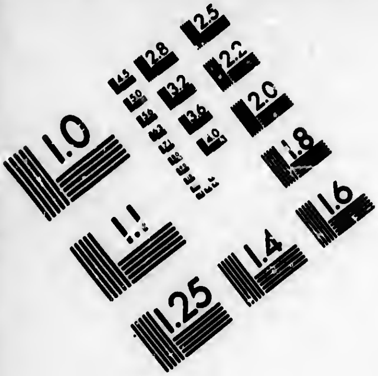

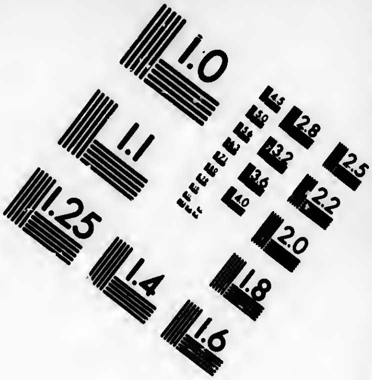

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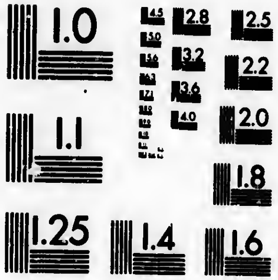

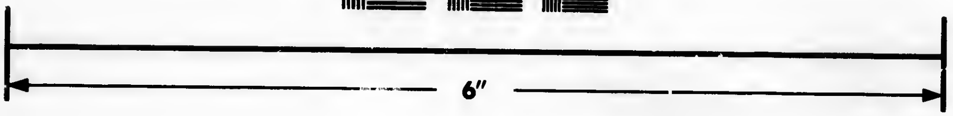

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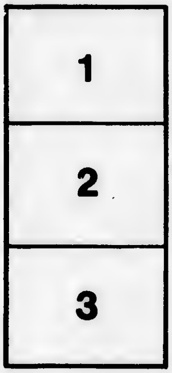
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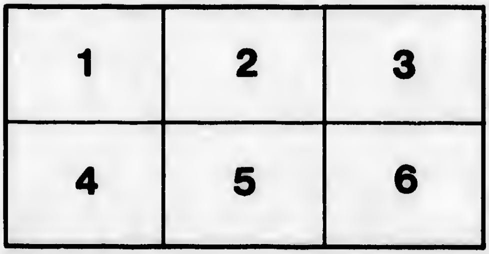
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GIRARD AVENUE BRIDGE, PHILADELPHIA.

(CLARKE, REEVES & CO., CONTRACTORS.)

ALBUM OF DESIGNS

OF THE

PHŒNIXVILLE BRIDGE-WORKS.

CLARKE, REEVES & CO.,

OFFICE No. 410 WALNUT STREET,

PHILADELPHIA.

J. B. LIPPINCOTT & CO.
PHILADELPHIA.
1873.

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Thomas C. Clarke,
Adolphus Bonzano,
John Griffen,
David Reeves.

PHŒNIXVILLE BRIDGE-WORKS.

Office of CLARKE, REEVES & CO.,

ENGINEERS, CONTRACTORS, AND BUILDERS OF IRON BRIDGES, VIADUCTS, ROOFS, ETC.

NO. 410 WALNUT STREET, ROOM 2.
P. O. Lock Box No. 2.
PHILADELPHIA.

In presenting our second circular, we take occasion to call the attention of our friends and customers to the following points:

We have entered into contract with the **Phœnix Iron Company**, Phœnixville, Pa., for a long term of years, by which that Company transfers to us all their iron bridge-building, and orders for bridges and viaducts are handed to us for execution.

By this arrangement the whole resources of the Phœnix Iron Company can be concentrated upon the fulfillment of our orders. Their present facilities are equal to turning out *one hundred feet of finished bridge for each working day in the year*, and can be increased, in case of necessity.

Everything is done upon the premises; beginning with the manufacture of the iron from the ore, next rolling it into the shapes required, and finally applying the machine-labor that completes the structure ready for erection.* It is believed that all this is done by no other single company in this country.

It results in a uniform excellence of quality of iron and workmanship, which cannot be got from bridge-builders who procure their iron from different makers, and generally at the cheapest rates.

We are prepared to construct any style of wrought-iron bridge, and according to any specified dimensions and weights; at the same time, we would call the attention of engineers and railway-men to that style of bridge which we have been building during the last five years, which has stood the test of use, with the marked approbation of those best able to judge.

What we claim as the peculiar advantages of our bridges are as follows:

We use that style of truss (originally developed in wood by PRATT and in iron by WHIPPLE) which experience has shown to be the best adapted for railway purposes, as there are more of them in use in this country than of any other kind.

So far as we have modified the connections and other details of construction, we have endeavored to be guided by the following principles:

Simplicity and uniformity of construction; least possible exposure of surface to corrosion; uniformity of strain on all parts alike; concentration of material along the lines of strain; and the use of the most suitable kind of material for the purposes required.

At the request of many railway-men, we have prepared a set of designs, accompanied by detailed specifications, covering the proportions and quality of material and workmanship under which they will be constructed.

They have nearly all been actually built by us, and have borne the test of use. Persons requiring bridges will find among these everything they want, unless for special cases, for which we will prepare special plans and estimates, free of charge, when requested.

We build our short spans stronger than has been heretofore customary, providing for a variable load of two tons per foot. We do this, because there is generally no slackening of speed in crossing a short span, and the live load of the locomotive bears a much greater proportion to the dead-weight of the structure in short than in long spans. At 250 feet span the live and dead loads are NEARLY EQUAL, while on a 30-feet span the live load is more than FOUR TIMES the dead load.

---

* See description of Phœnix Works, illustrated by woodcuts. Extracted, by permission, from *Lippincott's Magazine*. Appendix No. 1.

As the live load is accompanied with impact and vibration, and four-fifths of the strain comes from it, it is but prudent to take this into account.*

In proportioning the different parts of our bridges, the strain per square inch is diminished; or in other words, the strength of each part is increased in proportion to its nearness to its work. As the panel system is fully strained by the passage of each locomotive, it should have greater strength than the chord system, which can only get its maximum strain when the whole length of the bridge is covered with locomotives, which in practice seldom occurs on spans longer than 100 feet. The bolts which support the floor system, being subject to accidental shocks, have the greatest strength of all. This is merely following out in practice the principle of "uniformity of strains." Inasmuch as the strength of an iron bridge (like that of an iron chain) is measured by the strength of its weakest part, it follows that the structure in which this principle is most accurately carried out will be the strongest, while the purchasers of the bridge will not be compelled to pay for useless iron, which diminishes instead of adding to its strength. On the other hand, if bridges are too light, they will show this defect by excessive vibration under a passing train. This fault, we believe, our bridges cannot be charged with. We furnish diagrams of strains, giving the actual dimensions of each part, and the calculated strains.

We have given fourteen plates, in which are shown all the different kinds of iron bridges occurring in ordinary practice. Each style of bridge is distinguished by a letter and number.

Persons requiring bridges will please follow the following directions:

1. Give the *letter* and number of *figure* for the general style of bridge required, and the length of spans between centres of piers, and width of piers, if any are built.
2. State whether the bridge is at right angles or on a skew. If the latter, give the angle included between line of piers and axis of bridge.
3. Give the height of bottom of rail above bed of stream.
4. State whether the railway company will themselves build the lower staging up to the track-level, or not.
5. If not, give the depth of water, and whether the nature of the bottom requires piles, or not.
6. If a viaduct be required, it will be better to send a cross-section of the valley, indicating such points as require a fixed length of span,—such as streams, roads, etc.

If railway companies prefer to erect the iron-work themselves, we will furnish a competent person to superintend the erection, and guarantee the work coming together with exactness. It will generally be found more satisfactory that we should erect the bridge and lay the track upon it ready for use, the company furnishing ties and rails and the timber and other materials for staging.

With the above-mentioned data furnished, we can quote prices, by return of mail, to any one who wants bridges, and can construct the bridges in as short a time as any other bridge-builders can do. We wish it particularly understood that our cash rates are uniform to all persons alike; modified only by the amount of work ordered. We can always execute an order for a number of bridges for a less price each than for a single one, on account of the reduplication of parts lessening the cost of manufacture, and the less cost of erection, for various obvious reasons.

We will make special plans and estimates to suit any required case, but wish to point out that there will be a marked economy insured, both in cost and in time, by selecting one of our regular styles of bridge, as per plan and specification, as we have now on hand a large stock of dies and patterns which are applicable to them.*

The following is a list of the iron railway and other bridges and viaducts that we have built, or are building, since our connection with the Phœnix Iron Company; also, of the railways and their officers for whom they were built, and to whom we would respectfully refer parties desirous of further information as to our capacity:

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* See extract from paper read before American Society of Civil Engineers, by J. Griffen and T. C. Clarke. Appendix No. 2.

* See extract from *Railroad Gazette*, describing competition for new bridges in the Dominion of Canada.

LIST OF
WROUGHT-IRON BRIDGES AND VIADUCTS,
BUILT AND NOW BUILDING BY
CLARKE, REEVES & CO.,
FROM 1869 TO 1873.

FOR WHOM BUILT.	WHERE BUILT.	SPANS.		TOTAL LIN. FT. SINGLE TRACK.
		NO.	LENGTH.	
C. B. & Q.	Burlington, Mo.	1	123	123
Illinois Central	La Salle, Ill.	18	160	2880
Chicago & N. W.	Clinton, Iowa	2	150	300
Philad., Wil. & Baltimore	Chester, Pa. 2 tracks	1	154	308
" "	" " Draw. 2 tracks.	2	127	508
Reading R. R.	Flowertown	1	82	82
" "	"	1	55	55
Bridgeton, N. J.	Bridgeton. Draw.	1	125	125
North Pennsylvania R. R.	Saucon Creek	2	77	154
U. S. Arsenal	Rock Island, Ill. Highway.	4	150	600
Portland & Kennebec R.R.	Augusta, Me	7	4—174 1—154 1— 70 1— 55	975
Conn. Air Line R. R.	Viaduct	3	17	51
" "		...	48	48
" "	North Pond	1	120	120
" "	Baileyville	1	79	79
" "	Saddle Hill	1	56	56
" "	Pistol Factory	1	112	112
" "	Lyman Viaduct. 2 tracks	...	1112	2224
" "	Rapallo " "	...	1378	2756
Hudson River Bridge Co	Albany. 2 tracks	7 4 1* 1 1 1	73 185 274 110 40 65	3480
Portland & Ogdensb'rg R.R.	Hiram, Me.	1	185	185
Cambria Iron Co.	Johnstown	4	85	340
North Pennsylvania R. R.	Saucon Creek	5	3— 50 2— 47	248
Ches. & Ohio R. R.	New River	4	2—255 2— 75	660
Portland & Ogdensb'rg R.R.	Corway	2	158	316
Catawissa R. R.	Viaduct	...	...	226
Intercolonial Railway Co.	Miramichi	11	210	2310
" "	Ristigouche	5	212	1060
Wheelock Bridge Co.	Terre Haute. Highway	1	50	50
West Chester R. R.	Glen Mills	1	80	80
North Pennsylvania R. R.	Washington Station	5	1— 37 4— 23	129
Camden & Amboy R. R.	Hightstown	1	139	139
Alex. T. Stewart	Long Island	2	1— 54 1— 84	138
Ches. & Ohio R. R.	Greenbrier River	8	4—100 4—120	880
Maine Central R. R	Brunswick, Me.	4	2—183 2—186.6	739

FOR WHOM BUILT.	WHERE BUILT.	SPANS.		TOTAL LIN. FT. SINGLE TRACK.
		NO.	LENGTH.	
Ches. & Ohio R. R.	Rivanna Creek	1	97	97
S. Schofield	Manayunk. Highway	1	93	93
Ohio & Miss. R. R.	Cochran	1	145	145
" "	No. 11	1	147	147
" "	Medora.	2	1—147 1—163	310
" "	Scottville	3	177	531
" "	West Fork	2	207	414
" "	Big Sugar	1	113	113
" "	Little Sugar	1	32	32
" "	Little Wabash	1	92	92
Grand Trunk R'way of Can.	St. Hyacinthe	3	1—123 1—121 1—127	371
" "	Black River	1	...	155
" "	White River	2	1—154 1— 78	232
" "	St. Francis	2	1—151 1—146	297
" "	Magog	2	118	236
" "	Massawippi	1	117	117
" "	Coaticoke	1	117	117
" "	Island Pond	1	107	107
" "	N. Stratford	1	117	117
" "	Ammonoosuc	1	124	124
" "	Gorham	1	147	147
" "	W. Paris	1	138	138
" "	S. Paris	1	121	121
" "	Mechan's Falls	1	150	150
" "	N. Yarmouth	1	108	108
Philad., Wil. & Balt. R. R.	Ridley Park	2	1— 63 1— 31	94
Rock Island Arsenal	Moline, Ill.	5	142	711
Central R. R. of N. J.	Pamrapo. 3 tracks	1	96.3	289
North Pennsylvania R. R.	Sellersville	6	1— 73 5— 31	228
Geneva & Ithaca R. R.	Tanghanock	1	102	102
" "	Sheldrake Ferry	1	104	104
" "	Trumansburg	via	900	900
" "	Seneca Canal	1	88	88
Costa Rica Railway	Costa Rica	4	1—132 1— 68 1— 74 1— 16	310
City of Philadelphia	Girard Av., 100 feet wide. Seven trusses. Equal to six railroad tracks	3 2	197 137	5190
	No. of spans	176		35,063
	Miles $6\frac{61}{100}$			

* Draw.

JANUARY 1, 1873.

GENERAL SPECIFICATIONS,

ACCORDING TO WHICH THE

DESIGNS OF CLARKE, REEVES & CO.'S BRIDGES,

GIVEN IN THIS CIRCULAR,

ARE PROPOSED TO BE CONSTRUCTED.

1. These structures are proportioned to sustain the passage of the heaviest cars and engines in use, for coal, freight, or passenger traffic, at a speed of not less than thirty miles per hour, viz.: two locomotives coupled, weighing thirty tons on drivers, in space of twelve feet; total weight of engine and tender, loaded, sixty-five tons each, and followed by the heaviest cars in use, viz.: loaded coal cars, weighing twenty tons each, in twenty two feet. The iron-work will be so proportioned that the above loads, in addition to the weights of the structures themselves, shall not strain the iron over 10,000 pounds per square inch tensile, or 7500 pounds per inch shearing strain, and reducing the strain in compression, in proportion to the ratio of length to diameter, by Gordon's formula.

2. The iron used under tensile strains shall be of tough and ductile quality, and be capable of sustaining the following tests:

PHŒNIX DOUBLE REFINED OR "BEST BEST" IRON.

ROUND BAR.—1½ INCHES DIAMETER BY 12 INCHES LONG.

Ultimate strength,	55,000 to 60,000 lbs. per square inch.
No permanent set under	25,000 to 30,000 " " "
Reduction of area at breaking point, average	25 per cent.
Elongation " " " "	15 "

Cold bend without signs of fracture, from 90 to 180 degrees.

3. All workmanship shall be first-class. In work having pin connections, all abutting joints shall be planed or turned, and no bars of wrought-iron having an error of over 1-64th of an inch in length between pin-holes, or over 1-100th of diameter of pin or hole, shall be allowed. In riveted work, all plates and joint plates shall be square and truly dressed, so as to form close joints. Rivet holes shall be spaced accurately and truly opposite. Rivets shall be of the best quality of rivet iron, shall completely fill the holes, and shall have full heads.

Chord-links, main ties, and suspension bolts, shall be die-forged without welds. Screw-bars shall have threads enlarged beyond diameter of bar, and shall be fitted with radial nuts and washers.

All bars subject to tensile strains may be tested to 20,000 pounds per square inch, and struck a smart blow with a hammer while under tension; and if any show signs of imperfection they shall be rejected.

All the iron-work shall be painted, before leaving the Works, with one coat of metallic paint and oil. All machine-cut work shall be covered with white lead and tallow before leaving the Works.

4. These bridges shall not deflect, under the passage of a train of locomotives moving at thirty miles per hour, over 1-1200th of their length, and shall return to their original camber after the passage of the train.

DESCRIPTION OF PLATES.

PLATE No. 1.

Design A.—Figs. 1, 2, 3, show a simple form of girder bridge intended for spans of 25 feet and under.

It consists of two pair of rolled Phœnix beams, of 12 or 15 inches deep, according to span, braced together and resting on cast-iron plates.

Where the headway is extremely limited the arrangement shown in cross-section, Fig. 4, may be used, which requires a depth below bottom of rail of but 11 inches.

PLATE No. 2.

Design B is a trussed girder with two panels, intended for spans of 25 to 30 feet, where there is sufficient depth below the rail to truss the beams in the manner shown.

PLATE No. 3.

Design C shows a trussed girder with more than two panels, suited for spans of 30 to 75 feet.

PLATE No. 4.

Design D.—For longer spans than 75 feet we use our regular pattern of deck bridge, with top chords and posts made of Phœnix columns, and having side cross floor-beams. The track stringers can be either of wood, as shown in the plate, or of iron, if specially ordered.

Where preferred, the tops of masonry piers need not be carried above the bottom chords of the iron truss, and the level of bridge seat at abutments will be the same. In this case the ends of the iron trusses will be supported on vertical Phœnix columns.

PLATE No. 5.

This plate shows the details of construction of the deck bridge illustrated in Design D, Plate No. 4.

PLATE No. 6.

Design E.—This plan of what is sometimes called a "pony" truss bridge is used for through bridges, where the depth below rail is somewhat limited, in spans of from 30 to 60 feet, and may be carried up to 80 feet at points where it is desirable to give the engineer an unobstructed view over the tops of the trusses. We prefer, however, at 60 feet span to carry up the trusses and brace them overhead.

PLATE No. 7.

Design F.—This is our regular pattern of through bridge. 18 feet and upwards in clear height, and 14 feet in clear width for single track. For double track we recommend two trusses, with a clear width of 26 feet.

PLATE No. 8.

This shows the details of construction of the through bridges shown in designs E, F, and the highway bridge design G, Plate No. 11.

PLATE No. 9.

Design H.—This is our regular pattern of through pivot-bridges, with our patent turn-table, of a simple and effective construction. Where a pivot-pier has to be specially constructed, considerable economy will be obtained by carrying up a circular wall of masonry, and reducing the depth of iron ring, as shown in Fig. 35. Our pivot-bridges have always given satisfaction; and we refer particularly to that over the Hudson River at Albany, belonging to the New York Central and Hudson, and the Boston and Albany Railroads, as a model of a quick-working and substantial pivot-bridge.

PLATE No. 10.

This plate shows the details of our patent locking and self-centring arrangement for pivot-bridges, the operation of which will be best understood by the description of the patent itself, dated June 18, 1872.

IMPROVEMENTS IN PIVOT-BRIDGES.

Our invention relates to certain improvements in pivot-bridges, too fully explained hereafter to need preliminary description; the said improvements having for their object, first, the ready withdrawal of the corner-supports of the bridge, when the latter has to be turned on its pivot, and the ready restoration of these supports when the position of the bridge demands them; and second, the self-centring of the bridge, so that the nice and tedious manipulative adjustment demanded, in order that the rails of the bridge may coincide with those of the permanent track, is rendered unnecessary.

In the accompanying drawing, Fig. 37 is a view of a portion of the end of a pivot-bridge; Fig. 36, a side view of a portion of one end of the bridge; Fig. 38, a plan view of Fig. 1; and Fig. 39, a perspective view illustrating a part of our invention.

A and A′ are two transverse beams at one end of the bridge; these, together with other transverse beams of like character, supporting the longitudinal beams B, across which extend the ties D for receiving the rails *a a*. The transverse beams A are secured to the lower chord-beams by suspension-bolts *e*, this lower chord forming part of a truss-frame of which the pivot-bridge is composed, and of which F represents a portion of one of the diagonal end posts. To the transverse beam A are hung, by means of a pin *f*, a series of links *i i i i*, and to the latter are hung, by means of a pin *j*, a series of similar links *m*, and to a pin passing through the lower ends of the latter series of links are hung two rollers, *p p*, which are guided vertically by brackets *q q*, secured to the under side of the beams A. The two sets of links, as will be seen hereafter, form a knee-joint to the central pin *j*, of which two rods, G G, are jointed, the opposite ends of these rods being connected to the lower ends of arms H, which are hung to the transverse beams A A, and these arms are connected, by a rod, I, to lugs on a nut J, which is adapted to vertical guides arranged between the two beams A A, the said nut being also connected by similar appliances to knee-joint links arranged at the opposite corner of the bridge, which is not shown in the drawing. The nut J is controlled by a vertical screw, so confined to suitable bearings *h*, secured to the beams A A, that while it can be turned easily it is incapable of vertical movement. This screw may be operated by any suitable mechanism, but we prefer to operate it from a central point on the pivot-bridge, and to connect the operating mechanism by means of a horizontal shaft extending along the bridge beneath the ties, one end of the shaft being geared by bevel-wheels to the screw K at one end of the bridge, and the opposite end to a similar screw at the opposite end of the bridge, so that the knee-joint links, at all four corners of the bridge, may be operated simultaneously from one point. The outer ends of the rails *a a*, at each end of the bridge, admit of being raised and lowered by the same mechanism which operates the knee-joints. Thus the rails *a a*, in Fig. 1, are connected by rods *y y* to the rods I I, and these rails are adapted to chairs *d d*, which are secured to the permanent roadway or permanent part of a bridge, and which receive the ends of the permanent rails *b b* of the track, the chair thus insuring the coincidence of the rails of the pivot-bridge with those of the permanent track.

As seen in the drawing, the bridge is supposed to be closed, and free for the passage of trains, the rollers *p* at the lower end of the knee-jointed links at each corner of the bridge bearing in a cavity in the top of a plate *t*, secured to the foundation or pier; and, the pins of the knee-joint links being in the same vertical line, the links afford a steady support for the bridge at each of its four corners. When it is necessary to swing the bridge round, the screw K, at each end of the bridge, is turned so as to elevate the nuts J. This consequently draws the rods G and I in the direction of the arrows, and therefore so acts on the knee-joint links as to elevate the rollers *p p* in their guides; and this is continued until the bridge is in the first instance lowered and supported on its centre pivot only, and afterward until the rollers are clear of their bearings. Simultaneously with this movement of the knee-joint links, the outer ends of the rails, owing to their connections with the rods I I, were elevated clear of the chairs *d d*, as seen in Fig. 4, and consequently the bridge is free to be turned on its pivot. In restoring the bridge to its original position, it is turned round until the rollers *p p* of the knee-joint links are above the cavity of the foundation-plate *t*. It is very rarely, however, that the bridge can be arrested in its movement at a point where the said rollers are directly above the centre of the said cavity; but as soon as the screws K are operated to straighten the knee-joint links, and the rollers *q* begin to bear upon the plates *t*, the weight on the rollers will induce them to descend into the cavities of the plates, and hence, as the straightening of the knee-joints is continued, the bridge will be slightly turned, until the rollers have arrived at the most depressed portion of the cavities in the plates, and there remain while the straightening of the knee-jointed links is continued until their pins are in the same vertical line, as shown in Fig. 1. After the bridge had adjusted itself in the manner described during the preliminary straightening of the links, and this straightening was continued, the rails *a a* on the bridge descended until they rested in and were confined laterally by the shoes *d d* of the permanent track. It will be seen, therefore, that by connecting these rails *a a* to the mechanism which operates the knee-joints, the said rails are elevated out of the chair simultaneously with the releasing of the bridge from its corner-bearings, and when the knee-joints become the corner-bearings the rails are lowered into the chairs, and their coincidence with the rails of the permanent track is thereby insured. The accidents which have frequently occurred through the non-coinciding of the rails of a pivot-bridge with those of the permanent track are thus prevented.

The knee-joint bearings at the corner of the bridge possess this important advantage, that they can be operated with comparatively little exertion, either through the medium of the mechanism described or any equivalent operating devices.

Although we have shown and described a pivot-bridge constructed in a manner which we deem most appropriate, it should be understood that our improvements are applicable to any pivot-bridge. A change in the operating mechanism may be demanded in a bridge constructed in a manner differing from that described, but the principal features may remain; these features being the knee-joint links, forming corner-supports which can be easily withdrawn, and the plates *t*, which render the bridge self-centring.

We claim as our invention—

1. The combination, with a pivot-bridge substantially as described, of knee-joint supports and the mechanism described, or any equivalent to the same, for operating the said joints.

2. In combination with a pivot-bridge having movable links as supports, we claim plates *t*, constructed, substantially as described, so as to render the bridge self-centring.

PLATE No. 11.

Design G.—This is our usual pattern of highway bridge, with floor beams of iron, which may or may not be trussed, according to the available depth below roadway. It is constructed exactly like a railway bridge, except in the floor system, and is calculated to sustain a load of from 1500 to 2500 pounds per lineal foot, with a friction of safety of 5. Teams may cross these bridges at full speed without doing any mischief.

PLATE No. 12.

Design I is an iron highway bridge, to be used for roads crossing over railways. Fig. 45 is intended for points where abutments are already built, or where, from the railway being on a curve, it is not desirable to obstruct the view. On the right side of Fig. 45 a more economical construction than the ordinary stone abutment is suggested.

PLATE No. 13.

Design K shows our method of constructing wrought-iron piers for bridges, viaducts, etc. They are made of four Phœnix columns, braced together as shown, and secured at the joints by our patent system of connections.

As the lengths and weights of spans increase, we increase the dimensions of the columns and braces, but the same general form of construction is followed for all lengths of spans.

PLATE No. 14.

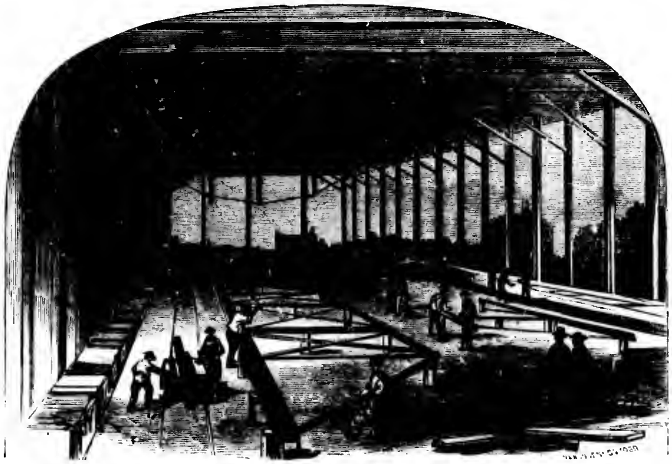
Design L shows a bridge on iron piers, intended for the crossing of a small stream or road, where good stone for masonry cannot easily be got. The piers can be built of split boulders, or of concrete, if stone cannot be had; and, as they are buried in the embankments, concrete will answer as well as stone. These piers can be coped with stone or iron.

Design M shows a wrought-iron viaduct resting on cast-iron screw piles, and suitable for crossing the wide river bottoms of the western and southern States, where stone is scarce, and where a wide water-way must be permanently maintained.

APPENDIX No. 1.

PHŒNIXVILLE BRIDGE-WORKS.

REPRINTED FROM LIPPINCOTT'S MAGAZINE FOR JANUARY, 1873.



"ASSEMBLING" BRIDGE UNDER SHED.

In a graveyard in Watertown, a village near Boston, Massachusetts, there is a tombstone commemorating the claims of the departed worthy who lies below to the eternal gratitude of posterity. The inscription is dated in the early part of this century (about 1810), but the name of him who was thus immortalized has faded like the date of his death from my memory, while the deed for which he was distinguished, and which was recorded upon his tombstone, remains clear. "He built the famous bridge over the Charles River in this town," says the record. The Charles River is here a small stream, about twenty to thirty feet wide, and the bridge was a simple wooden structure.

Doubtless in its day this structure was considered an engineering feat worthy of such posthumous immortality as is gained by an epitaph, and afforded such convenience for transportation as was needed by the commercial activity of that era. From that time, however, to this, the changes which have occurred in our commercial and industrial methods are so fully indicated by the changes of our manner and method of bridge-building that it will not be a loss of time to investigate the present condition of our abilities in this most useful branch of engineering skill.

In the usual archæological classification of eras the Stone Age precedes that of Iron, and in the history of bridge-building the same sequence has been preserved. Though the knowledge of working iron was acquired by many nations at a pre-historic period, yet in quite modern times—within this century, even—the invention of new processes and the experience gained of new methods have so completely revolutionized this branch of industry, and given us such a mastery over this material, enabling us to apply it to such new uses, that for the future the real Age of Iron will date from the present century.

The knowledge of the arch as a method of construction with stone or brick—both of them materials aptly fitted for resistance under pressure, but of comparatively no tensile strength—enabled the Romans to surpass all nations that had preceded them in the course of history, in building bridges. The bridge across the Danube, erected by Apollodorus, the architect of Trajan's Column, was the largest bridge built by the Romans. It was more than three hundred feet in height, composed of twenty-one arches resting upon twenty piers, and was about eight hundred feet in length. It was after a few years destroyed by the emperor Adrian, lest it should afford a means of passage to the barbarians, and its ruins are still to be seen in Lower Hungary.

With the advent of railroads, bridge-building became even a greater necessity than it had ever been before, and the use of iron has enabled engineers to grapple with and overcome difficulties which only fifty years ago would have been considered hopelessly insurmountable. In this modern use of iron advantage is taken of its great tensile strength, and many iron bridges, over which enormous trains of heavily-loaded cars pass hourly, look as though they were spun from gossamer threads, and yet are stronger than any structure of wood or stone would be.

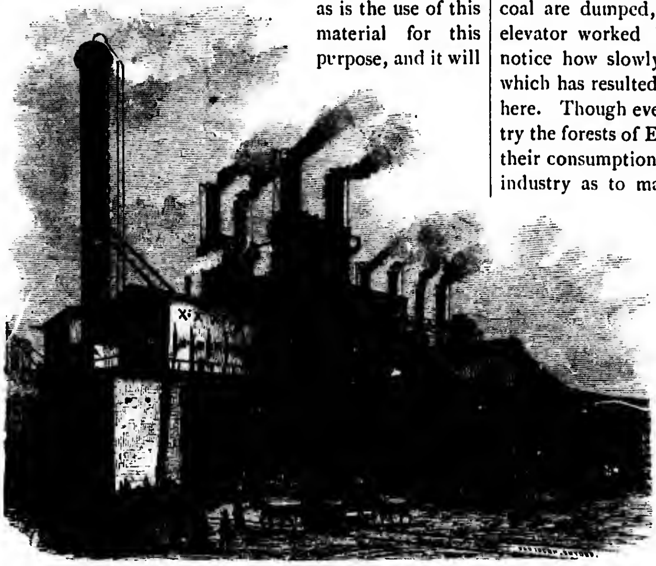
THE LYMAN VIADUCT.

Another great advantage of an iron bridge over one constructed of wood or stone is the greater ease with which it can, in every part of it, be constantly observed, and every failing part replaced. Whatever material may be used, every edifice is always subject to the slow disintegrating influence of time and the elements. In every such edifice as a bridge, use is a process of constant weakening, which, if not as constantly guarded against, must inevitably, in time, lead to its destruction.

In a wooden or stone bridge a beam affected by dry rot or a stone weakened by the effects of frost may lie hidden from the inspection of even the most vigilant observer until, when the process has gone far enough, the bridge suddenly gives way under a not unusual strain, and death and disaster shock the community into a sense of the inherent defects of these materials for such structures.

The introduction of the railroad has brought about also another change in the bridge-building of modern times, compared with that of all the ages which have preceded this nineteenth century. The chief bridges of ancient times were built as great public conveniences, upon thoroughways over which there was a large amount of travel, and consequently were near the cities or commercial centres which attracted such travel, and were therefore placed where they were seen by great numbers. Now, however, the connection between the chief commercial centres is made by the railroads, and these penetrate immense distances, through comparatively unsettled districts, in order to bring about the needed distribution; and in consequence many of the great railroad bridges are built in the most unfrequented spots, and are unseen by the numerous passengers who traverse them, unconscious that they are thus easily passing over specimens of engineering skill which surpass, as objects of intelligent interest, many of the sights they may be traveling to see.

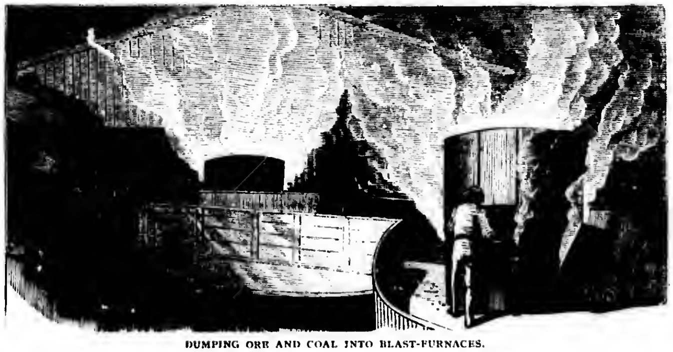
The various processes by which the iron is prepared to be used in bridge-building are many of them as new as is the use of this material for this purpose, and it will not be amiss to spend a few moments in examining them before presenting to our readers illustrations of some of the most remarkable structures of this kind. Taking a train by the Reading Railroad from Philadelphia, we arrive, in about an hour, at Phœnixville, in the Schuylkill Valley, where the Phœnix Iron- and Bridge-Works are situated. In this establishment we can follow the iron from its original condition of ore to a finished bridge; and it is the only establishment in this country, and most probably in the world, where this can be seen.



BLAST-FURNACES.

These works were established in 1790. In 1827 they came into the possession of the late David Reeves, who by his energy and enterprise increased their capacity to meet the growing demands of the time, until they reached their present extent, employing constantly over fifteen hundred hands.

The first process is melting the ore in the blast-furnace. Here the ore, with coal and a flux of limestone, is piled in and subjected to the heat of the fires, driven by a hot blast and kept burning night and day. The iron, as it becomes melted, flows to the bottom of the furnace, and is drawn off below in a glowing stream. Into the top of the blast-furnaces the ore and coal are dumped, having been raised to the top by an elevator worked by a blast of air. It is curious to notice how slowly the experience was gathered from which has resulted the ability to work iron as it is done here. Though even at the first settlement of this country the forests of England had been so much thinned by their consumption in the form of charcoal in her iron industry as to make a demand for timber from this country a flourishing trade for the new settlers, yet it was not until 1612 that a patent was granted to Simon Sturtevant for smelting iron by the consumption of bituminous coal. Another patent for the same invention was granted to John Ravenson the next year, and in 1619 another to Lord Dudley; yet the process did not come into general use until nearly a hundred years later.



DUMPING ORE AND COAL INTO BLAST-FURNACES.

The blast for the furnace is driven by two enormous engines, each of three hundred horse-power. The blast used here is, as we have said, a hot one, the air being heated by the consumption of the gases evolved from the material itself. The gradual steps by which these successive modifications were introduced are an evidence of how slowly industrial processes have been perfected by the collective experience of generations, and show us how much we of the present day owe to our predecessors. From the earliest times, as among the native smiths of Africa to-day, the blast of a bellows has been used in working iron to increase the heat of the combustion by a more plentiful supply of oxygen. The blast-furnace is supposed to have been first used in Belgium, and to have been introduced into England in 1558. Next came the use of bituminous coal, urged with a blast of cold air. But it was not until 1829 that Neilson, an Englishman, conceived the idea of heating the air of the blast, and carried it out at the Muirkirk furnaces. In that year he obtained a patent for this process, and found that he could from the same quantity of fuel make three times as much iron. His patent made him very rich: in one single case of infringement he received a cheque for damages for one hundred and fifty thousand pounds. In his method, however, he used an extra fire for heating the air of his blast. In 1837 the idea of heating the air for the blast by the gases generated in the process was first practically introduced by M. Faber Dufour at Wasseralfilgen in the kingdom of Würtemburg.

ELEVATOR.

In this country, charcoal was at first used universally for smelting iron, anthracite coal being considered unfit for the purpose. In 1820 an unsuccessful attempt to use it was made at Mauch Chunk. In 1833, Frederick W. Geisenhainer of Schuylkill obtained a patent for the use of the hot blast with anthracite, and in 1835 produced the first iron made with this process. In 1841 C. E. Detmold adapted the consumption of the gases produced by the smelting to the use of anthracite; and since then it has become quite general, and has caused an almost incalculable saving to the community in the price of iron.

THE ENGINE-ROOM.

The view of the engines which pump the blast will give an idea of the immense power which the Phœnix company has at command. Twice every day the furnace is tapped, and the stream of liquid iron flows out into moulds formed in the sand, making the iron into pigs — so called from a fancied resemblance to the form of these animals. This makes the first process, and in many smelting establishments this is all that is done, the iron in this form being sold and entering into the general consumption.

RUNNING METAL INTO PIGS.

The next process is "boiling," which is a modification of "puddling," and is generally used in the best iron-works in this country. The process of puddling was invented by Henry Cort, an Englishman, and patented by him in 1783 and 1784, as a new process for "shingling, welding, and manufacturing iron and steel into bars, plates, and rods of purer quality and in larger quantity than heretofore, by a more effectual application of fire and machinery." For this invention Cort has been called "the father of the iron-trade of the British nation," and it is estimated that his invention has, during this century, given employment to six millions of persons, and increased the wealth of Great Britain by three thousand millions of dollars. In his experiments for perfecting his process Mr. Cort spent his fortune, and though it proved so valuable, he died poor, having been involved by the government in a lawsuit concerning his patent, which beggared him. Six years before his death, the government, as an acknowledgment of their wrong, granted him a yearly pension of a thousand dollars, and at his death this miserly recompense was reduced to his widow, to six hundred and twenty-five dollars.

CARRYING THE IRON BALLS.

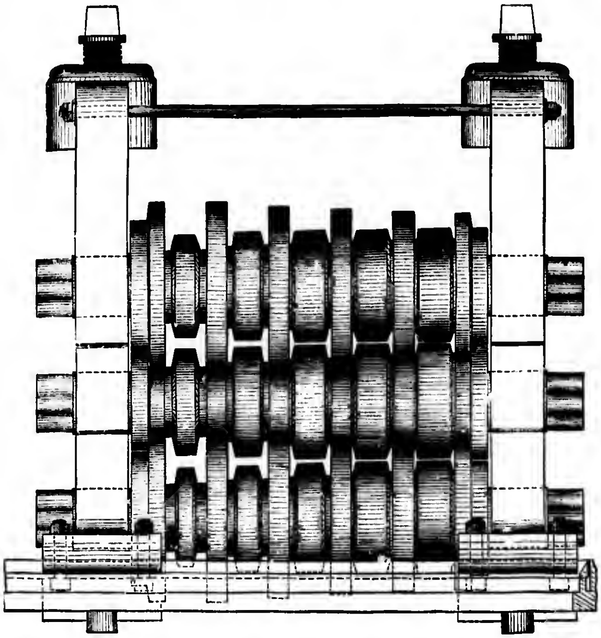
When iron is simply melted and run into any mould its texture is granular, and it is so brittle as to be quite unreliable for any use requiring much tensile strength. The process of puddling consisted in stirring the molten iron run out in a puddle, and had the effect of so changing its atomic arrangement as to render the process of rolling it more efficacious. The process of boiling is considered an improvement upon this. The boiling-furnace is an oven heated to an intense heat by a fire urged with a blast. The cast-iron sides are double, and a constant circulation of water is kept passing through the chamber thus made, in order to preserve the structure from fusion by the heat. The inside is lined with fire-brick covered with metallic ore and slag over the bottom and sides, and then, the oven being charged with the pigs of iron, the heat is let on. The pigs melt, and the oven is filled with molten iron. The puddler constantly stirs this mass with a bar let through a hole in the door, until the iron boils up, or "ferments," as it is called. This fermentation is caused by the combustion of a portion of the carbon in the iron, and as soon as the excess of this is consumed, the cinders and slag sink to the bottom of the oven, leaving the semi-fluid mass on the top. Stirring this about, the puddler forms it into balls of such a size as he can conveniently handle, which are taken out and carried on little cars, made to receive them, to "the squeezer."

BOILING-FURNACE.

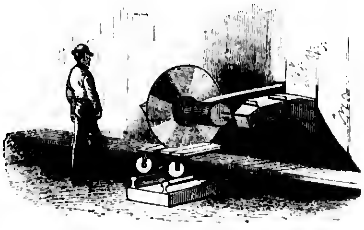
To carry on this process properly requires great skill and judgment in the puddler. The heat necessarily generated by the operation is so great that very few persons have the physical endurance to stand it. So great is it that the clothes upon the person frequently catch fire. Such a strain upon the physical powers naturally leads those subjected to it to indulge in excesses. The perspiration which flows from the puddlers in streams while engaged in their work is caused by the natural effort of their bodies to preserve themselves from injury by keeping their normal temperature. Such a consumption of the fluids of the body causes great thirst, and the exhaustion of the labor, both bodily and mental, leads often to the excessive use of stimulants. In fact, the work is too laborious. Its conditions are such that no one should be subjected to them. The necessity, however, for judgment, experience, and skill on the part of the operator has up to this time prevented the introduction of machinery to take the place of human labor in this process. The successful substitution in modern times of machines, for performing various operations which formerly seemed to require the intelligence and dexterity of a living being for their execution, justifies the expectation that the study now being given to the organization of industry will lead to the invention of machines which will obviate the necessity for human suffering in the process of puddling. Such a consummation would be an advantage to all classes concerned. The attempts which have been made in this direction have not as yet proved entirely successful.

ROTARY SQUEEZER.

In the squeezer the glowing ball of white-hot iron is placed, and forced with a rotary motion through a spiral passage, the diameter of which is constantly diminishing. The effect of this operation is to squeeze all the slag and cinder out of the ball, and force the iron to assume the shape of a short thick cylinder called "a bloom." This process was formerly performed by striking the ball of iron repeatedly with a tilt-hammer.


THE ROLLS.

The bloom is now re-heated and subjected to the process of rolling. "The rolls" are heavy cylinders of cast-iron placed almost in contact, and revolving rapidly by steam-power. The bloom is caught between these rollers, and passed backward and forward until it is pressed into a flat bar, averaging from four to six inches in width, and about an inch and a half thick. These bars are then cut into short lengths, piled, heated again in a furnace, and re-rolled. After going through this process they form the bar iron of commerce. From the iron reduced into this form the various parts used in the construction of iron bridges are made by being rolled into shape, the rolls through which the various parts pass having grooves of the form it is desired to give to the pieces. These rolls, when they are driven by steam, obtain this generally from a boiler placed over the heating- or puddling-furnace, and heated by the waste gases from the furnace. This arrangement was first made by John Griffie, the superintendent of the Phœnix Iron-Works, under whose direction the first rolled iron beams over nine inches deep that were ever made were produced at these works. The process of rolling toughens the iron, seeming to draw out its fibres; and iron that has been twice rolled is considered fit for ordinary uses. For the various parts of a bridge, however, where great toughness and tensile strength are necessary, as well as uniformity of texture, the iron is rolled a third time. The bars are therefore cut again into pieces, piled, re-heated, and rolled again. A bar of iron which has been rolled twice is formed from a pile of fourteen separate pieces of iron that have been rolled only once, or "muck bar," as it is called; while the thrice-rolled bar is made from a pile of eight separate pieces of double-rolled iron. If, therefore, one of the original pieces of iron has any flaw or defect, it will form only a hundred and twelfth part of the thrice-rolled bar. The uniformity of texture and the toughness of the bars which have been thrice rolled are so great that they may be twisted, cold, into a knot without showing any signs of fracture. The bars of iron, whether hot or cold, are sawn to the various required lengths by the hot or cold saws shown in the illustrations, which revolve with great rapidity.


COLD SAW.


HOT SAW.

For the columns intended to sustain the compressive thrust of heavy weights a form is used in this establishment of their own design, and to which the name of the "Phœnix column" has been given. They are tubes made from four or from eight sections rolled in the usual way and riveted together at their flanges. (See Plate XV.) When necessary, such columns are joined together by cast-iron joint-blocks, with circular tenons which fit into the hollows of each tube.

RIVETING A COLUMN.

To join two bars to resist a strain of tension, links or eye-bars are used from three to six inches wide, and as long as may be needed. At each end is an enlargement with a hole to receive a pin. In this way any number of bars can be joined together, and the result of numerous experiments made at this establishment has shown that under sufficient strain they will part as often in the body of the bar as at the joint. The heads upon these bars are made by a process known as die-forging. The bar is heated to a white heat, and under a die worked by hydraulic pressure the head is shaped and the hole struck at one operation. This method of joining by pins is much more reliable than welding. The pins are made of cold-rolled shafting, and fit to a nicety.

FURNACE AND HYDRAULIC DIE

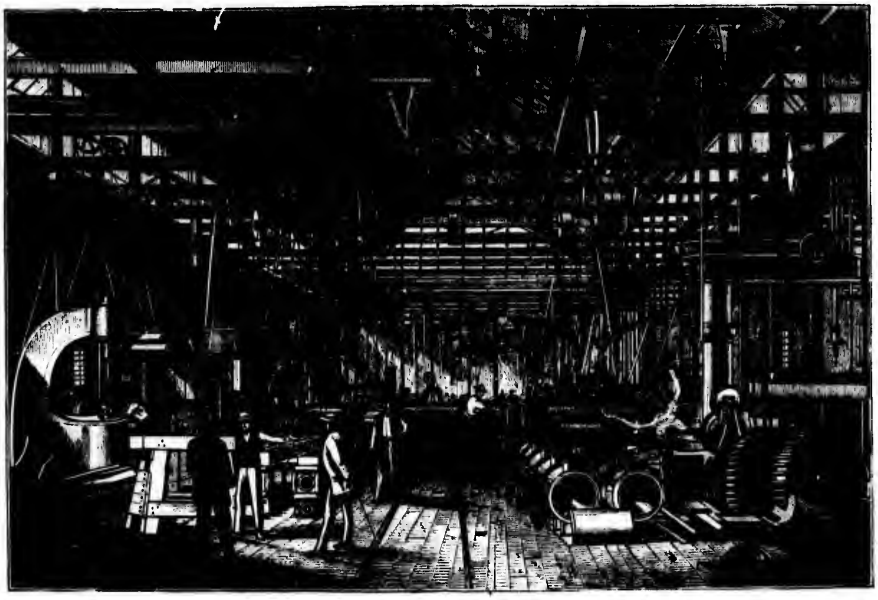
The general view of the machine-shop, which covers more than an acre of ground, shows the various machines and tools by which iron is planed, turned, drilled, and handled as though it were one of the softest of materials. Such a machine-shop is one of the wonders of this century. Most of the operations performed there, and all of the tools with which they are done, are due entirely to modern invention, many of them within the last ten years. By means of this application of machines great accuracy of work is obtained, and each part of an iron bridge can be exactly duplicated if necessary. This method of construction is entirely American, the English still building their iron bridges mostly with hand-labor. In consequence also of this method of working, American iron bridges, despite the higher price of our iron, can successfully compete in Canada with bridges of English or Belgian construction. The American iron bridges are lighter than those of other nations, but their absolute strength is as great, since the weight which is saved is all dead weight, and not necessary to the solidity of the structure. The same difference is displayed here that is seen in our carriages with their slender wheels, compared with the lumbering heavy wagons of European construction.

Before any practical work upon the construction of a bridge is begun, the data and specifications are given, and a plan of the structure is drawn, whether it is for a railroad or for ordinary travel, whether for a double or single track, whether the train is to pass on top or below, and so on. The calculations and plans are then made for the use of such dimensions of iron that the strain upon any part of the structure shall not exceed a certain maximum, usually fixed at ten thousand pounds to the square inch. As the weight of the iron is known, and its tensile strength is estimated at sixty thousand pounds per square inch, this estimate, which is technically called "a factor of safety" of six, is a very safe one. In other words, the bridge is planned and so constructed that in supporting its own weight, together with any load of locomotives or cars which can be placed upon it, it shall not be subjected to a strain over one-sixth of its estimated strength.

After the plan is made, working drawings are prepared and the process of manufacture commences. The eye-bars, when made, are tested in a testing-machine at double the strain which by any possibility they can be put to in the bridge itself. The elasticity of the iron is such that, after being submitted to a tension of about thirty thousand pounds to the square inch, it will return to its original dimensions; while it is so tough that the bars, as large as two inches in diameter, can be bent double, when cold, without showing any signs of fracture. Having stood these tests, the parts of the bridge are considered fit to be used.

When completed, the parts are put together or "assembled," as the technical phrase is, in order to see that they are right in length, etc. Then they are marked with letters or numbers, according to the working plan, and shipped to the spot where the bridge is to be permanently erected. Before the erection can be begun, however, a staging or scaffolding of wood, strong enough to support the iron structure until it is finished, has to be raised on the spot. When the bridge is a large one, this staging is of necessity an important and costly structure. An illustration on the next page shows the staging erected for the support of the New River bridge in West Virginia, on the line of the Chesapeake and Ohio Railway, near a romantic spot known as Hawksnest. About two hundred yards below this bridge is a waterfall, and while the staging was still in use for its construction, the river, which is very treacherous, suddenly rose about twenty feet in a few hours, and became a roaring torrent.

The method of making all the parts of a bridge to fit exactly, and securing the ties by pins, is peculiarly American. The plan still followed in Europe is that of using rivets, which makes the erection of a bridge take much more time, and costs, consequently, much more. A riveted lattice bridge, one hundred and sixty feet in span, would require ten or twelve days for its erection, while one of the Phœnixville bridges of this size has been erected in eight and a half hours.

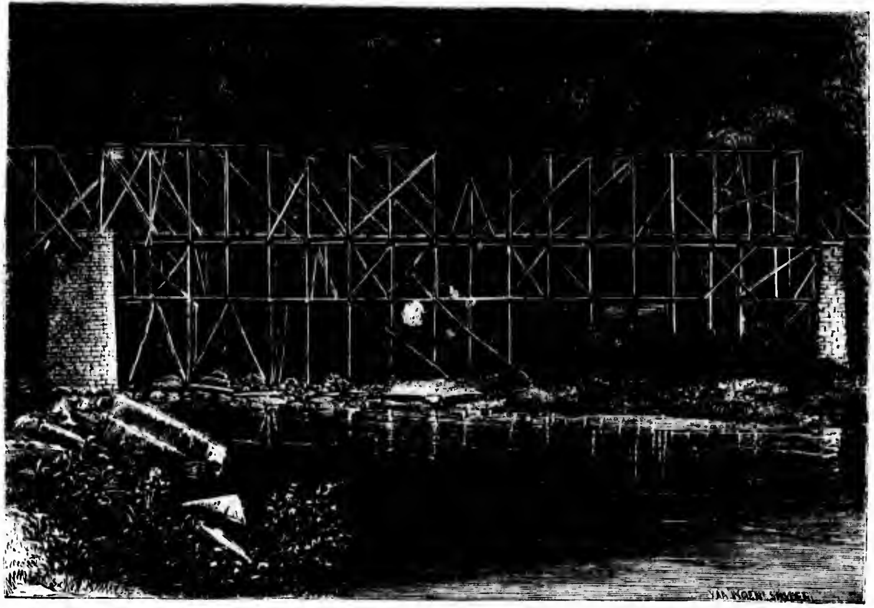


VIEW OF MACHINE-SHOP.

The view of the Albany bridge will show the style which is technically called a "through" bridge, having the track at the level of the lower chords. This view of the bridge is taken from the west side of the Hudson, near the Delavan House in Albany. The curved portion crosses the Albany basin, or outlet of the Erie Canal, and consists of seven spans of seventy-three feet each, one of sixty-three, and one of one hundred and ten. That part of the bridge which crosses the river consists of four spans of one hundred and eighty-five feet each, and a draw two hundred and seventy-four feet wide. The iron-work in this bridge cost about three hundred and twenty thousand dollars.

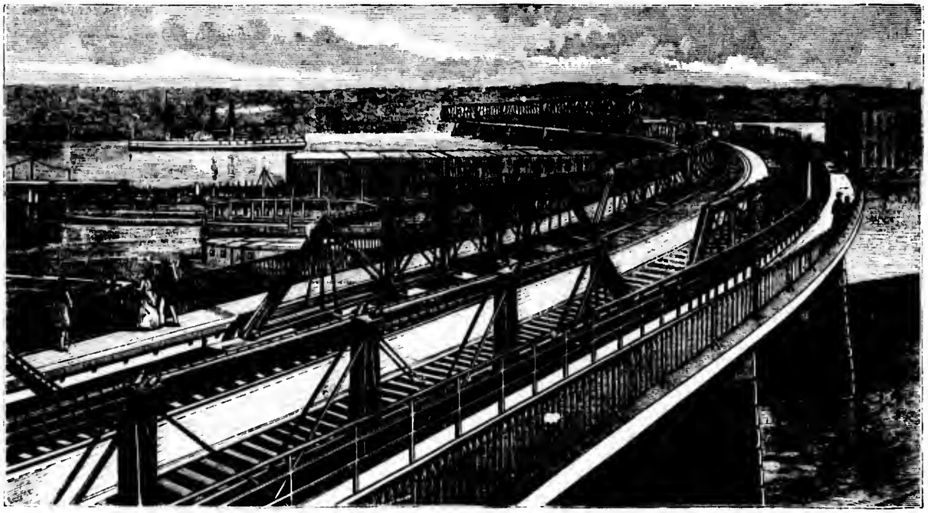
The bridge over the Illinois River at La Salle, on the Illinois Central Railroad, shows the style of bridge technically called a "deck" bridge, in which the train is on the top. This bridge consists of eighteen spans of one hundred and sixty feet each, and cost one hundred and eighty thousand dollars. The bridge over the Kennebec River, on the line of the Maine Central Railroad, at Augusta, Maine, is another instance of a "through" bridge. It cost seventy-five thousand dollars, has five spans of one hundred and eighty-five feet each, and was built to replace a wooden deck bridge which was carried away by a freshet.

The bridge on the Portland and Ogdensburg Railroad which crosses the Saco River is a very general type of a through railway bridge. It consists of two spans of one hundred and eighty-five feet each, and cost twenty thousand dollars. The New River bridge in West Virginia consists of two spans of two hundred and fifty feet each, and two others of seventy-five feet each. Its cost was about seventy thousand dollars.



NEW RIVER BRIDGE ON ITS STAGING.

The Lyman Viaduct, on the Connecticut Air-line Railway, at East Hampton, Connecticut, is one hundred and thirty-five feet high and eleven hundred feet long.



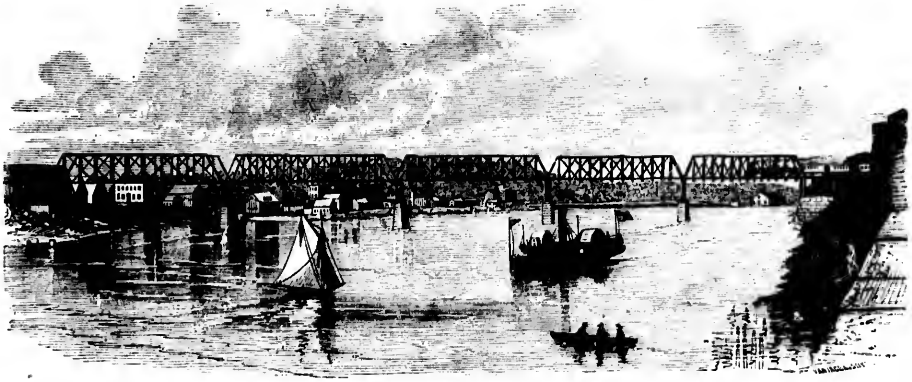
BRIDGE AT ALBANY.

These specimens will show the general character of the iron bridges erected in this country. When iron was first used in constructions of this kind, cast iron was employed, but its brittleness and unreliability have led to its rejection for the main portions of bridges. Experience has also led the best iron-bridge-builders of

America to quite generally employ girders with parallel top and bottom members, vertical posts (except at the ends, where they are made inclined toward the centre of the span), and tie-rods inclined at nearly forty-five degrees. This form takes the least material for the required strength.

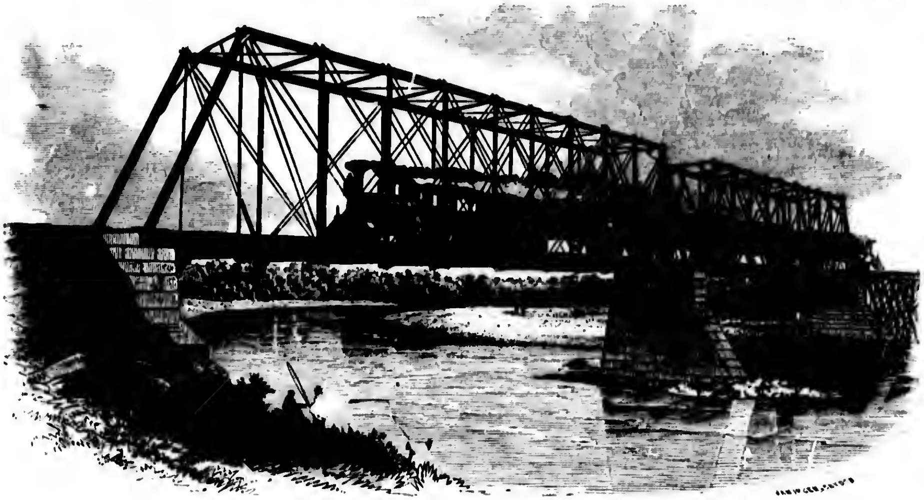
The safety of a bridge depends quite as much upon the design and proportions of its details and connections as upon its general shape. The strain which will compress or extend the ties, chords, and other parts can be calculated with mathematical exactness. But the strains coming upon the connections are very often indeterminate, and no mathematical formula has yet been found for them. They are like the strains which come upon the wheels, axles, and moving parts of carriages, cars and machinery. Yet experience and judgment have led the best builders to a singular uniformity in their treatment of these parts. Each bridge has been an experiment, the lessons of which have been studied and turned to the best effect.

LA SALLE BRIDGE.



BRIDGE AT AUGUSTA, MAINE.

There is no doubt that iron bridges can be made perfectly safe. Their margin is greater than that of the boiler, the axles, or the rail. To make them safe, European governments depend upon rigid rules, and careful inspection to see that they are carried out. In this country government inspection is not relied on with such certainty, and the spirit of our institutions leads us to depend more upon the action of self-interest and the inherent trustworthiness of mankind when indulged with freedom of action. Though at times this confidence may seem vain, and "rings" in industrial pursuits, as in politics, appear to corrupt the honesty which forms the very foundation of freedom, yet their influence is but temporary, and as soon as the best public sentiment becomes convinced of the need for their removal their influence is destroyed. Such evils are necessary incidents of our transitional movement toward an industrial, social, and political organization in which the best intelligence and the most trustworthy honesty shall control these interests for the best advantage of society at large. In the meantime, the best security for the safety of iron bridges is to be found in the self-interest of the railway corporations, who certainly do not desire to waste their money or to render themselves liable to damages from the breaking of their bridges, and who consequently will employ for such constructions those whose reputation has been fairly earned, and whose character is such that reliance can be placed in the honesty of their work. Experience has given the world the knowledge needed to build bridges of iron which shall in all possible contingencies be safe, and there is no excuse for a penny-wise-and-pound-foolish policy when it leads to disaster.



SACO BRIDGE.

PHŒNIX WORKS.

EDWARD HOWLAND.

APPENDIX No. 2.

LOADS AND STRAINS OF BRIDGES.

A paper presented by JOHN GRIFFEN and THOS. C. CLARKE, Civil Engineers, members of the American Society of Civil Engineers, at the Fourth Annual Convention of the Society, held at Chicago, June 5 and 6, 1872.

How to obtain uniformity of strength is the problem to be solved by the design of iron railway bridges. The strength of the weakest bridge, and of the weakest part of that bridge, measures the strength of all the bridges on a line of railway. The breaking of a single floor beam may wreck a train, and kill and wound many persons; and it is no consolation to know that all the other floor beams, tie rods, etc., of other bridges of the same line, have a superabundance of strength.

The strength of a bridge results from the following conditions:—

The heaviest loads to which it can be subjected.

The maximum strains resulting from those loads.

The sizes of the tensile and compressive members, and hence their strains per square inch of area.

The available strength of those members depending upon—First. The quality of the iron of which they are made. Second. The cross-section of the struts. Third. The mode of forming the connections.

Errors of design have been made in respect to all these points.

First. A uniform load per lineal foot has been assumed for all spans, short and long alike, while the actual load is greater for short, and less for long, spans, and is always in excess of the general load upon certain parts, such as floor beams.

Second. No distinction has been made between the effects of the dead load of the structure and the moving or live load of trains, suddenly applied and accompanied by shocks and vibrations.

Third. The margin of safety between the allowed strain and the disabling limit of the iron has been overestimated, as the margin of safety of the weakest part measures that of the whole.

Fourth. Sufficient distinction has not been made in specifications between a tough and elastic iron, and a hard and brittle quality, if the ultimate breaking strength of both were alike.

Fifth. The strains allowed upon compressive members are not based upon any definite knowledge of their ultimate powers of resistance.

These points will be considered in turn, and suggestions will be made toward a practice which shall result in uniformity of strength in all lengths of span, in all parts of every span, so that one part shall not give way before another.

The standard of strength must finally be determined by the engineer for each particular case. It would be useless to lay down any rules upon this point. Each man must be free to settle it for himself. But when he has decided it, and says, "I will adopt a margin of safety of three, four, five, or six," as the case may be, he wishes to feel certain that all his spans, and all their parts, form no exception to this rule. Uniformity of strength will then be attained; how much strength to give will be always an open question.

I. What are the actual loads to which railway bridges are subjected?

In Table No. 1, accompanying this paper, will be found a list of the weights and dimensions of the principal types of locomotives now used upon American railways, divided into three classes.

The first includes those engines of exceptional dimensions and weights which are used for pushing trains up heavy grades. Fortunately, their speed is slow.

The second class includes heavy freight and coal engines, whose average speed is ten to twelve miles an hour.

The third class the common form of four-driver passenger engines, which cross bridges at from twenty to fifty miles an hour.

Class four contains the various kinds of cars,—passenger, freight, and coal.

The following points may be discovered from inspection of this table:

That the weights of engines and loaded tenders average from 2300 to 2700 pounds per foot of track occupied, and that the weights of tenders, separately, are but little less.

That, owing to the concentrated weight of engine over drivers, the loads carried by spans of less than 100 feet will exceed these weights. As there are so many different types of engines we must select one of average dimensions and weight, leaving provision to be made for the passage of exceptionally heavy engines in the margin of safety which is to be fixed by the engineer of the bridge.

Take, therefore, an engine whose total weight with loaded tender is 125,000 pounds, occupying with pilot fifty feet of track, $\frac{125,000}{50} = 2500$ pounds per foot: distance occupied by wheel base of engine and tender alone is 41½ feet, $\frac{125,000}{41.5} = 3000$ pounds per foot; distance occupied on track by the concentrated weight over drivers, say 17 feet, and weight 60,000 pounds, $\frac{60,000}{17} = 3530$ pounds per foot; if the driving-wheel base is 15, $\frac{60,000}{15} = 4000$ pounds per foot; if the driving-wheel base is 12 feet, $\frac{60,000}{12} = 5000$ pounds per foot. This will give us the following loads:

Spans 12 feet and under	5000 pounds per foot.			
" 12 to 17 feet	4000	"	"	"
" 17 " 25 "	3500	"	"	"
" 25 " 83 "	3000	"	"	"
" 83 " 110 "	2500	"	"	"

Floor beams under 12 feet apart, and track stringers less than 12 feet long, will carry 5000 pounds per foot.

Floor beams 12 to 15 feet apart, and track stringers 12 to 15 feet long, will carry 4000 pounds per foot.

Inasmuch as the weight per foot of cars is considerably less than that of engines, in spans of over 100 feet, the actual load per foot will diminish with the length of span.

These results have been arranged in Table No. 2, showing, for different spans, the weights caused by—

1. All locomotives.
2. Reading coal cars, drawn by two Reading standard coal engines.
3. Same cars by one similar engine.
4. Pennsylvania box freight cars, drawn by two standard freight engines.
5. Same cars by one similar engine.
6. Pullman palace cars, drawn by one New York Central passenger engine.

These are the maximum loads which can come upon the chord systems of any of the forms of girder truss, upon the primary system of a Fink truss, or upon the arch and chord of a bowstring. Owing to the excess of weight of the locomotive above that of cars, the loads upon the panel systems of girder, trusses, and bowstrings, and the subsidiary systems of the Fink truss will be in excess, and should be taken for all spans at not less than 3500 pounds per foot.

II. It has been stated that it is not customary to make any distinction between the effects of the dead load of the bridge and the live load of trains. This varies very much in ratio, according to the length of span. Table No. 3 shows what the ratio of dead to live loads is for different spans.

There can be no doubt but that the short spans, where nine-tenths is live load, accompanied by vibration, are more severely strained than the long bridges where half the load is quiescent. It would appear that the margin of safety ought to be greater upon short than upon long spans, in order to give uniform strength.

It is difficult to say what the exact difference is between the effects of dead and live loads. Professor Macquorn Rankine, a very high authority, states in his "Applied Mechanics," "a suddenly applied force is equivalent in strain to twice the same force gradually applied."

This conclusion is confirmed both by the experiments made by order of the English Commissioners upon the application of iron to railway structures so far back as 1849, and by the later experiments of Fairbairn, which will not be quoted here in detail, as they are to be found in all the books.

From them it appeared that a tensile strain of six tons per square inch, applied to the bottom flange of a riveted plate girder, and accompanied by vibrations made to resemble, as much as possible, those caused by a passing train, did not break the girder, although repeated over three millions of times. But when the strain was increased to eight tons per square inch, it broke after 300,000 further applications. As the breaking strength of average English plate ranges from twenty to twenty-two tons, it would appear that the effect of live load was more than twice as severe as dead load. It is to be regretted that Dr. Fairbairn did not have the girders made of exactly the same dimensions, and of the same iron; ascertain the breaking static weight of one, and then apply one-half of this as live weight, and see how many applications it would bear before breaking.

If we agree with Rankine and Fairbairn, that the destructive effect of a live load is double that of a dead load, our course is clear. A suggestion, originally made it is believed by Unwin, in his treatise upon iron bridges, points the way to a simple solution of the problem. Multiply the live load by two, and add it to the dead load. Their sum will be a load which may safely be treated as an all dead load, and a strain per square inch and margin of safety used such as is proper for dead loads.

Table No. 4 shows the equivalent dead loads applicable to all spans. If these loads, or rather this principle of fixing loads, be adopted by engineers, one uncertain element will be eliminated from the problem, and the only point left open will be what limit of strain to put upon the iron.

III. It has been stated that the value of the factor or margin of safety is commonly over-estimated. It is not uncommon to read in specifications that the factor of safety shall be *six*, meaning that the working strain shall be one-sixth of the ultimate breaking strain.

A little consideration will show that the true margin of safety is the difference between the working strain and that strain which would give the iron a permanent set and unfit it for use, either by crippling the compressive members or by stretching the tension members so that the bridge would become distorted and "sag" below a level line. Even before this point was reached, the iron in tension would have become "overstrained," causing its particles to suffer permanent derangement. Although this "set," as it is called, does not diminish the ultimate capacity of the iron to support a dead load, yet, as has been pointed out by Stoney, when the "stretch" is taken out of an originally tough piece of iron, it becomes brittle. It is well known that a chain that has been overstrained in testing is liable to snap off with less than its proof load.

This limit of elasticity of wrought iron under tension is that point at which the elongations cease to be in uniform proportion to equal additions of load, and coincides very nearly with the point at which visible set takes place. It does not vary much from one-half of the ultimate strength of the iron. Common English plate, bar, and angle iron. of an ultimate strength of from twenty to twenty-two tons per square inch, has an elastic limit of not over ten tons per square inch. The highest grades of English and American double refined bar iron of an ultimate strength of 55,000 to 60,000 pounds per square inch, have an elastic limit of from 25,000 to 30,000 pounds per square inch; hence a working strain of 10,000 pounds per square inch gives an available margin of strength or safety, or whatever term we may prefer to call it, of from two to three, instead of six.

Whatever the engineer selects, it should be enough to allow for—1. Possible inequality of material. 2. Imperfection of workmanship. And 3. The effects of deterioration, arising both from use and from natural causes.

A dread of inequality of material is the reason why engineers prefer wrought iron to cast iron or to steel for the construction of bridges. If the engineer could always depend upon getting such a quality of cast iron as the late General Rodman made for artillery, which was worked up to a tensible strain of 27,000 pounds per square inch, and was really more like cast steel than iron, his objections to the use of cast iron would vanish.

It has been stated that in experiments upon the material for the St. Louis bridge, some steel bolts, 5¾ inch diameter, broke with 30,000 pounds per square inch, and no elongation; while small bolts ¾ inch diameter, of the same material, bore 100,000 pounds per square inch, and elongated considerably.

Imperfection of workmanship should not be found in our American bridges which are made by machine tools. In riveted lattice and plate girders it is a serious cause of the actual strength falling below that given by calculations. Giving a margin of strength beyond what seems to be required, is, as we have stated, a recognition of the fact that iron bridges will decay like all human works.

But it is not so generally known that if a bridge has not enough iron in certain parts, although built of good iron and put together strongly, it will *wear out* under a heavy traffic, just as locomotives, cars, and rails wear out. One or two instances will illustrate this. Where pin connections are used, owing to the concentration of strains which comes upon a pin, it is necessary to "reinforce," as it is termed, the plates of iron upon which the pins bear, and thus increase the bearing surface until the pressure is reduced to 7000 or 8000 pounds per square inch, or else the pin will cut into the iron, or the iron into the pin.

In the Crumlin viaduct, as originally built with pin connections, this principle was not recognized, enough bearing surface was not given, and the pin-holes became enlarged. The pins were removed, and the struts riveted to the chords, and this example is frequently quoted to show the superiority of riveted over pin connections, while in reality it only shows imperfect design.

Another still more striking example can be found nearer home. On the Reading railway, plate girder bridges of 25 feet span and under were originally proportioned for a rolling load of two tons per foot of track. It was found that under the heavy traffic of that road, the webs of these girders at the delivery end crushed or buckled. They have since been rebuilt, or strengthened and proportioned for a rolling load of four tons per foot of track, and now wear very well.

IV. Whatever be the adopted margin of safety, it would appear that a larger margin should be allowed in the case of hard and brittle iron than in that of a tough and ductile quality. But this is just what most bridge specifications do not do.

The experiments of Kirkaldy have clearly shown that a high ultimate breaking strength may be due to the iron being tough, or merely to its being hard and unyielding. In the former case, it will "draw down" and stretch considerably before breaking; in the latter, it will snap short off with but little elongation and contraction of area at the point of fracture. One is tough, the other is brittle, and yet both may have an equally great ultimate strength. How shall we know them apart?

The required iron should not be too soft, the limit of elasticity should not fall below 25,000 pounds per square inch before showing visible set. The breaking strength should run from 55,000 to 60,000 pounds per square inch. A bar a foot long, and of one square inch area, should elongate at least 15 per cent. before breaking.

As it is not always easy to measure accurately the contracted area at the point of rupture, there is no simpler nor better mode of testing ductility than by bending the bar cold, and such a bar should bend double, cold, without any signs of fracture.

Mr. G. Berkeley, in his valuable paper read before the London Institution of Civil Engineers at the session of 1870, states his experience with English irons as follows:—"Experience extending over twenty years, and comprising many thousands of experiments, has proved that a quality of iron can be obtained at the current prices of the day, which will bear the following tests:—

"For plates, an average breaking strength of 20 tons per square inch, and a minimum of 19 tons per square inch, and an average stretch of 1 inch in twelve lineal = 8.33 per cent.

"For angle and T irons, an average breaking strength of 22 tons per square inch, and an average stretch of 1¼ inches in twelve lineal = 10.5 per cent.

"For rivet iron, an average breaking strength of 18 tons per circular inch."

Common American bar iron will not ordinarily bear over 50,000 pounds ultimate strength, will not elongate over 8½ per cent., and will show signs of fracture when bent cold over 45 degrees.

The undersigned have tested iron as brittle as this, and quite unfit to go into a bridge, the breaking strength of which was over 60,000 pounds per square inch.

Engineers should provide such tests in their specifications as will distinguish the two sorts apart, and if they admit the use of the lower grade iron, should discriminate by fixing a larger margin of safety than for the tougher and better iron. If they do not, they will be pretty sure to get the poorer quality, as it costs less money, and the reason why will be shown.

The mode of making refined iron at Phœnixville is to take a high quality of gray forge pig iron, and work it in a furnace by the process technically known as "boiling," the boiling furnace being "fettled" with ore. This pig iron when "brought to nature" is balled up in the furnace in the usual way, squeezed in a Burden squeezer, and then rolled into a flat bar, technically known as a "muck bar," or No. 1 bar.

From each heat so made one bar is taken and bent to an angle of 45 degrees cold; if it stands without any signs of fracture the heat is passed as good, if not, it is rejected.

The iron that has passed this test is piled, charged in a heating furnace, heated and rolled into flat bars. This is called No. 2 bar, and is sold as "Phœnix Best." The iron so rolled is again cut, piled, and rolled into the finished bar, and is called No. 3 bar, and is the iron sold by the Phœnix Iron Co. as "Phœnix Best Best." A bar of this iron, 2⅜ inches diameter, has been bent cold so that the sides came in close contact without showing the least signs of fracture.

It should be borne in mind that the object of reworking iron is to refine it by getting rid of the surplus cinder and scoria, making the iron firm in texture and of a more uniform quality. This uniformity of quality results from the fact that the pile from which a bar of No. 2 is made consists of fourteen No. 1 bars, and the pile of No. 3 of eight No. 2, so that if by chance an inferior muck bar had been used, it would form but $\frac{1}{112}$ part of the No. 3, or "Best Best" bar.

All iron improves up to the third working, but if the quality of the pig is not suitable no amount of working will make the product good iron; hence the necessity for tests as to toughness and stretching.

The ordinary iron of commerce is made, as a rule, from an inferior quality of pig, is frequently worked in its conversion from carbonate to metallic iron by the process practically known as puddling, instead of boiling, and is only once worked from the puddle or muck bar, corresponding to No. 2 iron.

It is also made sometimes from scrap iron and often from old rails. Neither of these modes gives reliable iron, as there is no certainty of the quality of the scrap used, though bar iron made from scrap is ordinarily reckoned as good quality. Iron from old rails is always inferior, and not to be trusted for the uses of a high-grade iron, as rails are generally made in the first place of inferior iron.

Hence it follows that a reliable iron for bridge purposes should be made of a known quality of pig, worked in the best way in the boiling furnace, tested in the muck bar, and cut, piled, heated, and rolled once or twice thereafter, according as single- or double-refined iron is needed.

It is not to be expected, nor is it desirable, that the engineer should dictate the process of manufacture, but he should establish such tests in his specification as will distinguish an inferior from a high quality of iron, and what these tests should be has been previously stated.

TABLE No. I.

ACTUAL WEIGHTS OF ENGINES, TENDERS, CARS, ETC.

No.	DESCRIPTION.	No. of Driving Wheels.	No. of Truck Wheels.	Concentrated weight on Drivers divided by length of driving-wheel base.	Resulting weight per foot.	Total weight of engine and loaded tender divided by distance covered on track, including pilot.	Resulting weight per foot.
	CLASS No. 1.—"PUSHERS."						
1	Reading Railway Tank, all	12	None.	102,000 19 ft. 7 in.	5204	102,000 36 ft.	2833
2	Reading Railway Tank, with tender	10	"	82,200 15 ft. 8 in.	5268	132,200 54 ft. 1 in.	2448
3	Pennsylvania Railway, with tender	8	"	80,000 22 ft.	3636	140,000 54 ft.	2595
4	Baltimore & Ohio Railway, with tender	8	2	84,000 12 ft. 6 in.	6720	128,000 53 ft.	2415
5	Fairlie double-ender	12	None.	60,480 8 ft.	7560	120,900 52 ft.	2326
	CLASS No. 2.—HEAVY COAL AND FREIGHT.						
6	Chicago, Burlington & Quincy, Freight	6	4	72,000 12 ft.	6000	128,000 53 ft. 6 in.	2392
7	Reading, standard coal	6	4	53,000 9 ft. 6 in.	5578	122,128 50 ft. 3 in.	2430
8	Pennsylvania, standard freight	6	4	54,500 12 ft. 5 in.	4360	129,900 54 ft.	2405
9	Delaware, Lackawanna & Wilmington, standard freight	6	4	71,500 12 ft.	5948	138,900 54 ft.	2572
10	New York Central, special freight	6	2	65,000 15 ft. 6 in.	4193	120,000 45 ft.	2666
11	Erie broad gauge, special freight	6	4	72,156 14 ft. 6 in.	4976	137,444 54 ft.	2545
	CLASS No. 3.—MIXED PASSENGER AND FREIGHT AND PASSENGER.						
12	Reading, mixed passenger and freight	4	4	41,440 6 ft. 6 in.	6376	115,184 45 ft. 7 in.	2526
13	Reading, standard passenger	4	4	25,264 6 ft. 6 in.	3887	103,260 43 ft. 10 in.	2325
14	Pennsylvania, standard passenger	4	4	45,400 8 ft.	5675	125,300 53 ft. 6 in.	2342
15	Grand Trunk of Canada, standard passenger and freight	4	4	40,320 7 ft. 6 in.	5376	112,000 49 ft.	2275
16	New York Central, standard passenger and freight	4	4	40,000 7 ft. 6 in.	5460	100,000 44 ft.	2272
17	Average of loaded tenders	...	8	16,500 to 25,000 4 ft. 6 in.	3666 to 5550	33,000 to 50,000 20 ft.	1650 to 2500
	CLASS No. 4.—LOADED CARS.						
18	Pennsylvania Railway, sleeping and passenger cars	....	....	....	....	57,000 64 ft. 2 in.	890
19	Pennsylvania Railway, box freight cars	....	....	....	....	42,000 31 ft.	1355
20	Reading, long coal cars	....	....	....	....	40,000 22 ft.	1818
21	Lehigh Valley, short coal cars	....	....	....	....	19,000 13 ft.	1461
22	Pullman palace and sleeping cars	....	....	....	....	71,600 75 ft.	954

TABLE NO. 2.

WEIGHT IN POUNDS PER FOOT RUN OF TRACK, FOR DIFFERENT SPANS AND KINDS OF TRAINS.

LENGTH OF SPANS IN FEET.	1. All Locomotive Engines.	2. COAL TRAIN. Cars (No. 20) drawn by 2 Engines (No. 7).	3. COAL TRAIN. Cars (No. 20) drawn by 1 Engine (No. 7).	4. FREIGHT TRAIN. Cars (No. 19) drawn by 2 Engines (No. 8).	5. FREIGHT TRAIN. Cars (No. 19) drawn by 1 Engine (No. 8).	6. PASSENGER TRAIN. Cars (No. 22) drawn by 1 Engine (No. 16).
Under 12	5000					
12 to 17	4000					
17 to 25	3500					
25 to 83	3000					
83 to 110	2500					
110		2430	2094	2405	1870	1481
125		2365	2067	2262	1809	1418
150		2275	2026	2111	1740	1350
175		2200	2000	2065	1710	1285
200		2130	1974	1922	1665	1244
225		2100	1950	1864	1631	1211
250		2068	1943	1809	1603	1186
300		2026	1922	1733	1562	1147
350		2000	1907	1679	1532	1120
400		2000	1895	1638	1510	1100

TABLE NO. 3.

RATES OF DEAD TO LIVE LOAD, FOR DIFFERENT SPANS.

LENGTH OF SPANS IN FEET.	DEAD LOAD of Bridge, Track, Rails, etc., per foot.	LIVE LOAD of Coal Train with 2 Engines, per foot.	TOTAL LOAD, lbs., per foot.		RATIO OF DEAD TO LIVE.	
					DEAD.	LIVE.
Under 12	500	5000	5500		.09	.91
12 to 17	550	4000	4550		.12	.88
17 to 25	625	3500	4125		.15	.85
25 to 50	700	3000	3700		.19	.81
50 to 83	800	3000	3800		.21	.79
100	900	2500	3400		.26	.74
110	1000	2430	3430		.30	.70
125	1135	2365	3500		.32	.68
150	1225	2275	3500		.35	.65
175	1300	2200	3500		.37	.63
200	1500	2130	3630		.41	.59
225	1700	2100	3800		.45	.55
250	2000	2068	4068		.49	.51
300	2400	2026	4426		.54	.46
350	3000	2000	5000		.60	.40
400	4000	2000	6000		.66	.34

TABLE NO. 4.

DEAD AND LIVE LOAD PER FOOT, REDUCED TO EQUIVALENT DEAD LOAD.

1. LENGTH OF SPANS IN FEET.	2. Dead LOAD of Bridge, etc., per ft.	3. Twice Live LOAD of Coal Train per ft.	4. Sum of columns 2 and 3, being equivalent Dead Load per ft.
Under 12	500	10,000	10,500
12 to 17	550	8000	8550
17 to 25	625	7000	7625
25 to 50	700	6000	6700
50 to 83	800	6000	6600
100	900	5000	5900
110	1000	4860	5860
125	1135	4730	5865
150	1225	4550	5775
175	1300	4400	5700
200	1500	4260	5760
225	1700	4200	5900
250	2000	4136	6136
300	2400	4052	6452
350	3000	4000	7000
400	4000	4000	8000

APPENDIX No. 3.

FROM THE "CHICAGO RAILROAD GAZETTE," JULY, 1870.

ENGLISH AND AMERICAN IRON BRIDGES.

SOME two months ago tenders were solicited for the construction of iron railway bridges of spans of 100 and 200 feet, by the Intercolonial Railway of Canada, connecting Quebec and Halifax. This call was very generally responded to, there being tenders put in by nineteen English, one Belgian, and sixteen American bridge-builders.

The specification, which was a rigid one, called for uniformity of strength, but left the design open to each person. The bridges were all to be of wrought iron, capable of bearing 1¼ gross tons per lineal foot, in addition to their own weight, without straining the iron in tension to over 10,000 pounds per square inch. The iron of the 200 feet spans was to be capable of bearing 60,000 pounds per square inch before breaking, and that of the 100 feet spans 50,000 pounds per square inch.

Much interest was felt as to the result of this competition, which was virtually one between English and American systems of bridge building. The decision was that the long spans were awarded to an American firm, Messrs. **CLARKE, REEVES & CO.**, of Phœnixville, Pa., and the short spans to English bridge-builders, the Fairbairn Manufacturing Company, of Manchester. Of the thirty-six plans submitted, only three or four were rejected on account of not coming up to special strength.

The bridges of Clarke, Reeves & Co. were selected for the long spans, not only as being undoubtedly first-class, both in material and workmanship, but also as being the lowest responsible tender. Some curiosity has been expressed to know how American bridge-builders, using high-priced iron, and paying higher wages for labor than their English competitors, could yet build a less costly bridge.

While it is to some extent true that the specifications allowed of a lower quality and less expensive iron for the 100 than for the 200 feet span, yet one of the principal reasons why an American firm was lowest on the long and an English firm on the short spans is owing to the less weight of iron required by the American system of bridge, and this is more apparent the longer the span.

Some persons erroneously suppose that the more iron there is in a bridge the stronger it will be. But a little reflection will show that it is only the iron that is working, or, in other words, that is actually strained by the load, that contributes to the strength of the structure. All the rest is dead weight, and merely weighs down the bridge. In very short spans this is not disadvantageous, as it tends to diminish vibration, but in long spans where the weight of the bridge much exceeds that of the load passing over it, every pound of iron that does not contribute to the strength of the bridge is a positive injury. To illustrate this more clearly: if one bridge weighs 125 tons and another 250, and both are strained by the rolling load 10,000 pounds per square inch, the lighter is the stronger of the two. But if the 125 ton bridge be strained 10,000 pounds per square inch, while the 250 ton bridge is strained only 5000 pounds per square inch, then the latter has really double the strength and double the life of the former; for half the iron may corrode away, and then the working area of the bar will be equal. It is not clearly perceiving this fact—that the strength of the bridge depends upon the working area of its part—that has led our English friends to make such heavy bridges.

In several plans, if the strain per square inch are alike for similar loads they must all be of the same strength, providing the connections are equally perfect. Some take more iron than others to effect the result, but the result is the same.

The lightness of American bridges is due—1st, to the concentration of material along the lines of strain, which enabled a lighter web system to be used, and hence a higher truss; 2d, to this greater height of truss, which throws less leverage on the upper and lower chord system, and hence requires less iron in their members; 3d, to the use of eye and pin connections instead of rivets, by which there is no waste of metal to compensate for the deduction of rivet-holes.

American bridges are stiffer vertically and better braced laterally than English bridges, their greater height giving less deflection under a load, and allowing of overhead bracing as well as that below the track.

But the less quantity of iron required to do the work is not the whole explanation of the less cost of American as compared with English bridges. A second and equally important reason is the less amount of manual labor required to construct and erect them—owing to the general use of machinery in forming all the parts.

English bridges are made of low-price iron and require a great deal of it, and a great deal of hand-labor in constructing and erecting.

American bridges have all their principal parts formed by machinery. They are of exact uniform dimensions, in similar spans, and hence perfectly interchangeable, like the parts of the locks of the American rifles, or of sewing-machines. Hence machine-labor can be applied to their manufacture, and the cost at the works reduced to a minimum.

But American bridges have still another advantage. They are so made that nearly all the work is done at the shops, and they can be erected with the least possible amount of labor, and that unskilled. In fact, the cost of erecting the staging is the principal expense; after that a 200 feet span can be erected and made self-sustaining in the space of two days, if necessary. (See letter of T. D. Lovett, Ex-Chief Engineer Ohio and Mississippi Railway Company.)

But the English bridge is only about half done when the scaffolding is built and the iron placed upon it. It has then to be riveted together, which is expensive, as the conveniences for such work at the site of a bridge are not often great. It is slow and tedious, requiring from two to three weeks to put together a 200 feet span.

Taking all these things into account, it will be seen how American bridge-builders have been able to compete with English firms on the large bridge at Buffalo, and in the recent case of the long span bridges of the Intercolonial Railroad of Canada.

CINCINNATI, Nov. 11, 1872.

GENTLEMEN :—

Below please find a statement of the force employed and time consumed in raising the last span of Medora Bridge over White River, near Medora, Indiana, for the Ohio and Mississippi Railway Company. Length, centre to centre of end pins, 147 feet 6 inches. Height of truss, 28 feet.

The force consisted of—

Howard and ten men, one truss.

Buzby and ten men, one truss.

Kelly and ten men, running in iron.

Bussing and seven men, connecting top end of tie bars, afternoon only. Employed on other work not connected with raising in the forenoon.

Monday, February 5, 1872, commenced running in iron at 8 A.M., at 5.30 P.M., same day, span swinging clear and top laterals on. Iron moved on an average one hundred and fifty feet. The men all went to Medora for dinner, one and a half miles distant, which consumed one hour strong, making the actual working time eight hours and thirty minutes. Total force, three foremen and thirty men full time, one foreman and seven men four and a half hours, equivalent to three hundred and sixteen and a half hours for one man.

Style of truss, "Pratt or Whipple." Details of construction by Clarke, Reeves & Co., by whom the bridge was constructed at their works in Phœnixville, Pennsylvania.

E. S. Duval, Superintendent of Bridges, Ohio and Mississippi Railway, says:—

"I am satisfied that the same length with the same crew of men can be raised in less time than last span at Medora. We had no idea of swinging the span that day. We commenced in the morning; after dinner, however, seeing how rapidly we had advanced in the fore part of the day, we then determined to swing the span before leaving it."

Many of the men had been in the employ of the Ohio and Mississippi Company under my directions for a number of years.

You are at liberty to use the above in any manner you see proper.

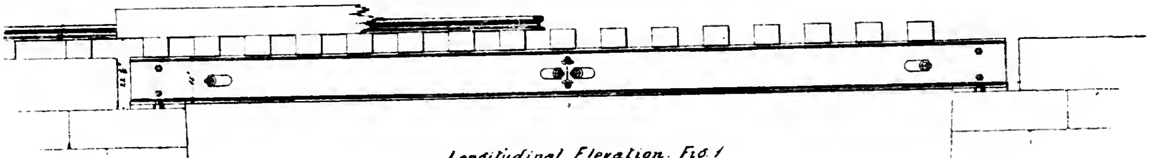
Very truly yours,

THOS. D. LOVETT,

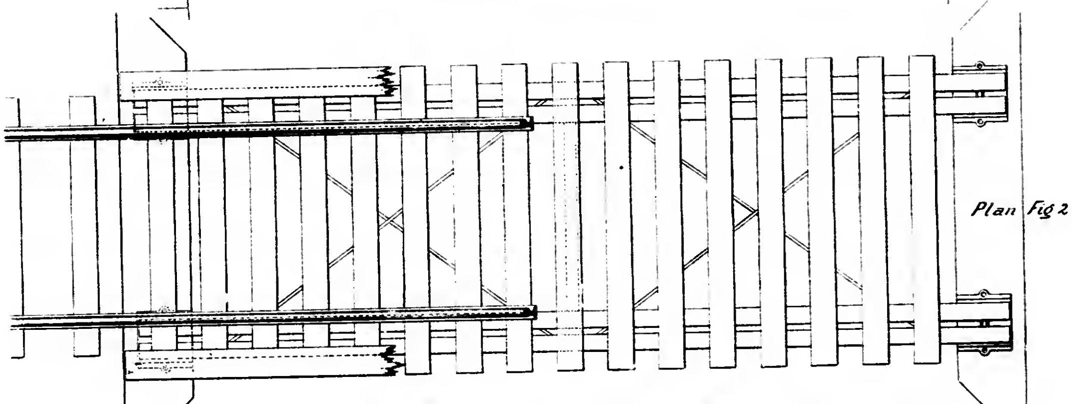
Ex-Chief Engineer Ohio and Mississippi Railway Co.

Plate. 1.

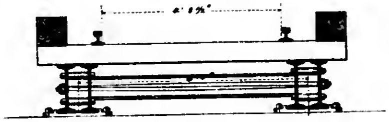
10 to 20 Feet.



Longitudinal Elevation. Fig. 1

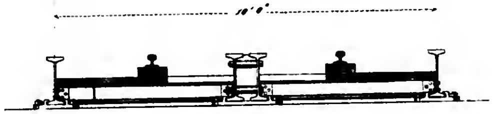


Plan Fig. 2



Cross Section. Fig. 3

Plain Girder. Design A.



Headway very much limited Fig. 4

Phoenixville Bridge Works.

Clarke, Reeves & Co.

410 Walnut Str. Phila.

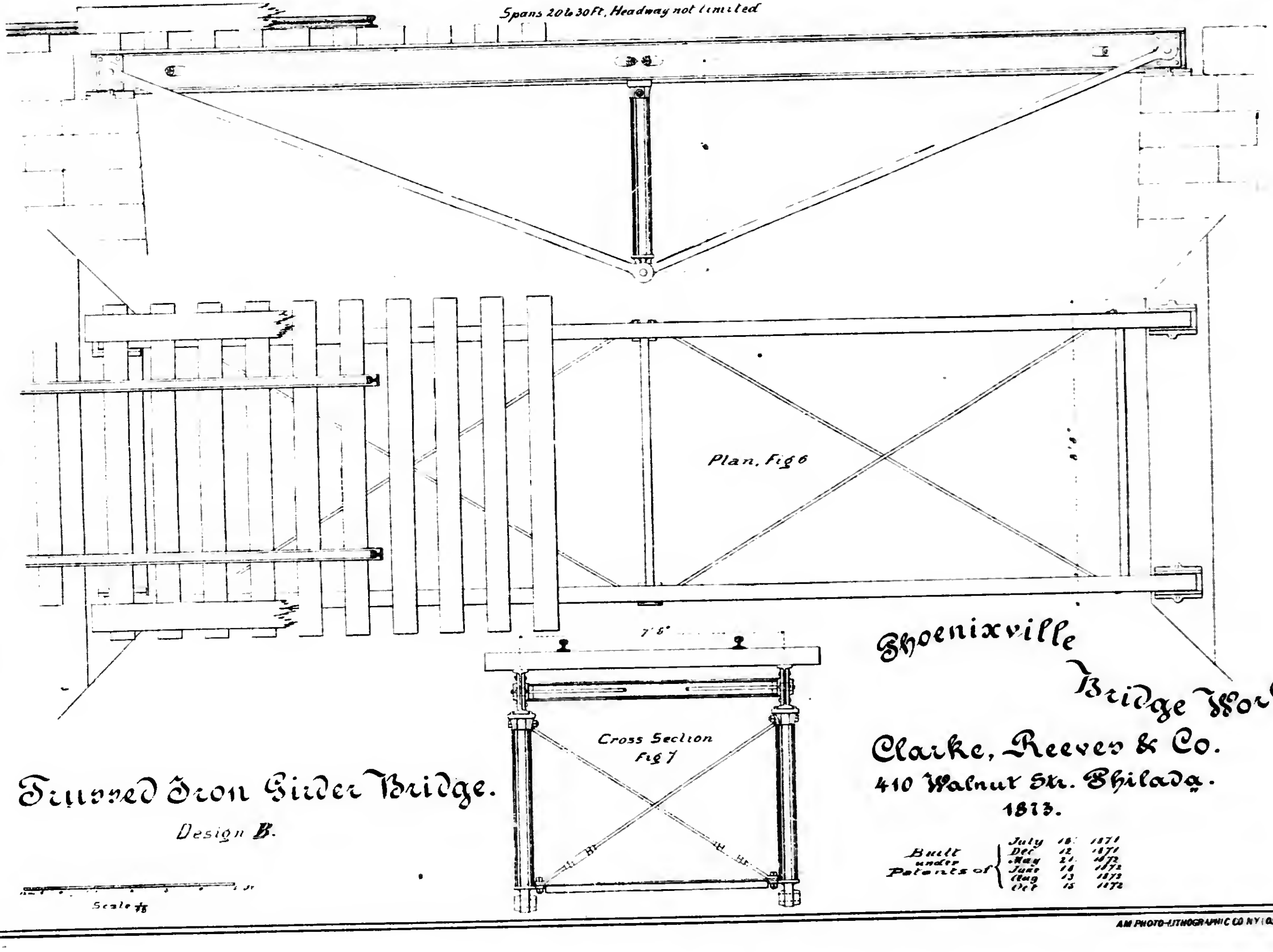
1873.

Built under Patents of
- July 18 1871
- Dec 12 1871
- May 21 1872
- June 18 1872
- Aug. 13 1872
- Oct 15 1872

Scale 1/48

AM PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS)

Plate. 2.



Trussed Iron Girder Bridge.

Design B.

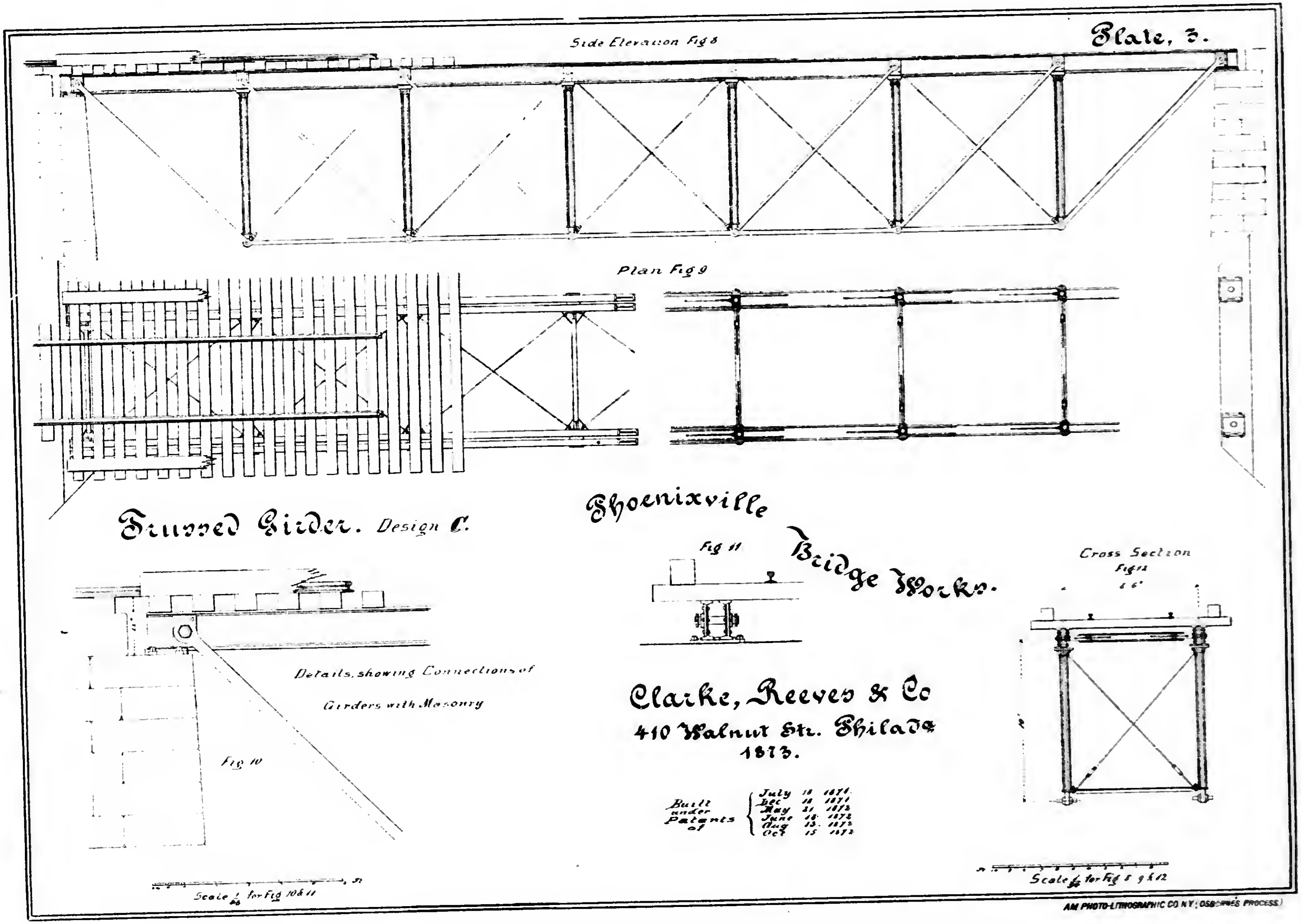
Phoenixville Bridge Works.

Clarke, Reeves & Co.
410 Walnut St. Philada.
1873.

Built under Patents of
July 18 1871
Dec 12 1871
May 21 1872
June 18 1872
Aug 13 1872
Oct 15 1872

AM PHOTO-LITHOGRAPHIC CO N.Y. (OSBORNES PROCESS)

Plate, 3.



Trussed Girder. Design C.

Phoenixville Bridge Works.

Clarke, Reeves & Co
410 Walnut Str. Philada
1873.

Built under Patents of {
July 18 1871
Dec 18 1871
May 21 1872
June 18 1872
Aug 13 1872
Oct 15 1872

AM PHOTO-LITHOGRAPHIC CO N.Y. (OSBORNE'S PROCESS)

Plate. 4.

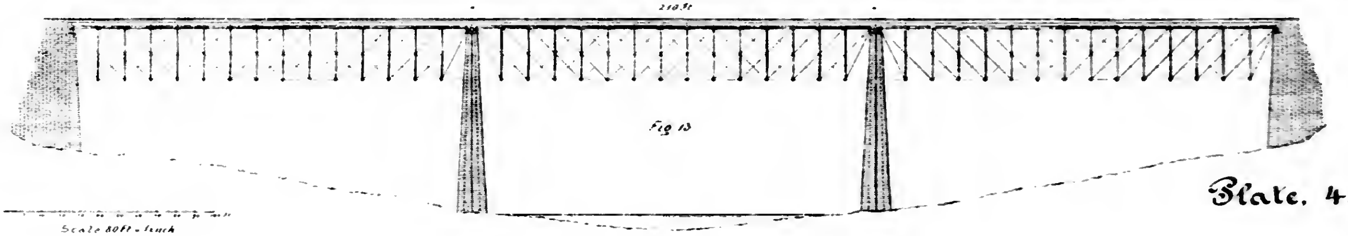
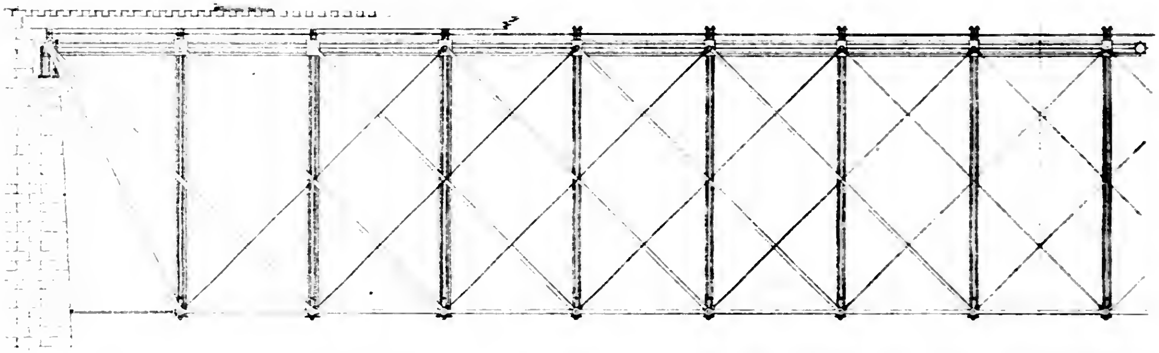
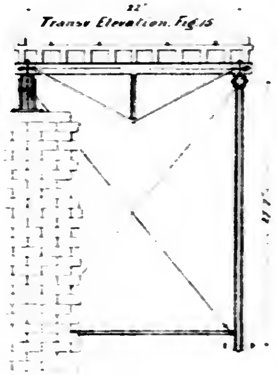


Fig 13

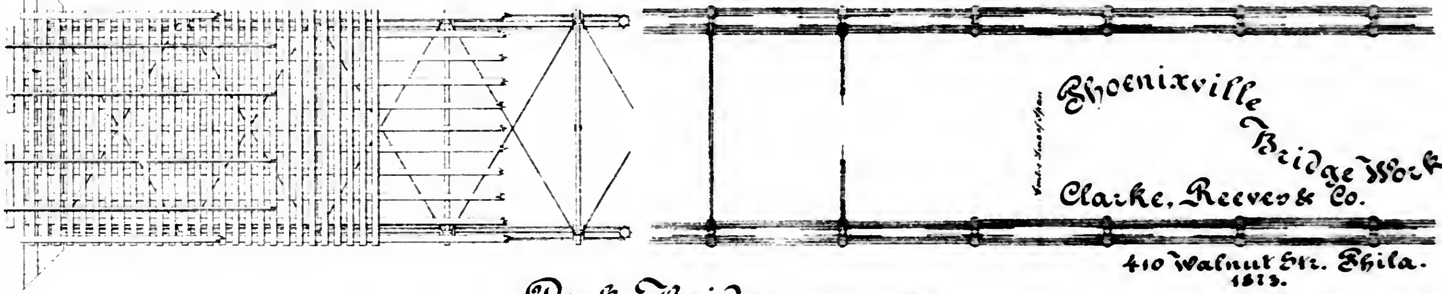
Side Elevation Fig 14



Transv Elevation. Fig 15



Plan Fig 16



Deck Bridge. Design D.

Phoenixville Bridge Works.
Clarke, Reeves & Co.
410 Walnut Str. Phila.
1873.

Built under Patents of
July 16 1870
Dec 16 1870
May 21 1872
June 18 1872
Aug 13 1873
Oct 15 1872

AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS)

Plate, 5.

Details of Design D.

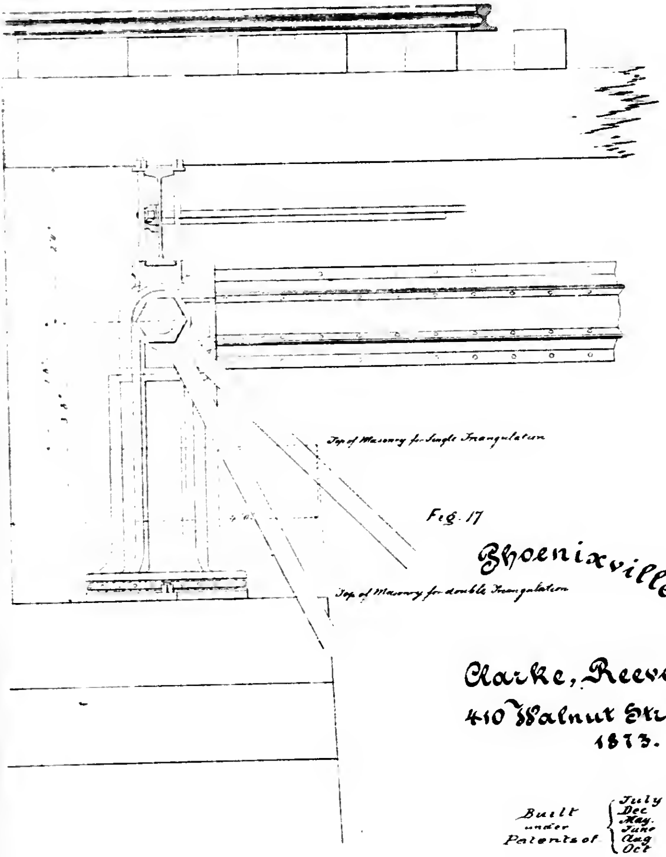


Fig. 17

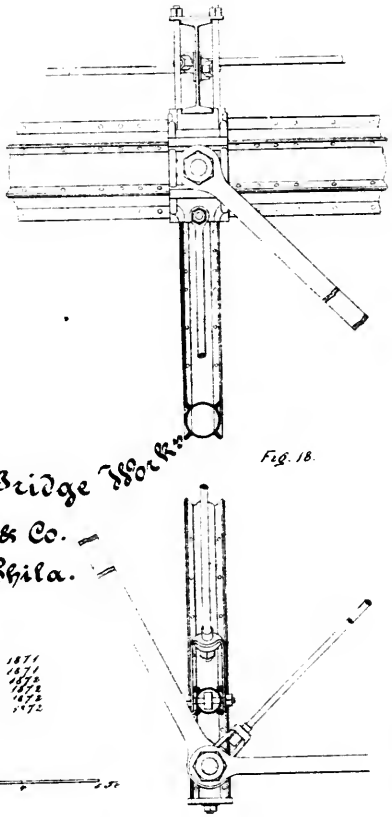


Fig. 18

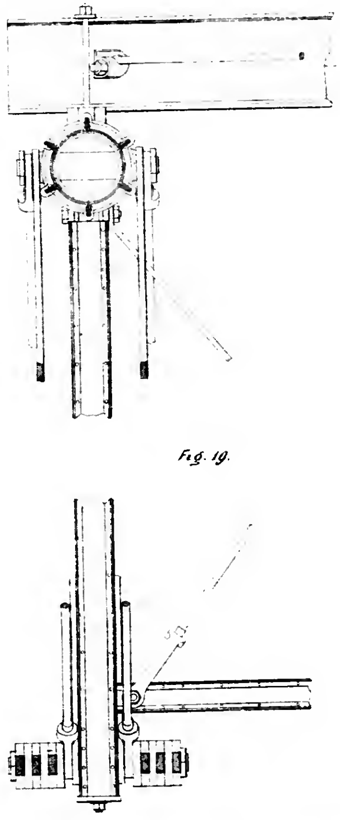


Fig. 19

Phoenixville Bridge Works

Clarke, Reeves & Co.
410 Walnut St. Phila.
1873.

Built under Patents of
July 18 1871
Dec 12 1871
May 21 1872
June 18 1872
Aug 13 1872
Oct 15 1872

Scale 1/24

AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS)

Plate. 6.

Low Truss. Design E.

Side Elevation. Fig 20

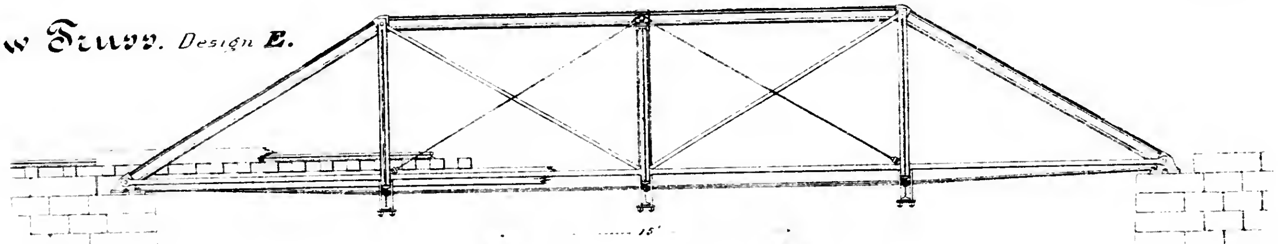
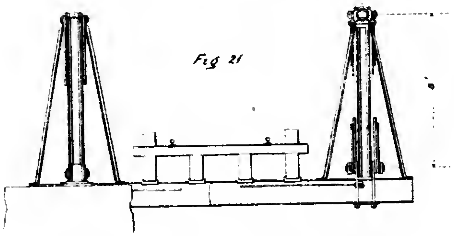


Fig 21



End Elevation

Interior Elevation

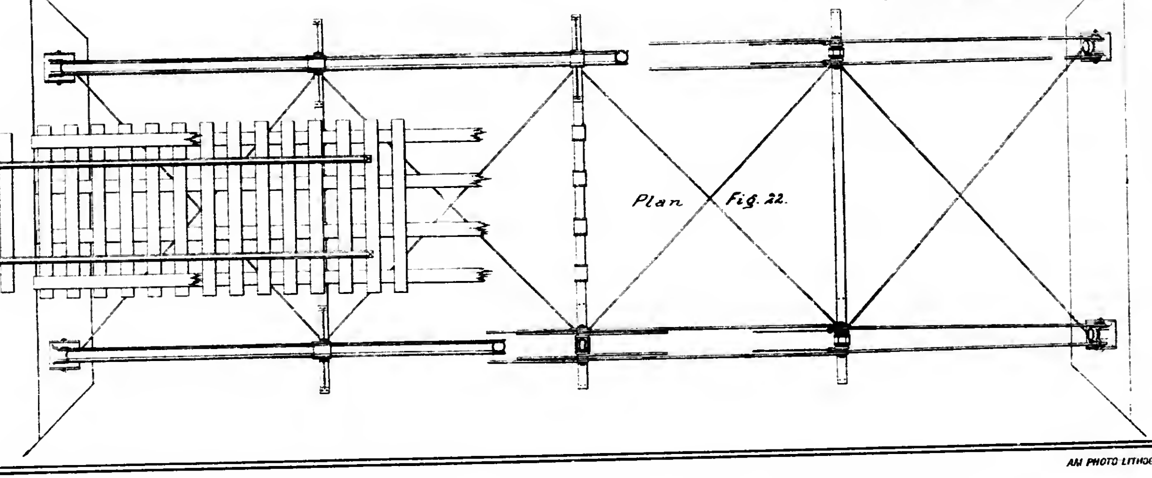
Scale 1/96

Phoenixville Bridge Works.

Clarke, Reeves & Co.
410 Walnut St. Phila.
1873.

"Built under Patents of

July 18 1871
Dec 12 1871
May 21 1872
June 18 1872
Aug 13 1872
Oct 15 1872



Plan Fig. 22.

AM PHOTO LITHOGRAPHIC CO N.Y. (OSBORNE'S PROCESS.)

Plate, 7.

255 Ft from ℄ to ℄ of End Pins

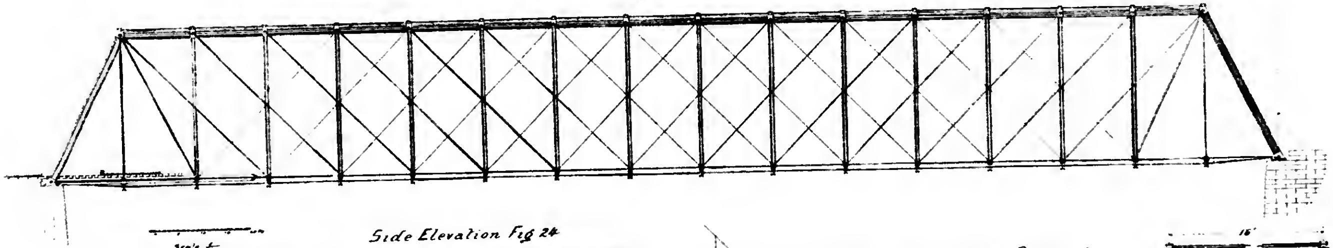
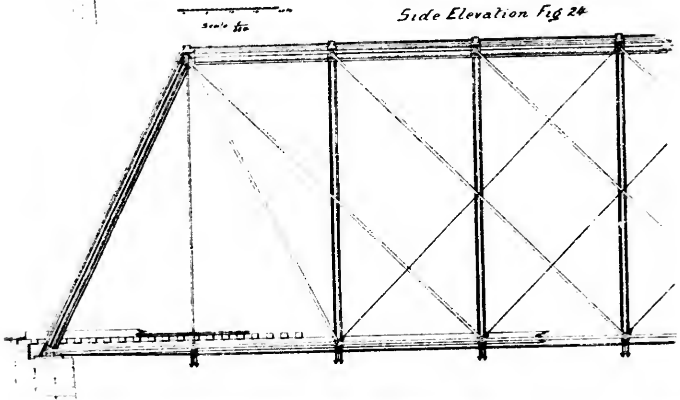
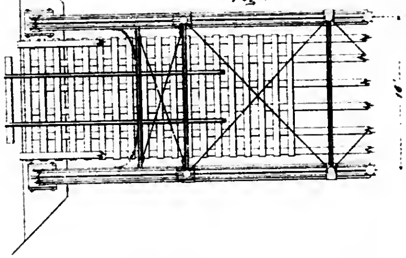


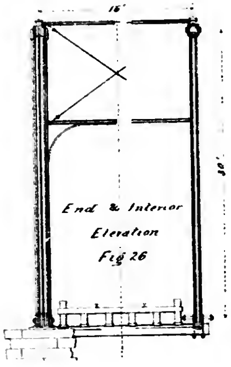
Fig 23

Side Elevation Fig 24



Plan of Upper Chord & Bracing
Fig 25

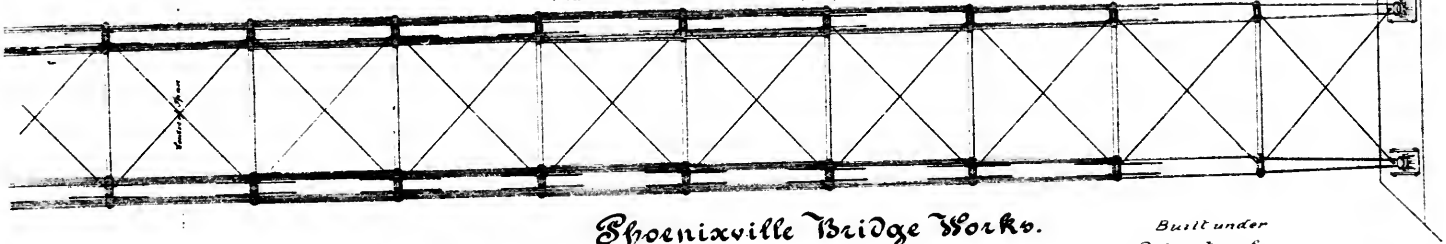




End & Interior
Elevation
Fig 26

Scale 1/12 for Fig 24, 25, 26 & 27.

Plan of lower Chord & Bracing Fig. 27



Through Truss Design F.

Phoenixville Bridge Works.
Clarke, Reeves & Co.
410 Walnut Str. Phila. 1873.

Built under
Patents of

July 18 1871.
Oct. 13. 1871.
May 21 1872
June 18 1872
Aug 13. 1872
Oct 15 1872

AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS.)

Plate, 8.

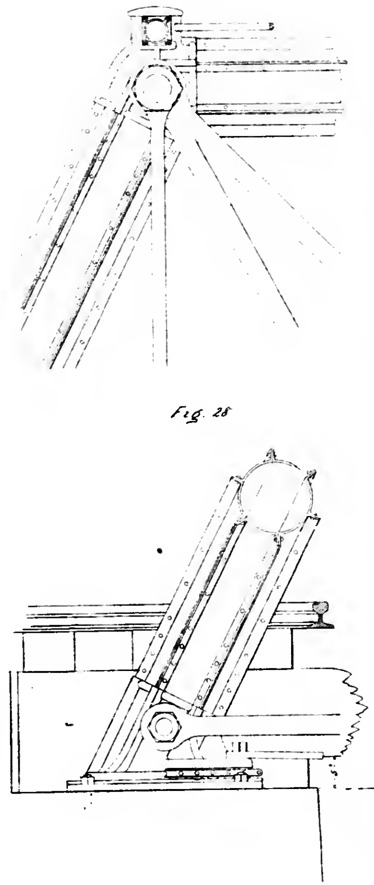


Fig. 28

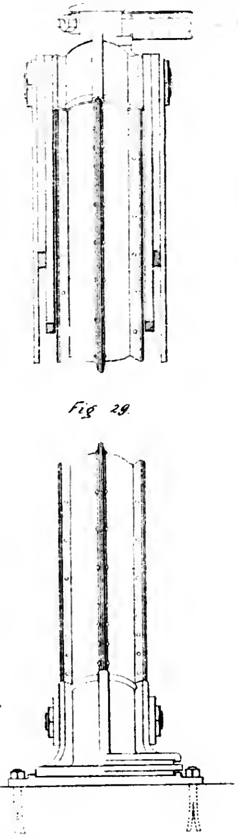


Fig 29.

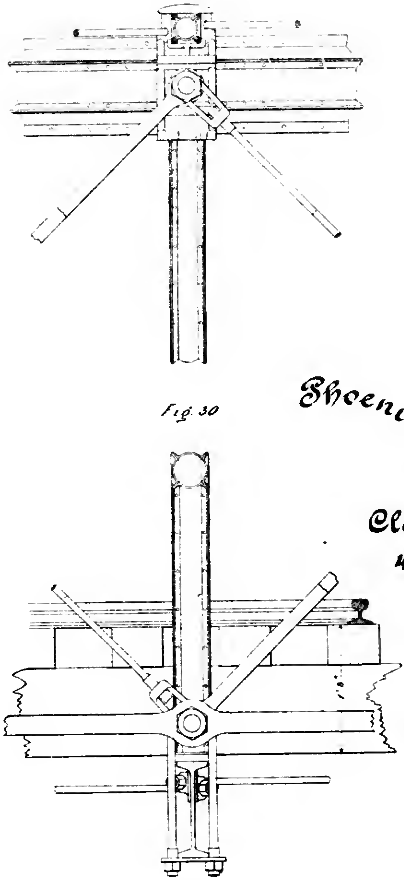


Fig. 30

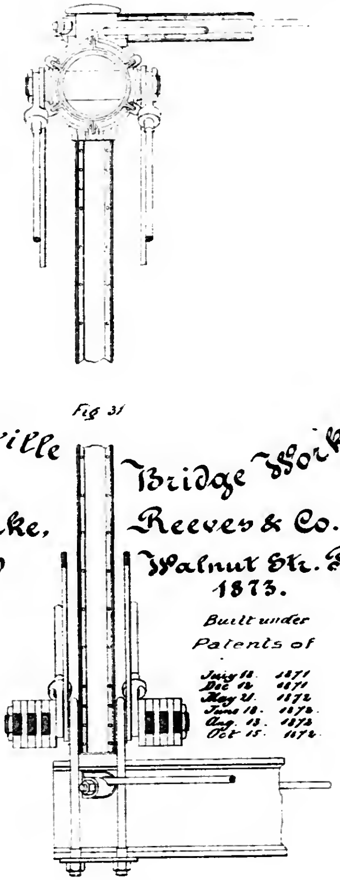


Fig 31

Phoenixville Bridge Works.
Clarke, Reeves & Co.
410 Walnut St. Phila
1873.

Built under
Patents of

July 18. 1871
Dec 12. 1871
May 21. 1872
June 18. 1872
Aug. 13. 1872
Oct 15. 1872.

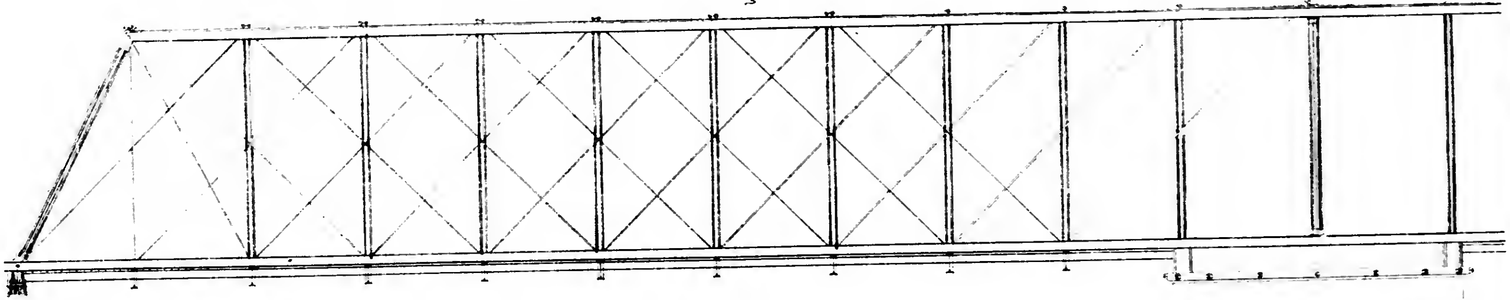
Details of Designs B. F & G.

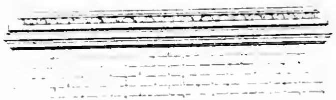
Scale 1/24

AM PHOTO-LITHOGRAPHIC CO N.Y. (OSBORNE'S PROCESS)

Plate. 9.

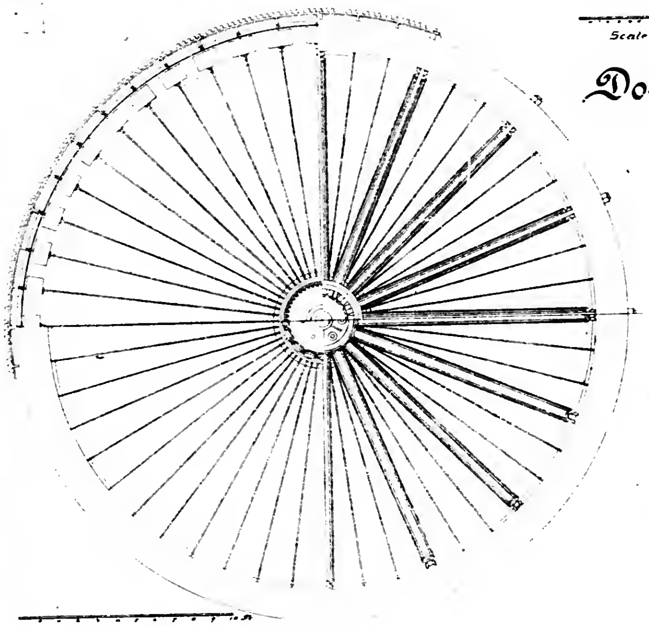
Fig 32





Scale 1/92 for Fig 32

Fig 33



Scale 1/36 for Fig 33, 34 & 35

Double Track Pivot Bridge.

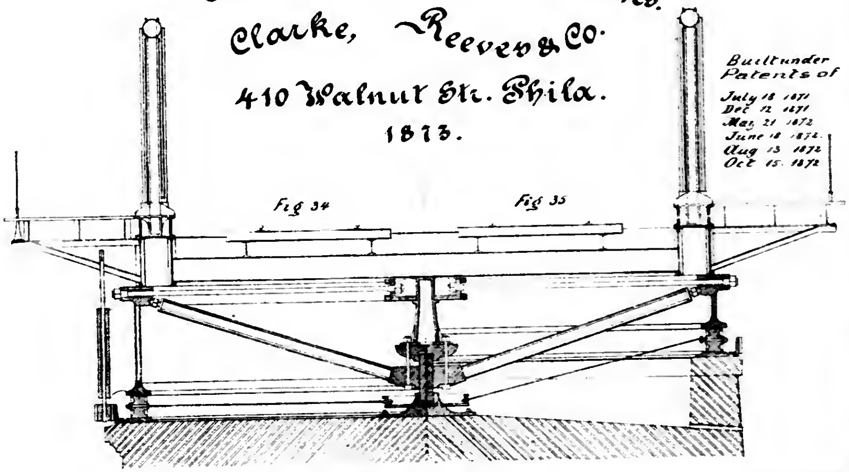
Design A.

Phoenixville Bridge Works.
Clarke, Reeves & Co.
410 Walnut St. Phila.
1873.

Built under
Patents of

July 18 1871
Dec 12 1871
May 21 1872
June 18 1872.
Aug 13 1872
Oct 15. 1872

Fig 34 Fig 35



AM. PHOTO-LITHOGRAPHIC CO N.Y. (OSBORNE'S PROCESS)

Phoenixville Bridge Works.

Plate, 10.

Clarke, Reeves & Co.

410 Walnut Str. Phila. 1873.

Details Design H.

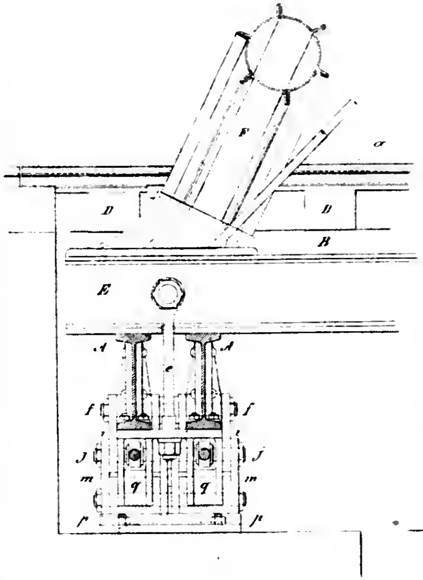


Fig 36

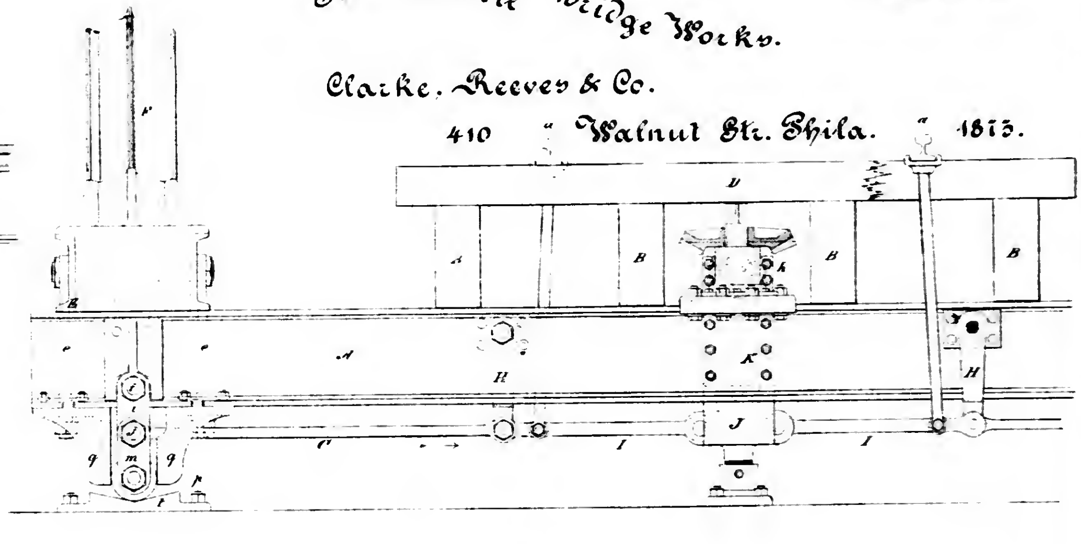


Fig 37

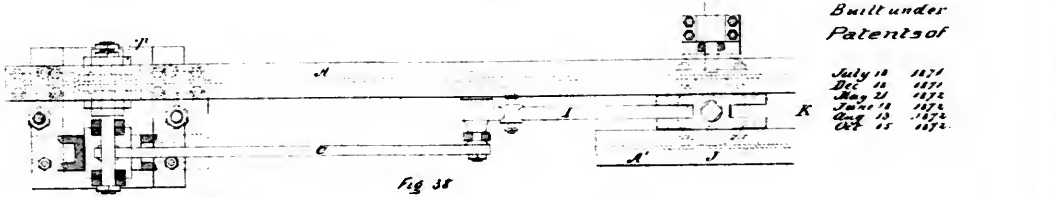


Fig 38

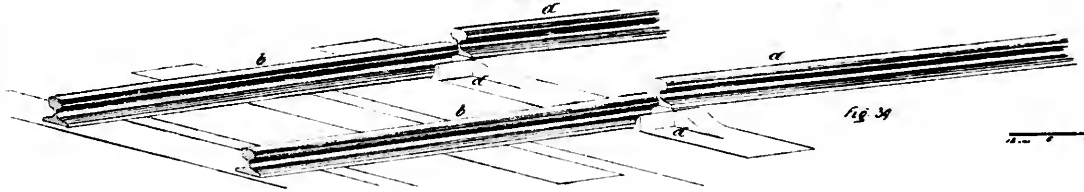


Fig 39

Built under
Patents of

July 18	1871
Dec 12	1871
May 21	1872
June 18	1872
Aug 13	1872
Oct 15	1872.

Scale 1/24

Am. Photo-Lithographic Co. N.Y. (Osborne's Process)

Plate. 11.

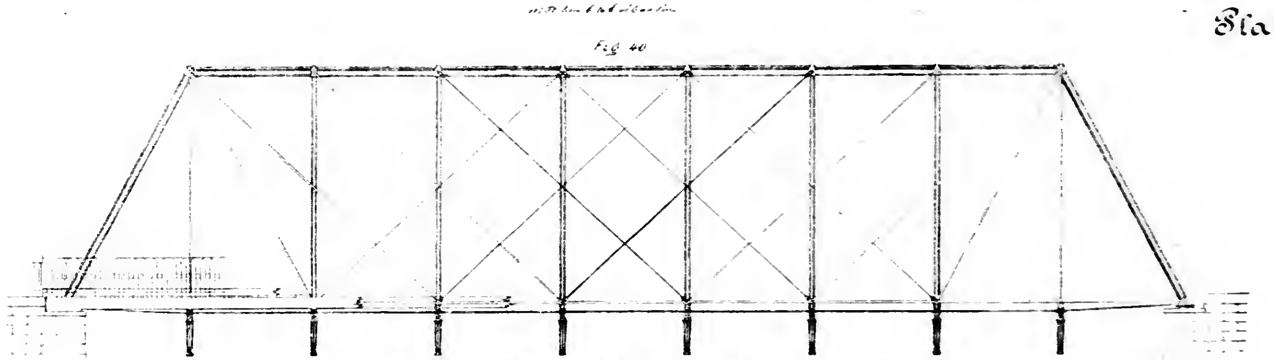


Fig 40

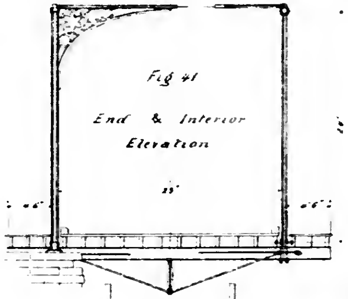


Fig 41

Highway Bridge.

Design F.

Phoenixville Bridge Works.

Clarke, Reeves & Co.

410 Walnut St. Phila.

1873.

Built under
Patents of

July 11 1871
Dec [illegible] 1871
May 21 1872.
June [illegible] 1872
Aug 13 1872
Oct 15 1872

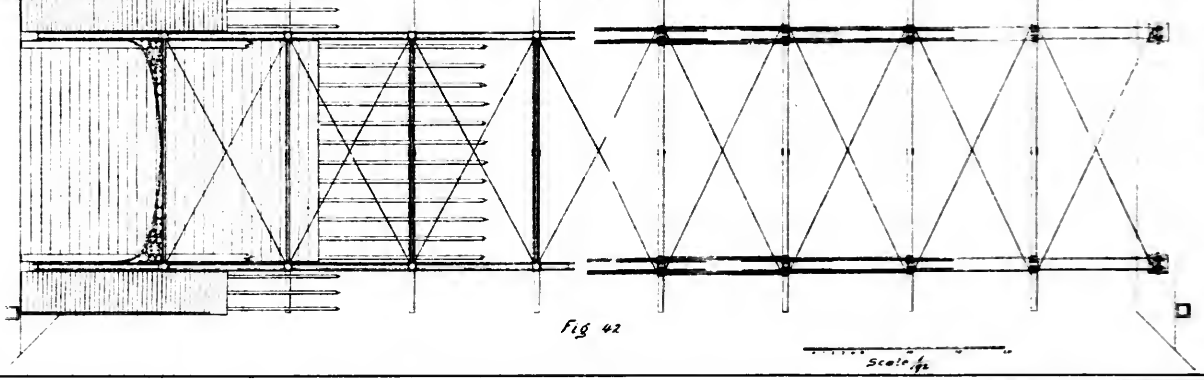


Fig 42

Scale 1/92

AM PHOTO-LITHOGRAPHIC CO N.Y. (OSBORNE'S PROCESS)

Highway over Railway. Design I.

Plate. 12.

Fig 43

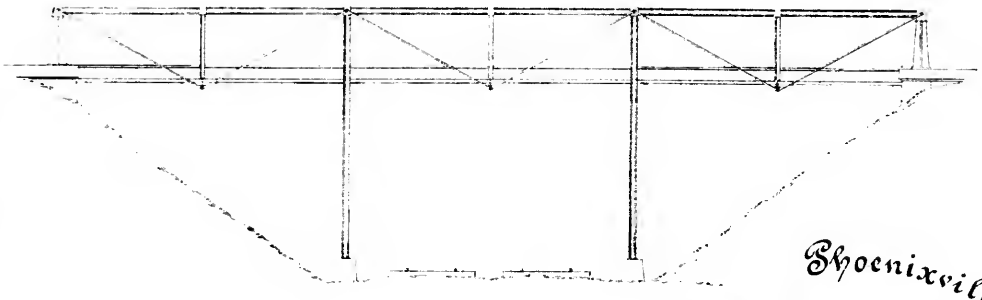
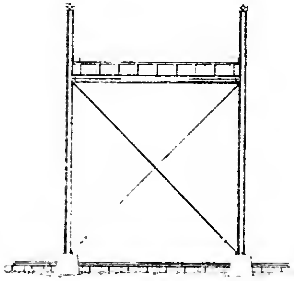


Fig 44



Phoenixville Bridge Works.

Clarke, Reeves & Co.

410 Walnut Str. Philada. 1873.

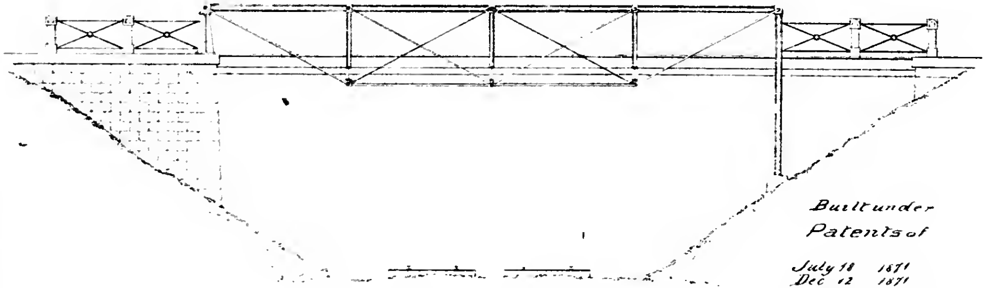


Fig 45

Built under
Patents of
July 18 1871
Dec 12 1871
May 21 1872
June 18 1872
Aug. 13. 1872
Oct 15. 1872.

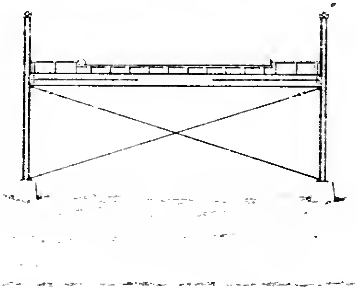


Fig. 46

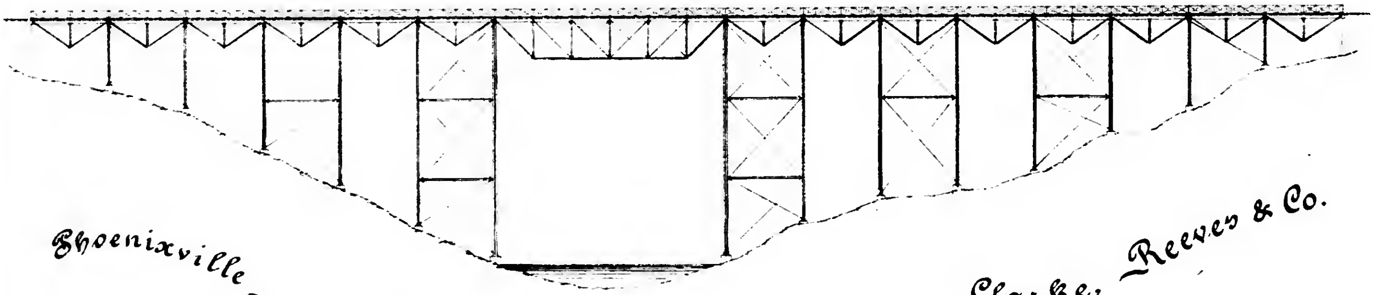
Scale 1/12

AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS)

Plate, 13.

Wrought Iron Viaduct. Design K.

Fig 47



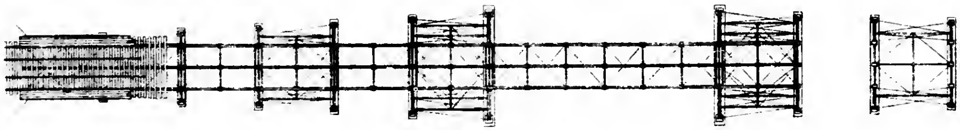
Phoenixville Bridge Works.

Clarke, Reeves & Co.

410 Walnut Str. Philada.

1873.

Fig 48



Built under Patents of

July 18 1871
Dec 12 1871
May 21 1872
June 18 1872
Aug 13 1872
Oct 15 1872

Scale 60 ft = 1 inch

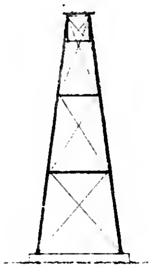


Fig 49

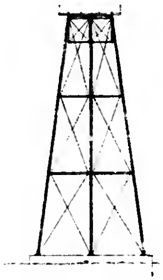


Fig. 50

AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS.)

Plate, 14.

Wrought Iron Viaduct. *Design* **L.**

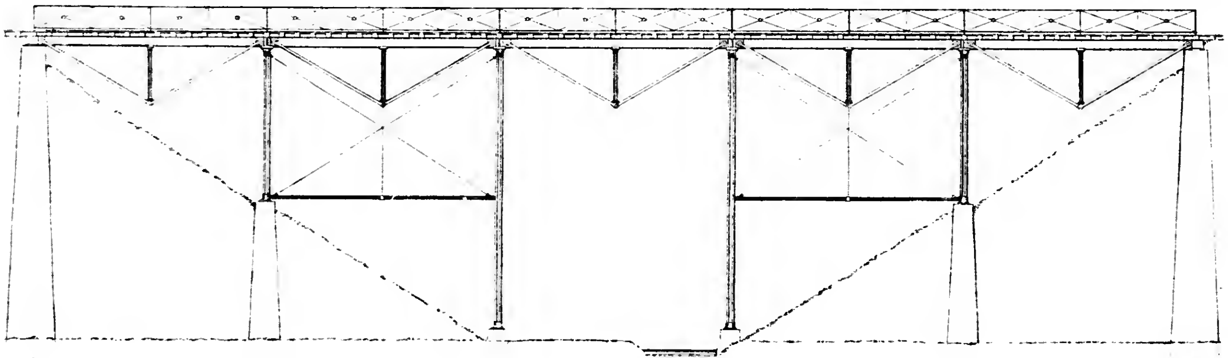


Fig 51

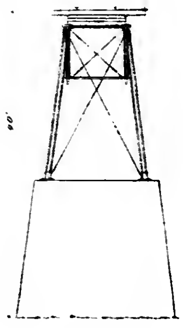


Fig 52
Cross Section of Piers 2 & 5

Screw Pile Viaduct. *Design* **M.**

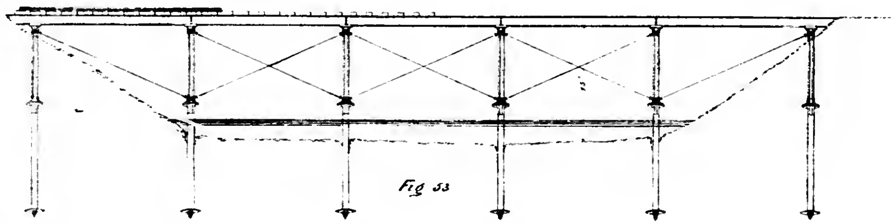
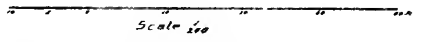


Fig 53



Scale $\frac{1}{200}$

Built under
Patents of

July	18	1871
Dec	12	1871
May	21	1872
June	18	1872
Aug.	13	1872
Oct	15	1872

Phoenixville Bridge Works.

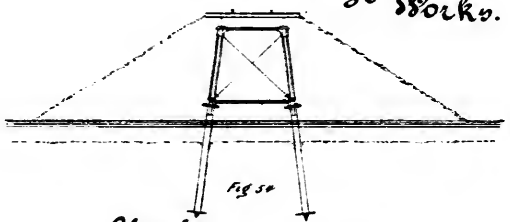


Fig 54

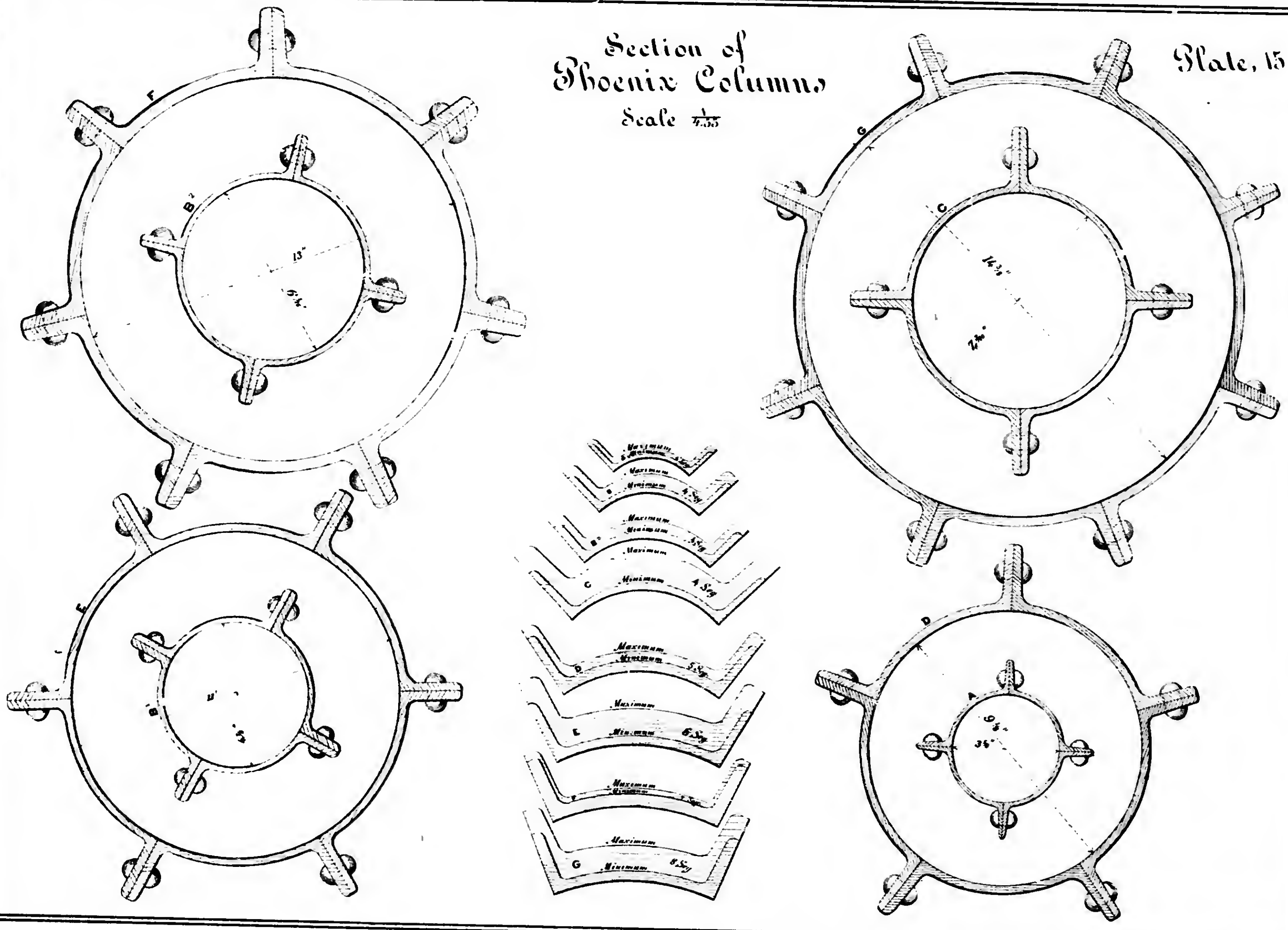
Clarke, Reeves & Co.
410 Walnut St. Phila.
1873.

AM PHOTO LITHOGRAPHIC CO (OSBORNE'S PROCESS)

Plate, 15.

Section of Phoenix Columns

Scale $\frac{1}{4.33}$



AM. PHOTO-LITHOGRAPHIC CO. N.Y. (OSBORNE'S PROCESS)

TESTS OF

Description of Column.
4 Seg. B^1 Column
4 Seg. B^1 "
4 Seg. A "
4 Seg. A "
4 Seg. A "
4 Seg. A "
*4 Seg. B^1 "
†4 Seg. B^1 "
‡4 Seg. C "
4 Seg. C "

---

*This Column af
26,712 lbs. per □ inch

†Length of Colun

‡This Column ha
holes.

TESTS OF PHŒNIX COLUMNS MADE AT THE PHŒNIX IRON WORKS, MAY 3, 1873.

Area of Piston of Hydraulic Press, 260 □ Inches.

Description of Column.	Mark	Length	DIAMETER. Inside	DIAMETER. Of Barrel	DIAMETER. Across Flanges	Ratio of Length to Diameter	Gross Weight	No. and Size of Rivets	Weight of Rivet Heads	Net Weight	Net Area	Pressure per □ inch of Piston.	Total Pressure on Piston	Ultimate Strength per □ inch of Section of Column	Ultimate Strength per □ inch according to Gordon's Formula	Shape of End Castings
4 Seg. B¹ Column	D	8″	4 29-32″	5½″	8″	1.46	16½ lbs.	12-½″○	1 lb.	15½ lbs.	0.975 □″	1,625 lbs	422,500 lbs	60,573 lbs.	35,974 lbs.	Flat Ends.
4 Seg. B¹ "	C	8″	4 29-32″	5½″	8″	1.46	16½ "	12-½″○	1 "	15½ "	0.975 □″	1,620 "	421,200 "	60,387 "	35,974 "	" "
4 Seg. A "	J¹	4″	3 21-32″	4 11-32″	6 5-16″	0.92	6½ "	8-⅜″○	¼ "	6¼ "	5.625 ″	1,425 "	370,500 "	65,867 "	35,990 "	" "
4 Seg. A "	J²	4″	3 21-32″	4 11-32″	6 5-16″	0.92	6½ "	8-⅜″○	¼ "	6¼ "	5.625 ″	1,425 "	370,500 "	65,867 "	35,990 "	" "
4 Seg. A "	A	4″	3 21-32″	3 31-32″	5⅞″	1.01	3½ "	8-⅜″○	¼ "	3¼ "	2.925 ″	640 "	166,400 "	56,889 "	35,988 "	" "
4 Seg. A "	B	4″	3 21-32″	3 31-32″	5⅞″	1.01	3½ "	8-⅜″○	¼ "	3¼ "	2.925 ″	625 "	162,500 "	55,555 "	35,988 "	" "
*4 Seg. B¹ "	E	23′0¾″	4⅞″	5 11-32″	8″	53.48	481 "	208-½″○	17¼ "	463¾ "	5.84 ″	680 "	176,800 "	30,274 "	18,430 "	" "
†4 Seg. B¹ "	H	24′0″	4⅞″	5⅜″	8″	53.58	475½ "	204-½″○	17 "	458½ "	5.95 ″	375 "	97,500 "	16,387 "	7,457 "	Round "
‡4 Seg. C "	L	23′4½″	7¼″	7 13-16″	11½″	35.90	836½ "	196-½″○	16¼ "	820⅛ "	10.21 ″	1,475 "	383,500 "	37,561 "	25,182 "	Flat Ends.
4 Seg. C "	K	22′8½″	7 3-32″	7 19-32″	10¾″	35.88	660½ "	204-½″○	17 "	643½ "	8.5 ″	1,250 "	325,000 "	38,235 "	25,191 "	" "

*This Column after having been crippled, was again subjected to pressure, and in this crippled state, failed under a total pressure of 156,000 lbs., or 26,712 lbs. per □ inch.

†Length of Column proper, 23′1½″—Radius of semi-spheric Castings, 5¼″—making length over all, 24′0″.

‡This Column had thirty-five 9-16″○ punched holes 8″ apart in each of 2 opposite Segments, and yielded in the direction of a plane through the punched holes.