact with the fire were melted."

The book is an exceedingly useful and suggestive one; so much so that we rather regret that it has not been published in a manner to render it more available for general circulation. One mistake we noticed; on page 16, lines 6, 7, the test numbers "874, 844, 845, Plate C," do not correspond with the numbers of the enlarged examples on plates I, J, K, to which the reader is referred; there has been some error in the references.

* An Account of some Experiments with Portland-cement Concrete combined with Iron, as a Building Material, with reference to Economy of Metal in Construction, and for Security against Fire in the making of Roofs, Floors, and Walking Surfaces. By Thaddeus Hyatt. London: Printed, for private circulation, at the Chiswick Press. 1877.

Wyman & Sons, Printers, 74-5, Great Queen Street, London, W.C.

bankment. The only essay received on the architectural treatment of concrete was not thought worthy of a prize.

CONCRETE AND IRON AS A BUILDING MATERIAL.*

A VERY interesting series of investigations have been lately made by Mr. Thaddeus Hyatt, well known as the inventor and manufacturer of the "lens light," upon Portland cement concrete in combination with iron, the endeavour being to explode the now recognised fallacy that iron is a fireproof material, and to show that its use in the form of iron beams in concrete floors is a perversion of its natural capacity when exposed to the action of fire and also a waste of metal. Mr. Hyatt well observes that Fairbairn, in his work on the "Application of Cast and Wrought Iron to Building Purposes," has led a great many to believe that iron is fireproof, and that all so-called "fireproof" floors that have ever been made, with only one exception—the Safe Deposit Building—have been constructed in accordance with this belief. He points out how this fallacy has vitiated every floor construction made from Mr. Fairbairn's time to this. We are ready to acknowledge, as indeed any one practically acquainted with the subject must, the failure of those systems which combine iron in such a way as to expose it to the action of fire, and especially the danger of exposing the lower flanges of girders, as we find to have been the case in all earlier systems of so-called "fireproof" construction. Softened, indeed, by heat the lower flange yields as a tie, and the girder no longer performs its function. The author, like other recent investigators, shows that if we protect this vital part of the girder from the heat by covering it or protecting it in a casing of concrete, properly compounded, a floor can be constructed equal in its fire-resisting qualities to those of the best fire-proof safes. Our readers will say they know this already, and that there have been several capital systems introduced lately which completely immerse the iron in concrete or cover it in a casing of some non-conducting material (by the way, the author has omitted to refer to the best and latest of these), but Mr. Hyatt has gone further, and shown how mere flat ties and cross bars inserted in the floor or beam of concrete below the neutral axis can be made to perform the office of resisting tension, the most vital force to be dealt with, simply and inexpensively. In his new building in the Farringdon-road (illustrated in the work before us) the author shows a massing of the fireproof materials at the ceiling level, the main girders being completely embedded in concrete. In the "Lens-lights" works, Mr. Hyatt has succeeded in developing the principle in the construction of illuminating fireproof floors and roofs, and "illuminating gratings," under the name of the "New Stone Light." In some of these floors the ceiling is upheld by series of blades of iron, which are notched upon the lower flanges of cross joists, and through these blades or ceiling holders wires are inserted, forming a net-work to hold the concrete which completely covers the iron both on the top and bottom. But a more simple, and quite as effective, floor is obtained by omitting the floor joists and substituting flat tie-irons for them, which act as the tensile member, while the concrete itself becomes the compressive member of the beam or slab. This, then, is the principle of Mr. Hyatt's system—one very similar to the plan used by Mr. Matthew Allen, of Tabernacle-walk and Stoke Newington, and described by us some years ago. Flat bars or ties of iron are introduced about 2in. or 3in. deep, and ¼in. thick, placed about 6in. apart, through which rods pass every 2in. to 3in.; these rest upon rolled joists placed about 3ft. from centres, and the whole embedded in concrete. The author proceeds to explain, in a very intelligible form, and by the aid of excellently drawn illustrations, the rationale of this system. One important point is the relative amounts of compressibility between concrete and iron. The compressibility of concrete, and also its resistance to extension, have been investigated by the author. He used a bar of cement ten days old, fitted into a frame loosely to prevent bending, and the results were ·048in. in 50in. in length, with a load of 1,000lb. per square inch, the bar returning to its original length on removing the load. Thus the ratio of expansion was, roughly, the 1000th part of length, and if the ultimate compressive strength is put at 2,000lb. per square inch, the final compression is given as 1-500 part of length. This being the case the tensional strain will be borne by the iron ties in any combination of the two materials, and Mr. Kirkaldy's experiments, given by Mr. Hyatt, confirm this conclusion. As regards, then, the compressive strength of concrete, we may put this generally at 2,000lb. per square inch. The fireproof qualities of Portland cement, the ratio of its expansion and contraction, compared with iron, the effect of the two in combination when heated, &c., have also been investigated by a series of experiments by Mr. Kirkaldy for the author. Thus we find, from the thermal chart given, which shows the heat imparted to iron bars protected by 2in., 3in., or 4in. thickness of concrete, that the temperature of the iron protected by 4in. of concrete, after 5½ hours' exposure to the heat, did not exceed 212°, or boiling point; in 8½ hours it was 450°; and, at the end of 12 hours, 550°, or less than the melting heat of lead—an intense heat being kept up all the time, and the concrete being red hot. By a simple diagram it is made clear that it is waste of metal to use iron in the form of beams. By omitting the web and upper flange, and only substituting a flat tie for the lower flange, it is clearly shown that equal results are obtained, it being proved that the upper part of the floor or beam of concrete offers an excess of compressive resistance to the demands of the tie-metal below the neutral axis; or, as worked out, we get a resisting fulcrum of 150,000lb., as against 120,000lb., the resistance of the metal in tension. The question as to whether the metal and concrete would act in concert, and become united effectively, is answered by numerous experiments, illustrated in Mr. Hyatt's treatise. Here we find that all the iron bars inserted in the bottom of the concrete beams were perfectly held while under strain, that both materials worked in harmony, and that better results were obtained when the metal blades were placed at the bottom of the section, and became tie metal, than when they lost the character of ties, and were made deeper—in the latter case the blades became so much metal lost. Without going into the figures of the author, which are clear enough, we may refer to two sections of floors given in the book. One represents a floor made of 7in. rolled joists 1ft. apart, with a span of 15ft., filled with concrete 10in. thick. The iron of this floor weighs per foot super 14lb.; weight of concrete, 100lb.; safe distributed gross load, 384lb., or 270lb. net. The other shows a floor of tie metal in blades, with cross bars running through them. The weight per foot of iron is only 5lb., thickness of floor 14in., the safe distributed gross load being 415lb., or 270lb. net. These facts show the value of Portland cement concrete as a compressive member in floors and beams, and that iron can be combined with it in a manner which recommends itself to all engaged in construction, especially to architects and engineers. Every architect will, we are sure, hail the results and experiments thus brought forward by Mr. Hyatt as tending to indicate the value of a combination of concrete and iron in a safe, convenient, and economical form. Various forms of combinations of composite beams are shown, with the actual fractures, under various loads, in which the ties are placed in various ways within the concrete, to which we call the attention of our readers. We may just remark that floors or beams of great span may be composed by employing the metal in gridiron form in the top and bottom, the concrete forming the web connection.

* An Account of Some Experiments with Portland Cement Concrete, Combined with Iron, as a Building Material with Reference to Economy of Metal and Security against Fire, &c. By THADDEUS HYATT. London: Printed at the Chiswick Press.

A CHAPTER ON CURVED BEAMS.

HAVING seen how straight beams, of any size and power, may be formed, we can proceed to examine another class. On Trajan's column, at Rome, has stood since A.D. 114 the sculptured representation of that Emperor's bridge over the Danube, which (like the construction of the column itself) dwarfs modern efforts, with few exceptions, by its colossal nature. The bridge was 3,000ft. in length, and had twenty-two arches of timber, so that it is not going far aside to allude to it in a notice of curved beams.

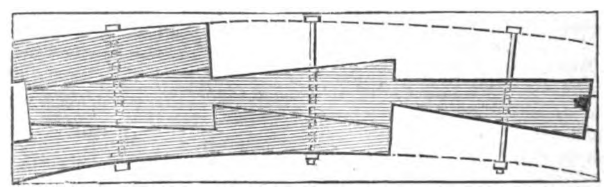
They are of four classes or systems of formation—namely, the scarfed, the bent, the flitched, and the laminated. The first consists in making a curved beam out of straight logs, and is probably an ancient plan, of which the use has been occasional during a long period, or, if sometimes forgotten, as frequently revived. Palladio used such beams, and may have received the idea from the sculptured record on Trajan's column. About a century ago the Brothers Grubenman, of Switzerland, were famous, and the arched ribs used by one of them in a bridge at Wettenghen were of formidable dimensions. The space being 230ft., the beams were composed of seven logs in depth, with serrated tabulations throughout the length, so that the camber could be obtained without any actual bending of the wood. The heading joints in each layer were 12ft. apart, but so arranged as to form an interlacing bond, and the whole was strongly keyed and bolted. It was ligneous masonry.

The following account, "published under the superintendence of the Society for the Diffusion of Useful Knowledge," is too remarkable an instance of the difficulty encountered by ordinary literati in describing technical affairs to be neglected:—

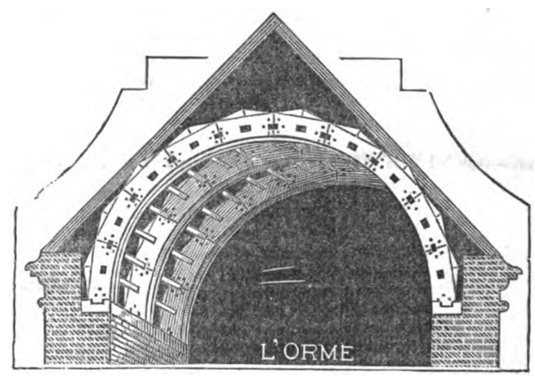
"The abutments were 25ft. high, and the arch between them was a catenary—that is, the same form which a rope or flexible chain assumes by its own weight when hung over two fixed pegs. This arch was, of course, inverted in the same manner as the iron chain bridges that have lately been constructed in this country, and, making allowances for the difference of materials and the mode of junction, it may be fair, perhaps, to consider it as the first chain bridge that ever was constructed in Europe." Misled by the idea of a catena the writer failed to reflect that it would be as difficult to suspend an arch of timber, convex downwards, as to erect a flexible chain of iron, convex upwards. My illustration is not drawn from a particular example, but is intended to represent the serrated tubing referred to, and which was attended with a waste of material, equal to one-third of the total quantity consumed. The large volumes of Krufft and Emy afford more express and extended information on this bold and powerful form of combination than I can propose to present.

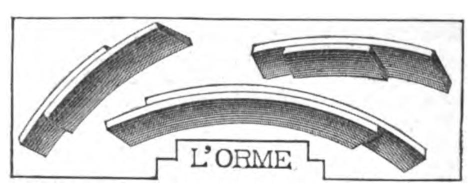
The second class began early in the present century, when M. Wiebeking, an able German constructor, effected an important improvement. He contrived to bend to the requisite curvature timbers as large as 15in. square and 50ft. long, thus reducing the number of heading-joints and the waste generally attendant on short pieces. For, when the grain could be forced into the direction of the curve, the great labour of the serratures and the loss of material they occasioned could be at once avoided. The qualities of economy and grace were thus added to the masculine character of earlier work. With the same artist also originated the practice of increasing the depth by additional logs as the beam receded from the crown—an expedient that has been fully approved by science and experience. Mr. Herman Haupt, A.M., of New York, for instance, who, from his knowledge of American examples, is well entitled to speak, says "the lightest and most simple system, and the one best calculated to attain the maximum limits of span, consists in a solid beam of parabolic curvature, increasing in depth from the vertex to the ends." A figure will be given in the next chapter, but nothing could more exactly illustrate this description than the beams employed by Mr. Wiebeking in the bridge at Bamberg in 1809. The span is 208ft., and the rise 17ft. The beams are three logs in depth at the crown, and five at the springing, keys being introduced in the longitudinal joints to prevent sliding. Beams compacted on this plan of bending the fibres are probably more vibratory than where the parts are cut to the requisite shape, according to the old rule, and this property must increase with the length in either case. There are several American examples of more than 300ft., and that of Grubenman over the Linnant, at Wettenghen, was 390ft. The components may, in fact, be multiplied to any extent, and the crushing point of the material marks their only limit. But when beams of enormous dimensions, and exposed to the disturbance of moving loads, are supported by stone abutments, the most careful provision ought to be made, lest they crush the mortar and fracture the masonry. Æsthetics have a higher standard now than at the beginning of the age, and when beams constitute the leading elements of structures, it seems only fitting that their forms should be displayed. Casing has no greatly preservative effect, and when made to imitate stonework degenerates into an unworthy deception. The carpenter owes some devotion to his proper material, and it affords an ample range for his ability. If less monumental than stone, it is oftener available, and he who might almost span the Thames in a single bow may well leave to the Arno and to Florence, unpirated, the moderate yet many-centred elliptics of Sa. Trinità.

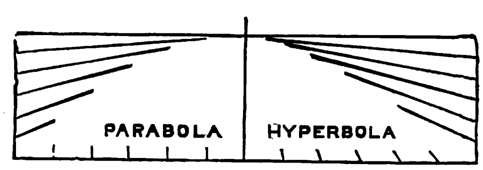
With regard to the third class or flitch beams, exact information exists. It was the invention of a French architect of the first celebrity, the contemporary of Palladio. He travelled in Italy, probably visited the great Vicentine, and studied his works. Returning to France, L'Orme soon acquired especial *éclat* from this constructive novelty. "We have no further need," said he, "of great trees for the beams and rafters of our roofs, for they may be formed of ribs that will seem to grow out of the walls." His mode was this:—Stopping the inner portion of the wall at some distance below the eaves, he placed on the bed thus formed a strong wall plate, with mortises at proper distances. At these intervals he raised ribs constructed of two thicknesses of boards of equal lengths and breadths, but commencing with a half length on one side, so as to make the abutting joints alternate. These boards being pinned and keyed together, formed a rib of considerable stiffness, and commonly of semicircular shape. Supplementary ribs were added at the eaves and apex when requisite. Three boards were sometimes joined, and the strength proportionally augmented. It was no ephemeral contrivance, to be laid aside as soon as novelty was over, but one that has maintained a permanent place in the carpenter's repert... In proof of this, it is only necessary ... instance their use by Mr. Decimus Burton in the dome of the Colosseum, so long a striking feature of the Regent's Park, but recently taken down. They appear also, at frequent intervals, in the temporary erections for exhibitions, and other works of great capacity, where the effect is occasionally enhanced by transverse members of ornamental character. The facility with which any form of arch, pointed or otherwise, can be produced, is a prominent merit of the flitch method.



Straight Logs Curved in the Tabling.







Mr. Price, in his "British Carpenter," recommended curved beams on the flitch principle for bridges; but that is an application for which they are ill-suited. Neither the headings nor the lateral cohesion can be regarded as trustworthy under a strain of much severity; though for carrying a light load, such as temporary roofing and skylights, over a large space, these beams are eminently convenient. Mr. Price was not the first to conceive them, nor was any British carpenter. They are due to the eminent Frenchman above-named, and in L'Orme's "Nouvelles Inventions pour Bien Bastir," A.D. 1561, are to be found, in addition to very numerous exemplifications of the kind, indications of arches made by two thicknesses of boarding, bent concentrically on the flat.

Whether through the survival of this suggestion or the natural development of Wiebeking's system, modern constructors have produced beams perfectly distinctive in character and name from the whole-timber and the flitch classes. This fourth sort being compacted of thin planks or boards are called "laminated," and are described in the "Nouveau Système d'Arcs pour les Grandes Charpentes, par A. R. Emy, Paris, 1828." They were introduced ...re in railway bridges by Messrs. Green, of Newcastle, in 1837. The example best known in London, however, and probably the neatest anywhere produced, was that by Mr. Lewis Cubitt, at the terminus of the Great Northern Railway, King's-cross. The station, 105ft. in width, was spanned by semi-circular ribs, 11in. wide and 12in. deep, made of nine thicknesses, and moulded at the angles. On the haunches next the walls were open spandrels of iron, and there were extra laminations of wood at the crown, 9in. wide and 12in. deep. The distance between the principals was 20ft., and their simple figure and accompaniments produced a remarkable impression of strength, lightness, and economy. They are represented in the later editions of Tredgold's "Carpentry," "Gwilt's Cyclopædia," and "Weale's Rudimentary Series" (the "Art of Building"). Unfortunately, the confined hot vapour from the engines proved destructive, and the wood has been replaced by iron substitutes.

These several methods offer to the modern carpenter a great choice of means, of which he can avail himself according to the nature and conditions of his works, but in all I would again venture to suggest the use of iron screws, of which the thread should cross the joint and draw the surfaces forcibly together. Having at the same time an eye to the possible effect of shrinkage, it may be judicious to connect only two thicknesses with the same screw.