iron, to which must be added 50 tons for the platform, making the total weight of each bridge 294 tons 10 cwt. The cost, exclusive of the masonry of the abutments, and of the permanent rails, but inclusive of the staging for fixing and the expense of testing, was £11,003.

The Crumlin Viaduct, begun in 1853, and completed in 1857 (fig 4, Plate XIX.), is a fine example of the Warren girder; it was erected on the Taff Vale Extension Railway under Messrs Liddell and Gordon as engineers, by Mr T. W. Kennard as contractor. The following description is compiled from that given in Mr Humber's work:—The length of the bridge is 1800 feet, divided into two parts, one consisting of seven spans of 100 feet, and the other of three similar spans. The greatest height of the road-way

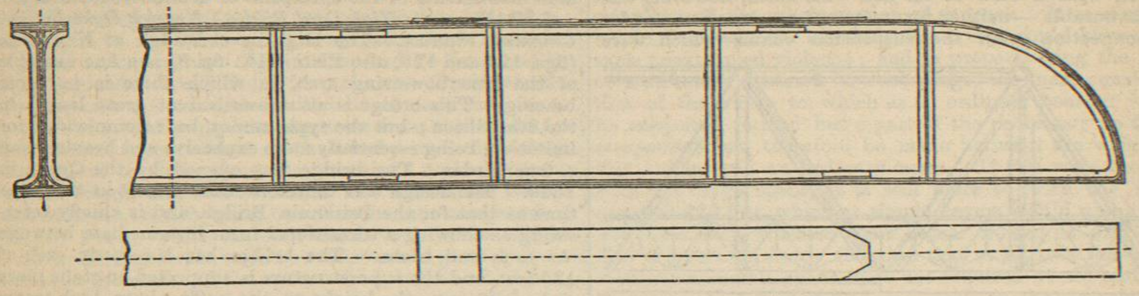

Fig. 129.—Common type of Wrought Iron Girder.

above the surface of the water is not less than 200 feet. The piers are formed of cast-iron hollow columns, each 17 feet long and 1 foot in diameter; the thickness of the metal varies from 1 inch to $\frac{5}{8}$th inch; these columns are arranged in tiers, each containing fourteen columns, the distance between which at the base of the pier measures 13 feet 6 inches, excepting between the centre rows, where it measures 6 feet throughout the height. The wrought iron girders are 150 feet in length and 14 feet 6 inches deep. Some details of the construction are shown in fig. 128.

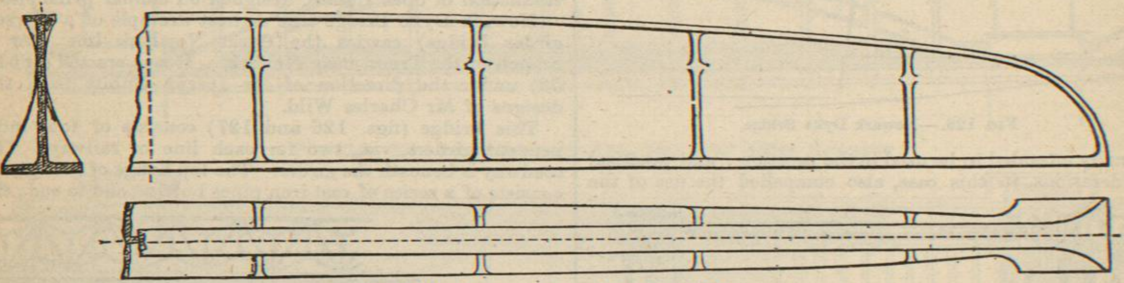

Fig. 130.—Common type of Cast-Iron Girder.

Fig. 129 shows a plan and elevation and cross section for half a wrought iron girder of a usual type for small spans. Covering plates are used to connect the main plates of the top and bottom webs, and stiffening angle irons are shown at the sides.

Similarly, fig. 130 shows a plan and elevation of a cast-iron girder of a usual type.

§ 80. *Niagara Suspension Bridge.*—Fig. 5, Plate XIX., shows Niagara Suspension Bridge, a structure described as follows in the 8th edition:—

"It crosses the Niagara River at a height of 245 feet above the water by a single span of 821 feet 4 inches, and forms the connecting link between the American States and Canada.

"The superstructure may be best described as a hollow rectangular box, 18 feet deep and 24 feet wide, on the top of which the railway is laid, while the bottom, which is 25 feet wide, forms the roadway for public traffic—both these floors are constructed of timber beams; and each connecting side consists of a row of double posts or uprights of timber, each pair being 5 feet apart; between them wrought iron diagonal bars are made to pass, extending each way to the fourth pair of posts at an angle of 45 degrees. The upper or railway floor is suspended from two wire cables at intervals of 5 feet, and the lower floor is suspended at similar intervals from two other wire cables which have a deflection of 10 feet more than the upper ones; these cables, four in number, are each 10 inches in diameter, and composed of seven strands, each containing 520 wires, making a total of 3640 wires. One strand forms the axis round which the other six are twisted. Sixty wires are equal to 1 square inch of solid section; therefore the total area of each cable is 60·4 square inches, or the total sectional area of iron supporting the structure is 241·6 square inches.

"Each cable rests upon a separate saddle, there being two on the top of each of the four towers. The saddles are placed on ten cast-iron rollers, 5 inches diameter and $25\frac{1}{2}$ inches long, which bear upon cast-iron plates 8 feet square and $2\frac{1}{2}$ inches thick, strengthened by three parallel flanges which form two compartments for the reception of the saddles.

"The ends of the cables are attached to cast-iron shoes, in each of which is inserted a wrought iron pin which forms the connection with the anchor chains. These anchor chains are each embedded in a solid shaft of masonry 7 feet by 3 feet, enlarged at the bottom to form a chamber 8 feet square cut in the rock. The shafts are sunk to a depth of 25 feet on the New York side, and 35 feet on the Canada side.

"Each anchor chain is composed of nine links, the eight lower links being 7 feet long, and the ninth or uppermost 10 feet long. The lowest link consists of seven wrought iron bars, 7 inches by 1·4 inches each, and amounting

collectively to an area of 69 square inches. They are secured to a cast-iron anchor plate, by a pin $3\frac{1}{2}$ inches diameter. From the fourth link the chain curves, and the section is gradually increased to an area of 93 square inches. There are two towers at each end of the bridge, based upon a mass of masonry 60 feet by 20 feet, which is pierced by an arch 19 feet wide, forming the entrance to the lower roadway. The towers are 60 feet high, 15 feet square at the base, and 8 feet square at the top.

"Above the floors are 64 diagonal stays, extending from the saddles to the suspenders, amongst which they are equally distributed; they are formed of wire-rope $1\frac{3}{8}$th inches diameter. There are also 56 stays attached at their upper extremities to the soffit of the bridge, and at their other ends well anchored to the rocks below. The superstructure is thus tied down as well as suspended, and all undulations directly resisted.

"The bridge was commenced in September 1852, and opened for traffic in March 1855. The total cost was £80,000."

The use of two chains of different versed sines is certainly a defect in this design.

There are several other suspension bridges in the United States of great span, *e.g.*, Cincinnati, 1057 feet; Brooklyn 1600 feet.

§ 81. *Saltash, Victoria, and Coblentz Bridges. Fink Truss.*—Fig. 131 shows one span of Saltash Bridge erected by

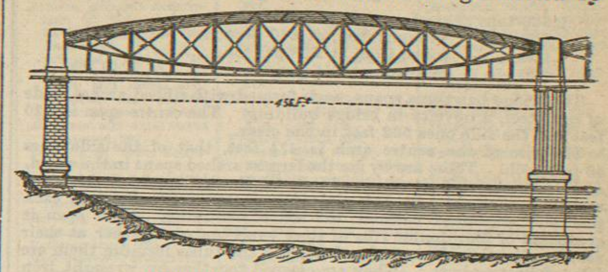

Fig. 131.—Span of Saltash Bridge.

Brunel. The span is 455 feet. The pier is a column or circular pillar of solid masonry, 35 feet diameter and 96 feet high from the rock foundation to above high-

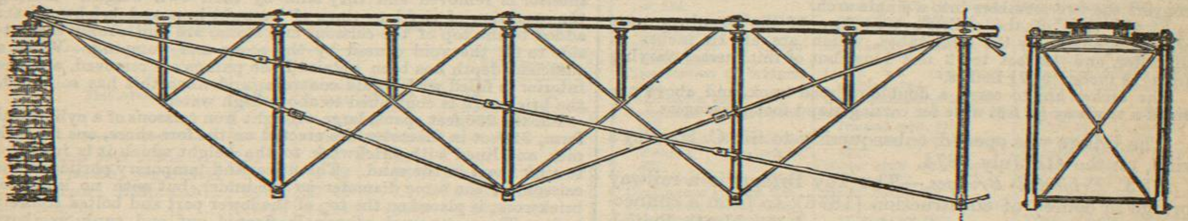

Fig. 132.—Fink Truss.

water mark. Upon this are placed four octagonal columns of cast-iron, 10 feet diameter, carried up to the level of the roadway, which is 100 feet above high-water mark.

Victoria Bridge, Montreal The Victoria Bridge over the St Lawrence at Montreal is a tubular bridge of great length (7000 feet), chiefly remarkable for its ice breakers, shown in fig. 93.

Fig. 132 shows some details of a Fink truss as used in America. The mode of computing the stresses on this truss has already been explained in § 59. All the struts are cast-iron tubes.

Fig. 133 shows one of the wrought iron arches of a Coblentz bridge over the Rhine at Coblentz. The bridge consists of three spans of about 315 feet each. Coblentz

§ 82. *St Louis and Illinois Bridge.*—The St Louis and St Louis Bridge.

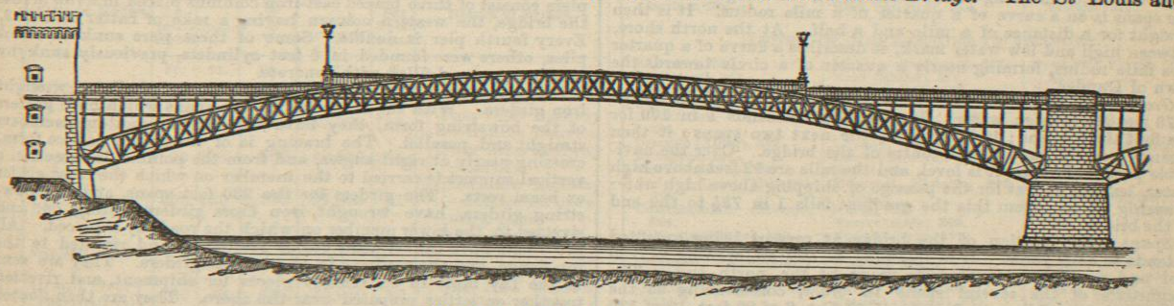

Fig. 133.—Arch of Bridge at Coblentz.

Illinois bridge over the Mississippi (fig. 5, Plate XVIII.) is the finest example of a metal arch yet erected. It is described as follows by Sir Charles A. Hartley, who visited it in 1873:—

"The Mississippi at St Louis is confined to a single channel 1600 feet wide and 8 feet deep at extreme low water by an embankment or levee on the Illinois side, which is carried up to the level of extreme high water, at which time the width is augmented to 2200 feet. Both shores are revetted below the low water, some with rubble stones, and protected by the wharf pavements above that line. The extreme range between high and low water is 41 feet. Owing to the narrow gorge through which the whole volume of the Mississippi flows the variations in the bed of the river are very great. Captain James B. Eads, M. Inst. C.E., the distinguished engineer who designed the bridge and superintended its construction, informed the author that a rise of 13 feet less than high-water mark caused a scour of 18 feet, and that in the freshet of 1870 the scour reached a depth of 51 feet below low-water mark alongside the east pier. These facts induced him to believe it possible that the scour, at times of extraordinary high flood, might extend even to the rock itself. He therefore determined to establish the piers and abutments on the rock; and this was done by means of caissons provided with air chambers and locks at depths for the east pier and east abutment reaching 136 feet below high-water mark, or 110 feet from the surface of the water where the foundation work was actually performed. This feat, which was satisfactorily executed in 1870–71, is quite unprecedented in the annals of engineering.

The piers and abutments are composed of coursed rubble masonry up to low-water mark. Above this level they are faced with grey granite from the State of Maine, which cost £10 per cubic yard *in situ*. The interior of the work is of magnesian limestone. The massive appearance of the granite rock facing is very striking.

The contract prices, and the total quantities of the steel and iron work required for the bridge, are as follows :—

2,500 tons of steel, at £60 per ton	}	of 2000 lbs.
500 „ wrought iron, at £40 per ton...	}	of 2000 lbs.
1,000 „ rolled iron, at £28 per ton......	}	of 2000 lbs.
200 „ cast-iron at £16 per ton..........		of 2240 lbs.

The bridge has three spans, each formed with ribbed arches made of cast steel, a novelty in bridge building. The centre span is 520 feet and the side ones 502 feet in the clear.

The rise of the centre arch is 47½ feet, that of the side ones 46 feet each. These are by far the largest arched spans in the world, and under the able direction of Colonel Read, Captain Eads's chief assistant, they are now being rapidly erected gradually from each pier and abutment without the aid of centering. Each span is composed of four double ribs of steel (well braced together at their relative distances from each other), and the tubes forming them are jointed butt to butt. They are clasped together by wrought iron couplings (which proved to be much better than steel), furnished with parallel grooves corresponding with similar grooves in the tubes. Steel pins, varying from 4½ inches to 7 inches in diameter, pass through the centre of the couplings and the ends of the tubes at every joint. The vertical bracing between the upper and the lower tubular ribs, which are 12 feet apart from centre to centre, convert the two members into a single arch.

At the time of the author's visit two of the openings were already spanned by the steel tubes, which are all 18 inches in diameter, and 12 feet to 13 feet long, but of thicknesses varying from 1½ inches to 2⅜ inches.

The arches are to carry a double railroad track, and above the track a roadway 54 feet wide for carriages and foot passengers."

The bridge was opened, subsequently to Sir C. Hartley's visit, on the 4th July 1874.

§ 83. *Projected Bridges.*—The Tay Bridge is a railway bridge in course of construction (1876), to form a connection between the town of Dundee and the North British Railway system in Fife, and crosses the Firth of Tay about a mile and a half to the west of Dundee. The length of the bridge exceeds two miles. It will therefore be the longest iron bridge in the world. The following description has been furnished by Mr A. D. Stewart, who assisted the chief engineer, Mr T. Bouch, in the design of the bridge :—

Curves.—Commencing at the south shore, the bridge for the first five spans is on a curve of a quarter of a mile radius. It is then straight for a distance of a mile and a half. At the north shore, between high and low water mark, it describes a curve of a quarter of a mile radius, forming nearly a quarter of a circle towards the town of Dundee.

Gradients.—The level of the rails at the south end of the bridge is 78 feet above high water. The gradient descends 1 in 100 for the first three spans; it is level for the next two spans; it then ascends 1 to 353 towards the centre of ths bridge. Over the navigable part of the river it is level, and the rails are 92 feet above high water, leaving 88 feet for the passage of shipping above high water of spring tides. From this the gradient falls 1 in 73½ to the end of the bridge.

Spans.—The portion of the bridge at present being executed extends to 3420 yards. It is intended to add an opening of 120 feet and a number of 27 feet spans at the north end. The magnitude of the several spans in order, commencing at the Fife shore, is as follows:—3 spans of 60 feet, 2 of 80 feet, 10 of 120 feet, 12 of 136 feet, 13 of 230 feet, 1 of 150 feet, 11 of 120 feet, 25 of 60 feet, 1 of 155 feet, and 6 of 27 feet—the total number of spans being thus 84.

Piers and Foundations.—The first fourteen piers are founded upon rock, which was generally covered to the depth of a few feet with clay or other soft material. These piers consist of double solid cylinders of brickwork, built with strong Portland cement mortar, connected by a wall of brickwork from low water to the superstructure. Foundations for these piers were obtained by placing caissons or hollow cylinders on their site, excavating within them, and sinking them by forcing out the water by air pressure. These caissons were built on the foreshore on a properly prepared foundation, and lined internally with brickwork to such a height that when fully sunk the brickwork extended above low water. When carried out and placed in position, this brickwork formed part of the permanent pier, and gave weight and stability to the caisson when the water was displaced from the inside. When the whole material above the rock was thus excavated, the working chamber and shaft of the caisson were filled with concrete, put in in a liquid state, and when this solidified the building upwards of the pier was continued. A difficulty arose in keeping the cylinders vertical during the sinking. This was overcome by combining them into a single caisson. Between the fourteenth and fifteenth pier the rock disappears. At the sites of the next six piers the bed consists of a layer of hard material resting on silt. It is proposed to pile these piers from an outside staging within an oval-shaped wrought iron caisson. After the piles are driven, their heads are to be surrounded with concrete, the water is then to be pumped out of the caisson, and brickwork to be built up to the level of about 5 feet above high water. The upper portions of these, and of all the piers to the north of them, are to consist of cast-iron columns braced together.

From the twenty-second pier northwards the bed of the river consists of sand, with occasional layers of coarse gravel and boulders. It was, however, necessary to modify the designs for the piers, and the method of founding and building them, according to the load each had to carry.

For the 120 and 136 feet spans there are eighteen piers. For each pier two wrought iron caissons are prepared, partly cylindrical and partly conical in shape, and having a base of 15 feet. These are built on the fore-shore, and lined with brickwork; they are then floated out by means of pontoons having hydraulic machinery for lowering; when they have been sunk in their proper place until they take a bearing in the sand, the pontoons are removed, and by means of sand-pumps the material from the interior is removed and they sink by their own weight. During the operation of sinking, rings of wrought iron and brickwork are added to the top of the caisson, and stones are laid round the outside to fill the void caused by the scour and pumping. When a sufficient depth has been obtained the pumps are removed, and the interior is filled with liquid concrete; and when this has solidified, the brickwork is continued to above high water.

For the 230 feet spans, large wrought iron caissons of a cylindrical form, 31 feet in diameter, are erected on the fore-shore, one for each pier, and lined with brickwork to the height which it is intended to sink them in the sand. The upper and temporary portion of the caisson, of the same diameter as the under, but with no lining of brickwork, is placed on the top of the lower part and bolted securely to it. The compound caisson is floated out and sunk, as above described, by means of sand-pumps, and the permanent portion of the caisson is filled with concrete. The temporary portion is then unbolted by divers, and removed for further use. From the surface of the ground to above low water, the pier consists of a brick oval-shaped hollow cylinder, which is built on the fore-shore on girders; and when it has thoroughly set, it is also floated out and lowered on the concrete foundation. The interior of this brick pier is then filled with concrete, and the building of the brickwork is continued to above high water as tidal work.

For the 60 feet spans towards the north end of the bridge, the piers consist of three braced cast-iron columns placed in a row across the bridge, the western column having a rake or batter of 1 in 3. Every fourth pier is double. Some of these were sunk as screw piles, others were founded in 6 feet cylinders, previously sunk by sand-pumps, and filled with concrete.

Superstructure.—The superstructure consists wholly of wrought iron girders. With the exception of two spans which have girders of the bowstring form, they have the top and bottom members straight and parallel. The bracing is of the double lattice form, crossing nearly at right angles, and from the point of intersection a vertical support is carried to the member on which the cross-girder or beam rests. The girders for the 230 feet spans, and the bowstring girders, have wrought iron cross girders resting on, and rivetted to, the lower member on which the roadway is placed. All the others have timber cross-beams resting on and rivetted to the top flange, and the roadway is above these girders. They are sent to the Tay built in convenient pieces for shipment, and rivetted together on jetties prepared near the shore. They are then floated out and raised to their places by machinery suited to their respective weights. They are generally continuous in groups of four consecutive spans. In order to make continuity perfect, the further end of each girder is raised through a certain calculated height before rivetting it to the next.

Montreal papers state that a bridge 15,500 feet in length is about to be constructed over the St Lawrence at Montreal, from the designs of Mr Legge. It will have one span of between 500 and 600 feet, and 60 smaller spans, with a height of 130 feet above the water at high tide. The estimated cost is £800,000.

§ 84. *Statistics.*—Table XVI., from the 8th edition, gives some statistical information as to the weight, cost, and dimensions of some of the principal cast-iron bridges.

Tables XVII. and XVIII. give various details regarding some important bridges of various construction and dimensions.

TABLE XVI.—*Cast-Iron Bridges.*

NAME OF BRIDGE.	No. of Openings.	Span.	Rise.	Total weight of Iron-work.	Cost.	Date of Completion.
		Ft. In.	Ft. In.	Tons		
Coalbrookdale	1	100 6	50 0	378½	...	1779
Buildwas	1	130 0	30 0 / 14 0	174	£6,034	1796
Sunderland Bridge	1	236 0	34 0	260	27,000	1796
Laason Bridge	1	43 0	...	...	...	1794
Staines Bridge	1	180 0	16 0	...	...	1802
Pont du Louvre ...	9	57 0	10 8	263	...	1803
Pont d'Austerlitz..	5	106 0	10 8	...	...	1806
St Denis	1	39 5	3 3	...	...	1808
Bristol Bridge	1	100 0	15 0	150	4,000	...
Craigellachie Bridge	1	150 0	20 0	...	8,200	...
Witham Bridge.....	1	86 0	5 0	...	...	...
Vauxhall Bridge ..	9	78 0	29 0	...	300,000	1816
Southwark Bridge	3 { 1 / 2	240 0 / 210 0	24 0 / 21 0	5780	800,000	1819
Tewkesbury Bridge	1	170 0	17 0	...	...	...
Galton Bridge	1	180 0	18 0	...	...	...

TABLE XVII.—*Dimensions of Large Masonry Bridges.*

Flat Arches.	Span in feet.	Versine in feet.	Maximum Radius in feet.	Thickness. Of Crown in feet.	Thickness. Of Abutments at base.
Trezzo over Adda......	251·	...	134·	...	...
Dorlaston, Segmental	86·51	13·48	76·1	3·510	32·022
Trilport, Elliptical ...	80·38	27·69	...	4·462	19·
Nantes „ ...	115·16	34·41	89·5	6·397	28·
Neuilly „ ...	127·89	31·95	160·	5·315	35·
Waterloo „ ...	120·	32·	112·5	4·5	40·
London Bridge „ ...	152·	29·6	...	4·75	...
Alma (Béton) „ ...	141·4	28·2	...	4·92	...
Grosvenor Bridge, Chester	200·	42·	143·	4·	...

TABLE XVIII.—*Dimensions and Cost of Large Bridges.*

Name of Bridge.	Maximum. Approx. Hght.	Maximum. Span.	Length.	Reputed Cost. Total Amount.	Reputed Cost. Per Foot run.	Nature of Bridge.
	Ft.	Ft.	Ft.	£	£	
Britannia ...	125	460	1,511	601,865	398	Two lines Railway —tubular.
Charing-cross	50	154	1,365	180,000	131	Four lines Railway —double Warren.
Boyne	90	264	550	140,000	254 ?	Four lines Railway —lattice.
Crumlin	200	150	1,800	39,000	21	Two lines Railway —lattice on open-work piers.
Craigellachie	20	200	413	12,200	29·5	One line Railway —lattice, and plate girder.
Grand river (Mauritius)	130	12	620	30,000	50	One line Railway —plate girder.
Deepdale......	150?	60	740	20,266	27	Two lines Railway —lattice on open-work piers.
Westminster	20	120	1,160	235,000	202	Road — cast and wrought iron arch, 83 feet wide.
Fribourg	167	...	808	24,000	29	Wire-rope Suspension Bridge—road only.
Niagara	245	808*	800	80,000	100	Wire-rope Suspension Bridge—road and railway.
Landore	75	110	1,760	28,720	16·3	Wooden Trusses.

* Platform.

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(F. J.)