THESIS

ON

DEVELOPMENT OF THE

BRIDGE 18th - 19th CENTURY

BY

WILLIAM P. CANNING

FOURTH YEAR INDUSTRIAL DESIGN

N.C.A.D.

PRINCES ST.

DUBLIN.

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"Bridges should be convenient, beautiful and durable".

Palladio 1570

Bridges have the virtue of being pure structure, though as in other fields of design the engineering and architectural aspects are hidden under the period costume. Bridges have taken the names of places, people and events and in turn places have been named after them - Newbridge, Leighlinbridge, Goresbridge, Knightsbridge. Battles have been fought for them, and others because of their geographical position, they are the gateway into a new country or city.

A Bridge will represent the state of technology of its time and of earlier periods for once a crossing point has been chosen it is common for a bridge to be repaired, widened, improved and eventually replaces on the same site. Bridges continuously change. London Bridge was always "falling down" and once it even left the country.

In the political and Industrial revolutions of the eighteenth century, great names of famous bridge builders were to emerge from Great Britain - names like John Rennie, Thomas Telford, George Stehpenson, other countries produced people like Eades and Roebling and Eiffle. All these men represent an era where one man was responsible for the construction of the bridge, where one mans reputation could be made or lost in the field of bridge engineering. The above names are memorable for their achievements compared to somebody like Sir Thomas Bouch who is remembered for his mistakes (Tay Bridge disaster 1879).

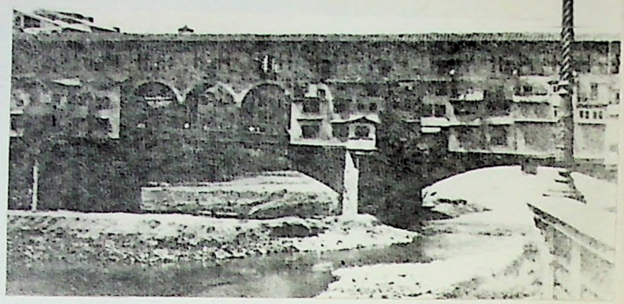
The Bridge built by Gauis Julius Lacer over the Tagus for the Emperor Trajan comes perhaps the boldest inscription of all. "Pontem Perpetui Mensuram in Saecula Mundi".
(I have made a bridge that will last till the end of the world). The Bridge still stands and looks as though it might last till the end of the world. In fact seventeen centuries afterwards the Durham Junction Railway Company decided to copy its structure for carrying a railway over the river Wear.

Generally bridge designers are inclined not to be arrogant, for failures can still occur. During construction novel methods may perhaps be tried; afterwards it would be discovered that the most economical solution to a particular problem has generated by its very lightness, a new range of aerodynamic dangers.

Thus some failures can be historically notable, for investigation of failure often produces information for the next generation of designers, who learn nothing from the ones that stand up.

Bridges are among the biggest things man has made; they are almost architecture in the sense that unless they are persistently though briefly inhabited, they need not exist at all. They can do good or harm to the culture or landscape in which they exist, they are susceptible to all critical tests we might apply to worlds of architecture. Their materials and the forms in which they are used, the functions of the ports in collecting and transmitting variable moving loads are all worthy of close study.

In this study we explore some of the great principles of bridge building. We will look at the famous men and their famous bridges. We will explore the design principles involved and show how they were demonstrated in these stepping stones of civil engineering.



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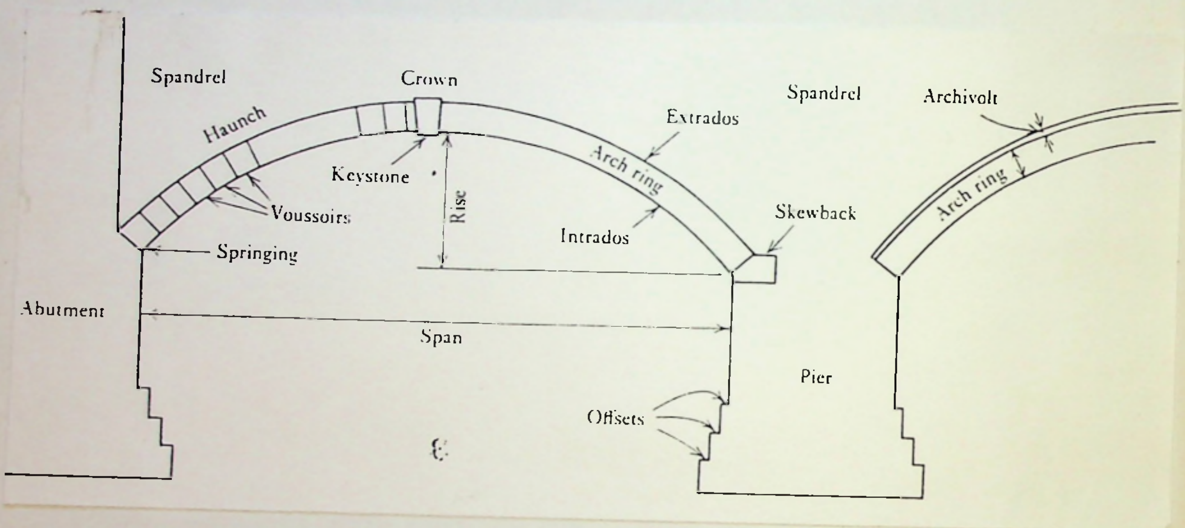
Spandrel
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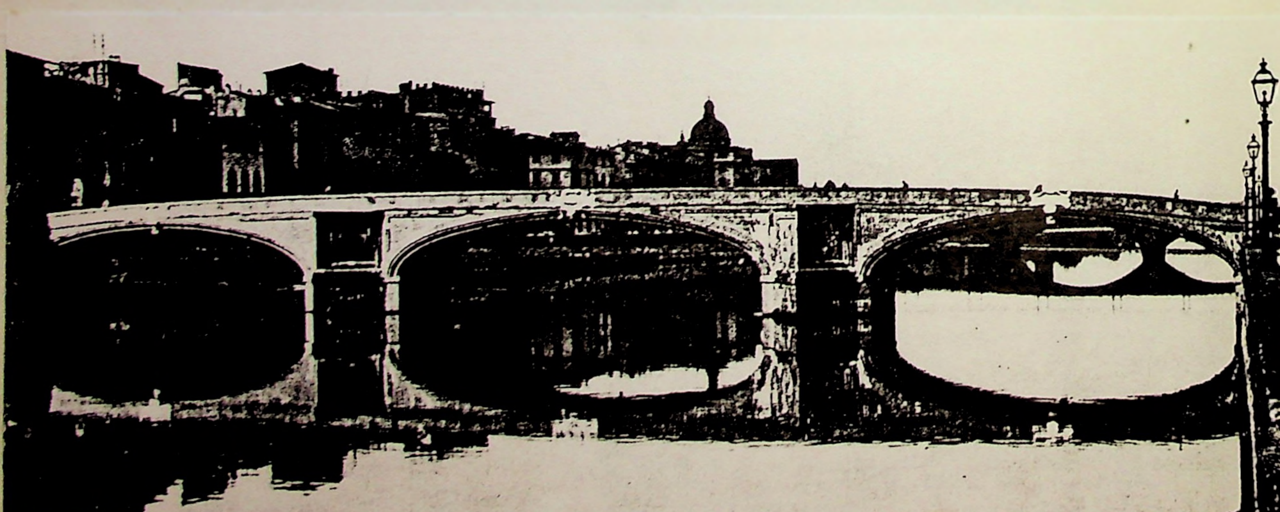

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MASONARY - STONE ARCH BRIDGES

Stone arch bridges have evolved from the heavy stone piers and semicircular arches of the Romans to the three-centered arch of Benezet (Pont d'Avignon) to the segmental arch of the Gaddi (Ponte Vecchio)(Figure 1) to the elliptical arches of ammonati (Ponte Santa Trinita) (Figure 2) to the thin arch and narrow piers of Perronet.

Jean Perronet was probably the first man to understand the true significance of the arch, thus in the eighteenth century, the age of reasoning in structural engineering began. Perronet was responsible for the successful construction of many beautiful stone arch bridges and his Pont de Neuilly has been called "the most graceful stone bridge ever built".

This bridge was built in the second half of the eighteenth century when Perronet took the important step of reducing the width of the piers to just enough to take the vertical load of the arches. The Pont de Neuilly had five flattened arches, each with a span of 120 ft.and piers only 13 ft. thick. Engineers of the day claimed it would never stand, it did stand proud until 1956 when it was removed for a motorway bridge.

In the same style as the Pont de Neuilly Perronet's last bridge the Pont de la Concorde (Figure 3) still stands although widened to allow modern traffic, it was designed to have arches with rises less than one tenth of the spans carried on piers with widths only a little greater than one tenth of the spans and each divided into two parts, one on each side of the bridge. He was cautioned when his design was submitted and this forced him to raise the arch to make the piers more continuous over the bridge.

Pont de la Concorde was built in 1791 and remains a monument to arch bridges.

Large masonry arch bridges continued to be built until the beginning of the present century, but rarely with Perronet's distinctive flat arches.

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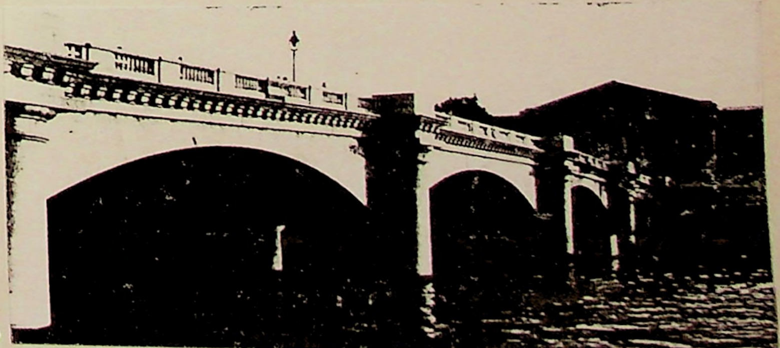

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STONE ARCH BRIDGES IN IRELAND

There are three notable masonry arch bridge designs in the south east of Ireland. They resulted from the damage caused by torrential flood on the river Nore on 2nd October 1763 which destroyed four bridges over the River as well as several of its tributaries bridges. The bridge nearest to the mouth of the Nore was that of Inistiogue and it was badly damaged but not destroyed. The design of its repair as well as those of two new bridges to replace two which were ruined in Kilkenny town, was given to a George Smith who had been a director since 1761 of the work of making the river Nore navigable between Inistiogue and Kilkenny.

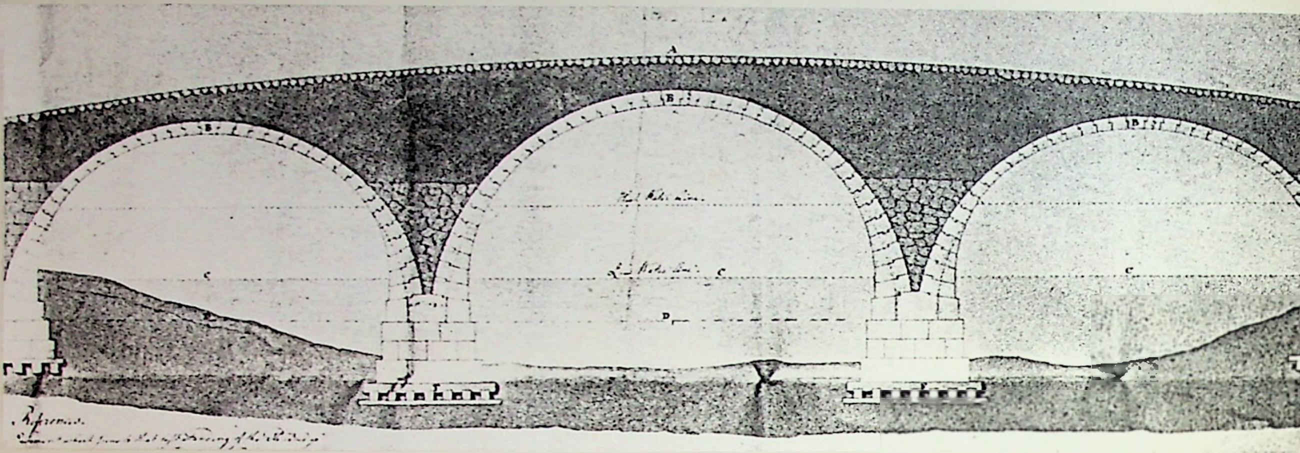
The bridge at Inistiogue (Figure 8) was adjoined to the estate of the Tighe family and they probably contributed to the cost (£900) which was spent on the construction out of Government funds.

Smith's architecture was applied to the downstream side of the bridge only and is said to be directly derived from Mylne's Blackfriary design. It is actually more true to the triumphal bridge model, for its nine arches are all semicircular and equal and therefore the line of its parapet is horizontal. The spandrels are of good dark-coloured rubble but decorated by pairs of ionic pilasters in a pale and sharp edged granite. The arch rings are also of granite, and this feature appears to have needed little maintenance since 1762.

In Kilkenny Smith used a different style which was based on the bridge of Rimini (Figure 4). This bridge is called Greens Bridge and it has a horizontal roadway over most of its length reached by approach ramps which are symmetrical in shape, it has five arches, of which the middle three are equal, and a pedimented aedicule on every spandrel. The arches are elliptical, and the arch rings sharply moulded but bounded with square blocks (Figure 4). It is almost as true a copy of Rimini as was ever built in Britain or Ireland.

The second bridge in Kilkenny, St. John Bridge (Figure 5) was of three segmental arches with a similar parapet profile and aedicules on the spandrels. It was replaces by a concrete bridge in 1910.

In the same part of the country, namely Graignamanagh lies **(7)** a bridge over the river Barrow a sister river of the Nore. This bridge replaced a timber bridge near the castle of Tinnahinch



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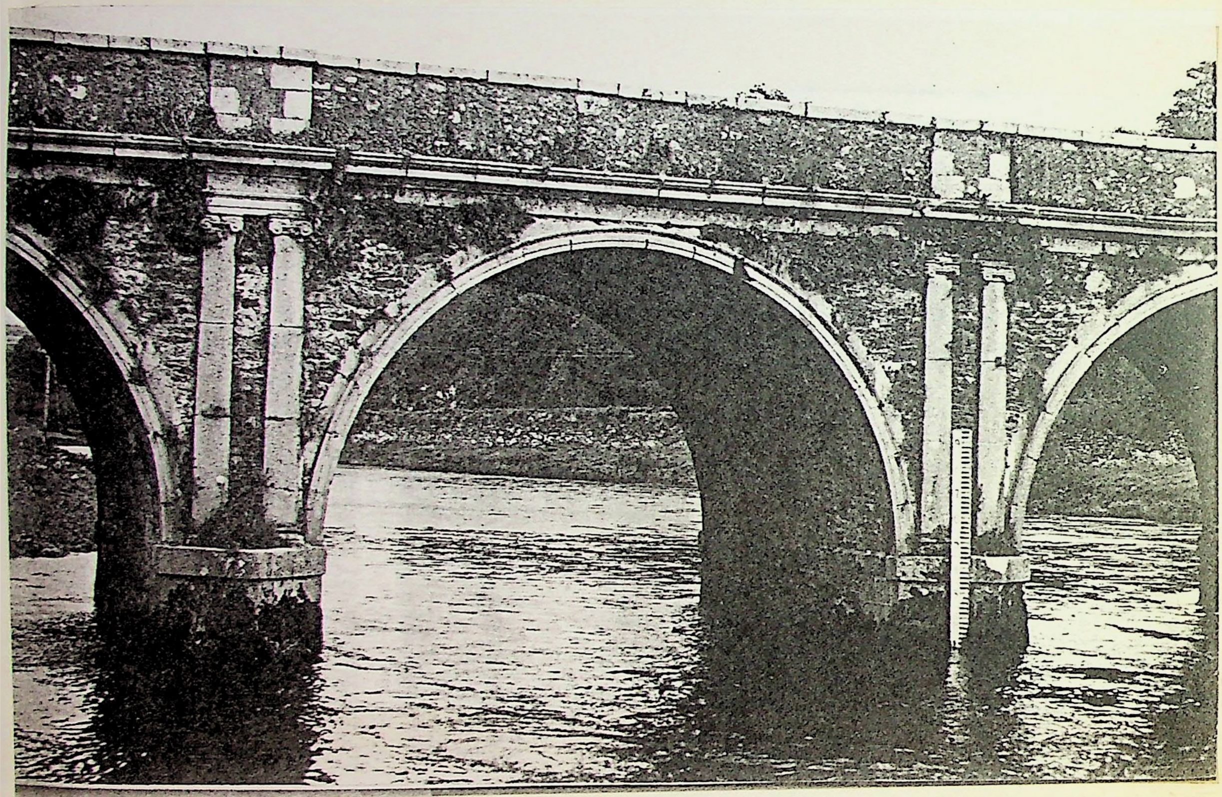
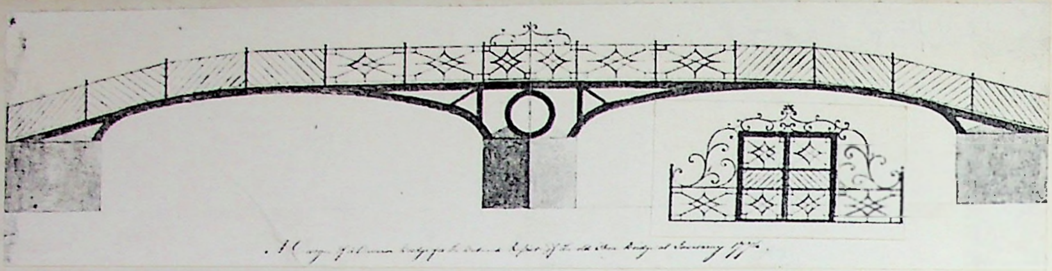
and may have been financed by the owner of the castle, since there is no record of a parliamentary grant as was necessary for almost every large bridge in Ireland at the time. The date of construction was certainly before 1777 and the design and/or construction are credited in one pamphlet of 1895 to George Semple. Semple was responsible for the construction of the Essex Bridge in Dublin, and as no concrete proof that Semple was responsible for Graignamanagh Bridge is available (he made no references to the bridge in his book published in 1776) it does bear a resemblance like the Essex Bridge to Westminister Bridge. The spandrels reduce in size towards the ends of the bridge as John Price had done in his design for Westminister but the arches are all semicircles, while Price's were segments and the arch rings are rusticated in a way suited to the use of local slated stone. The internal construction of the spandrels were revealed during repairs a few years ago and was similar to Labelyes work at Westminister longitudinal and cross walls of rubble dividing the space into compartments filled with gravel, though the walls were apparently of mortared stone, unlike Labelyes dry rubble.

Although it is hard to credit this design to George Semple, it is equally hard to disassociate it entirely from his knowledge of Westminister Bridge and this suggests that his former assistant George Smith (Inistiogue, Greens, St. John's Bridges) or his brother John or any other member of the Semple family who were active builders in the south east of the country were responsible. These four bridges established a local tradition which can be traced in the spandrel decoration of a number of other bridges on the River Barrow and Nore notably the bridges at Ennisnag, Athy Brownsbarn and Maganey.

Another reference to Mylnes for Blackfriars could be seen in Dublin a year or two after Smith began the repair of the Inistiogue Bridge. Queen's Bridge across the Liffey was built in the years 1784-8 under the direction of Colonel Charles Vallancey who like Labelyes was the son of a French protestant. He was appointed 'ongineer in ordinary' in Ireland in 1762. The arches of his Queen's Bridge are shown in an original drawing (Figure 6) with all voussoirs joggled, not by inserted blocks as in Mylne first design for Blackfriars but by interlodes cut on the bedding surface of the stone themselves.

There is no recent confirmation that the arches had joggled stones in their construction but the exterior corresponds exactly to the original drawings.





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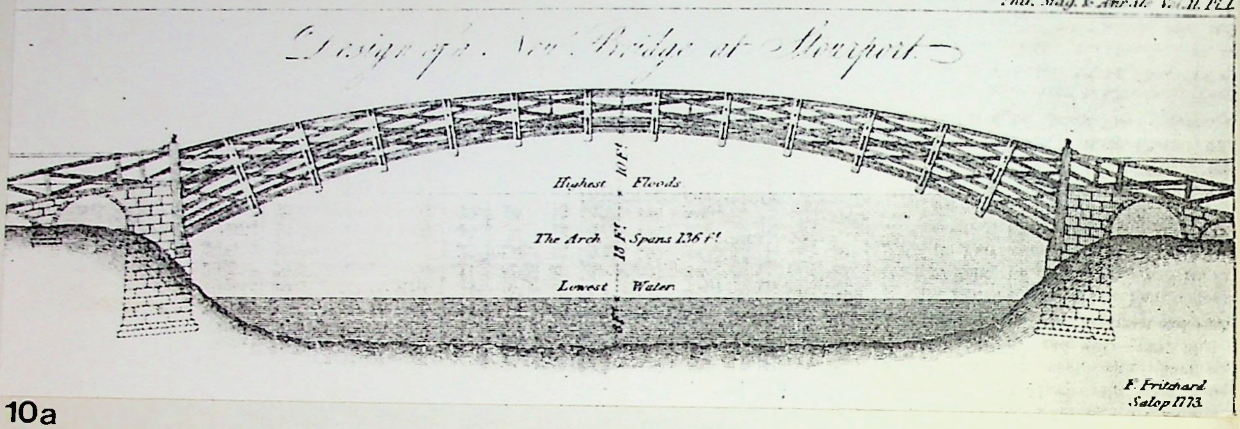
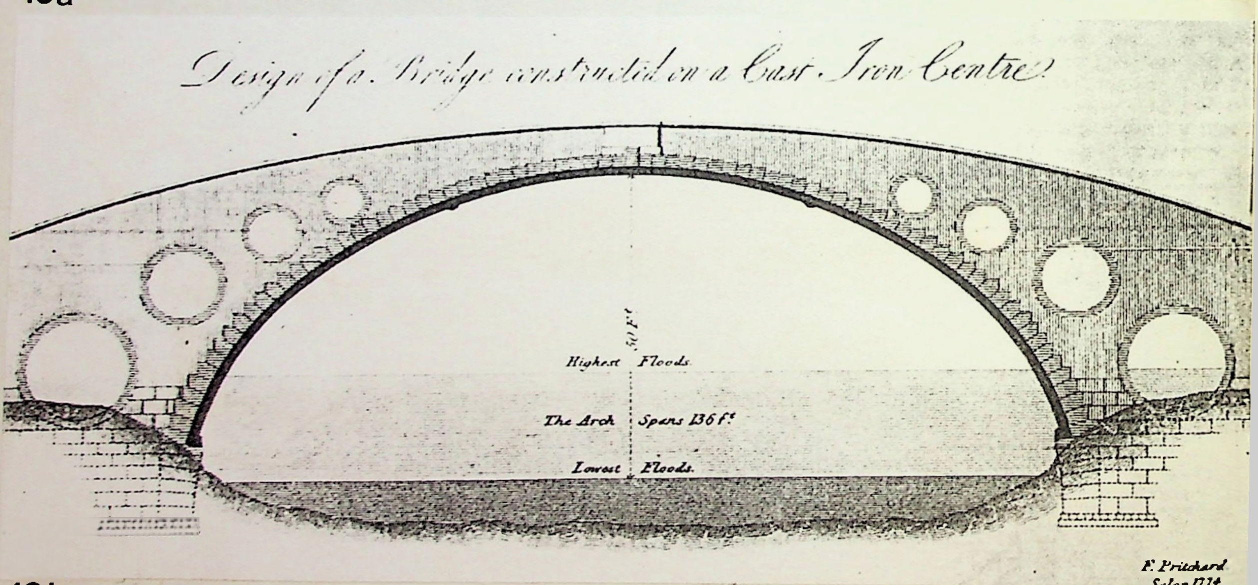
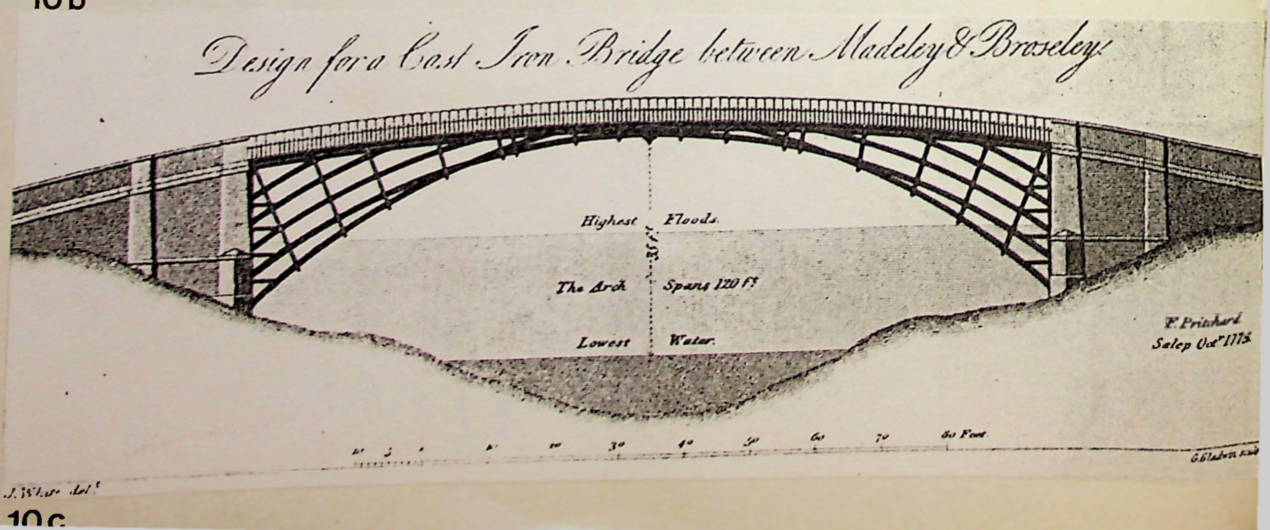

Design of a New Bridge at Stourport
Highest Floods
The Arch Spans 136 ft
Lowest Water
F. Pritchard
Salop 1773.

10a


Design of a Bridge constructed on a Cast Iron Centre
Highest Floods.
The Arch Spans 136 ft
Lowest Floods.
F. Pritchard
Salop 1774.

10b


Design for a Cast Iron Bridge between Madeley & Broseley
Highest Floods.
The Arch Spans 120 ft
Lowest Water.
F. Pritchard
Salop Octr 1775
80 Feet

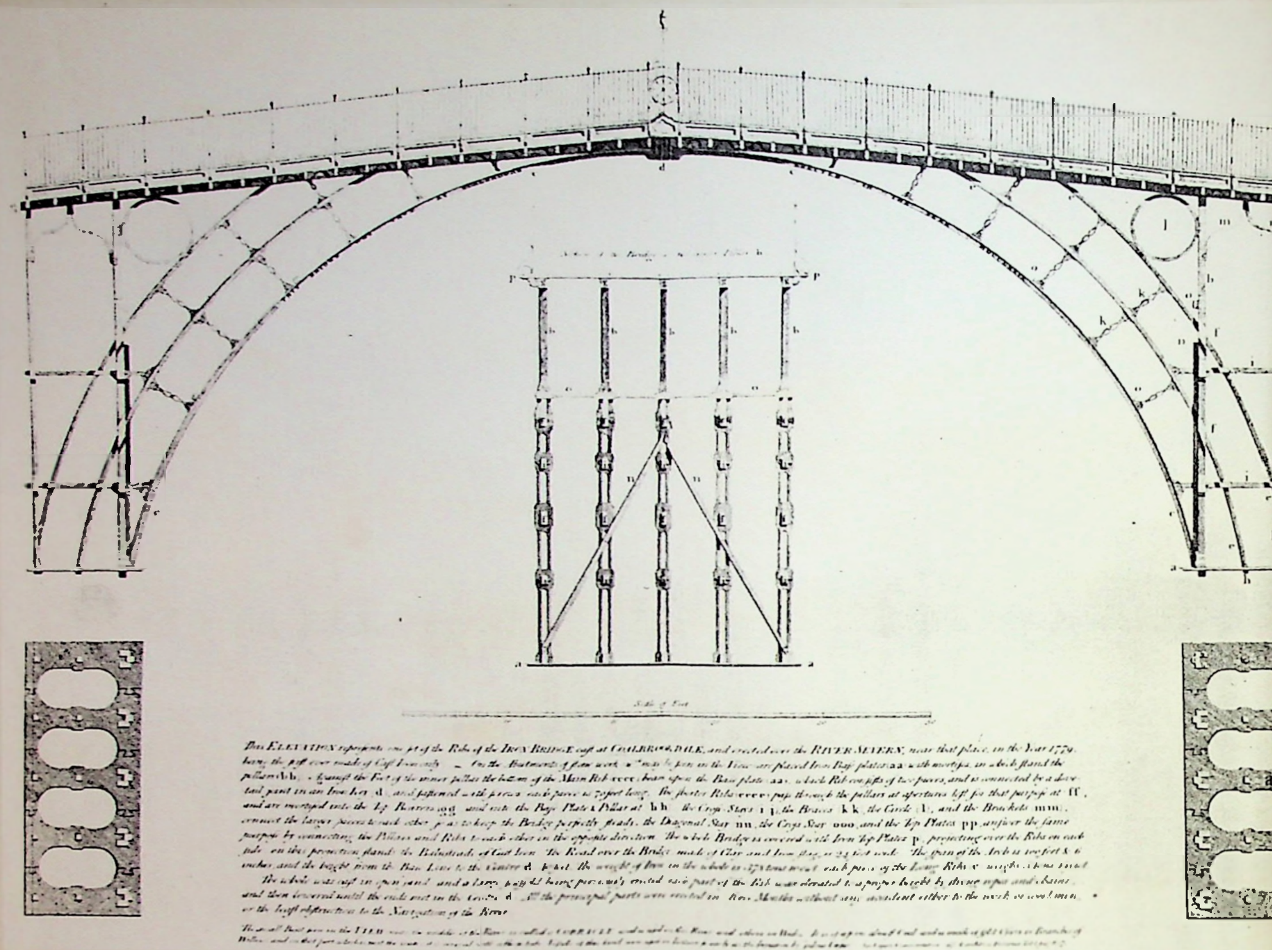
10c

FIRST IRON BRIDGES

Robert Mylne designed a bridge which was found at Inveraray Castle and is probably the earliest surviving design of an iron bridge. There are two drawings (Figure 9) both by Mylne and both dated 1774. They show a bridge of two arches to be built on the pier and abutements of the old 'town' bridge at Inveraray.

For the bridge Mylne designed two very light arches (Figure 9) of 43 ft. span and apparently each of two iron sibs carrying a timber floor of crossbeams, longitudinal joists and boards. In the drawing it shows a gateway across the bridge, probably because it was to be an entry to the estate from the old town, and light guard-rails, both are of iron and in Chinese ornamental style. Though Mylne lived well into the era of iron bridges this is his only known design in iron and apparently it was not built.

Progression from a timber arch design to an iron one is clear in a sequence of designs (Figure 10) made by Thomas F. Prichard of Shrewsbury in 1773-5. The first is a timber arch of 136 ft. span and 20 ft. rise designed for a crossing of the Severn at the new canal port of Stourport in 1773; the second a masonry design of the same span made in 1774, to be constructed on a cast iron centre and the third a design for a cast iron bridge between Madeley and Broseley dated October 1775. In the first design the spanning structure seems to be concentrated in two ribs or frames of braced timbers in the planes of the guard-rails, the main members lying more or less parallel to the soffit (the order surface of any structural member) with radial piers crossing them. The use of the iron bars in the third design is quite similar, but the whole of the structure is below the road, so it is possible that in this design Prichard intended to have more than two ribs. The span is 120 ft. and rise about 29 ft. putting the crown of the arch 55ft. over low water and 16 ft. over the highest flood. The arch rib shown on the elevation consists of one bar forming a complete segment from abutement to abutement and four other broken segments, three of them concentric with the first and above it, rising from the abutement walls till they intersect the line of the road, the fourth rising more steeply from below the complete segment and crossing it.


This ELEVATION represents one set of the Ribs of the IRON BRIDGE cast at COALBROOKDALE, and erected over the RIVER SEVERN, near that place, in the Year 1779.

The bridge which is more often held to have begun the 'Age of Iron' was built at Coalbrookdale on the Severn Gorge in east Shropshire, England often referred to as 'the cradle of the Industrial Revolution'. During the mid 1700's there was the thriving iron-smelting works of the Darby family and John Wilkinson, in addition there were potteries, tile and brickworks, all based on the rich deposits of coal, iron-ore, limestone and clays of the neighbourhood. The main method of transport was barge or by horse and cart both of which were becoming useless to the local industrial needs. In 1775 therefore, a group of local industrialists met to begin planning a single-arch bridge between Madeley and Broseley to solve this problem.

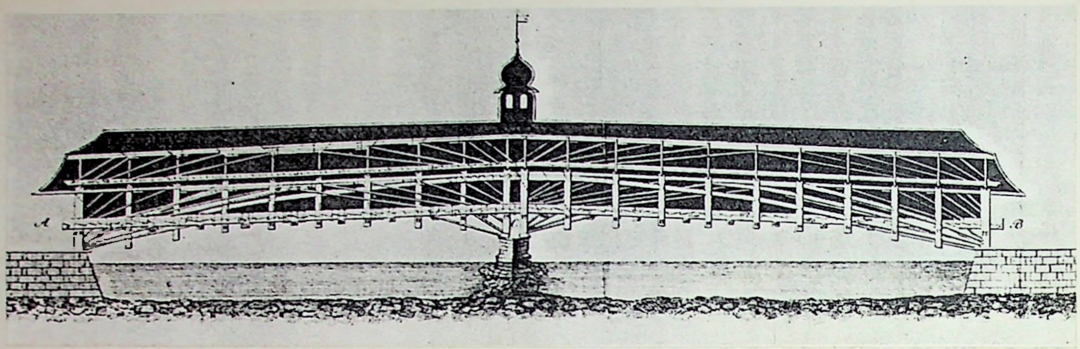
In its authorising act there were no material specifications, in fact iron was only listed among the possibilities. Prichard was the first to be commissioned to prepare a design, in a month he had come up with a plan for an iron structure, with four segmental ribs and a 120 ft. span.

Considerable debates and modifications lasting two years ensued, involving Abraham Darby III, John Wilkinson and a group of local businessmen. Prichard died in 1777 and although it is not known how much he had to do with the final design his contribution is thought to have been significant.

Darby took charge of the construction. He enlarged his furnaces at Coalbrookdale to cope with the casting of the then massive 70 foot ribs for each half of the main arch. He also supervised the building of the large stone abutements necessary to carry the roadway high over the river and he kept detailed records of the expenditure, down to nine guineas, spent on beer.

Virtually all the connection between the members were made by dovetailed end or by fusing one member through a hole cast in the other, and bosses or brackets were cast on to allow mutual bearing, many of the joints being tightened with iron wedges (Figure11), there were some screws but no bolted connections. It has never been established who was exactly responsible for this design, having dealt with Prichard's involvement it has been said that Darby and his foreman pattern - maker Thomas Gregory and Daniel Onions who directed 'the practical operations' all had some part in it.

The first large iron bridge in the world was opened on New Years Day 1781, and was, from that day forward a spectacle to be admired by all.



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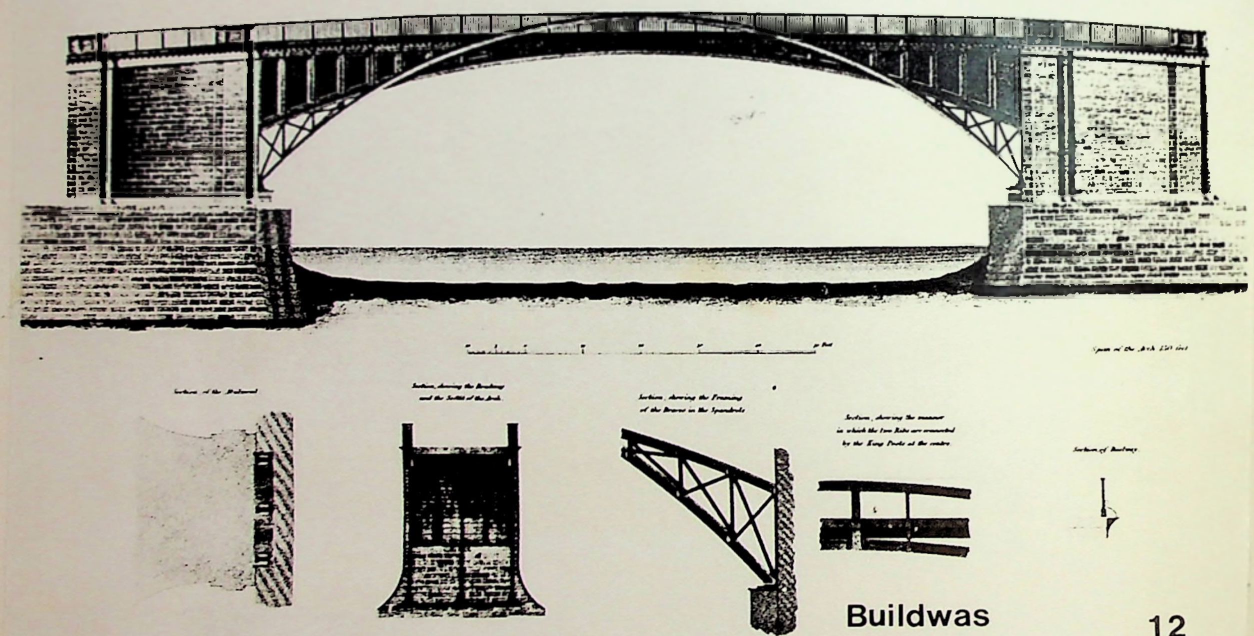

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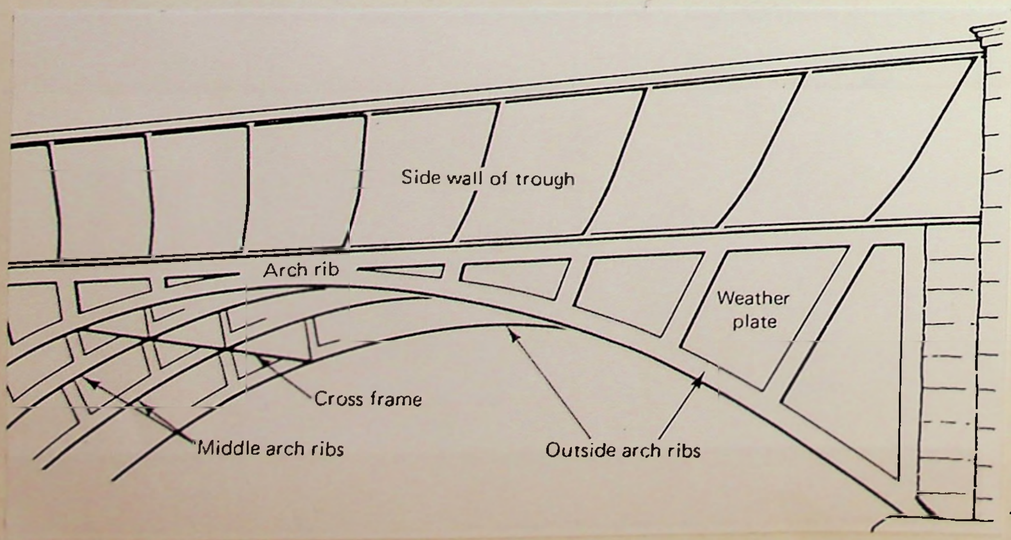

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The present Ironbridge Trust Guide describes it as "The bridge was more than just an important development in civil engineering. It was part of a sublime Romantic spectacle which helped to change the way in which artists, and ultimately other people, looked upon the achievements of Industry".

The bridge itself had little influence on later designers but, it was an important juncture in the use of iron. The only serious error in the design was not in the actual iron work but in the approaches and abutements which being high and built on steep and unstable sides of three gorge were forced towards the river. If a flatter curve were used on the arch, the horizontal force exerted by the abutements would have been lessened. But the high arch at Coalbrookdale exerted little horizontal thrust and the masonry and abutements had to be repaired frequently after 1784 onwards.

However the fact that the arch is still standing probably owes much to the caution of Darby, Prichard and the others in the handling of its design.

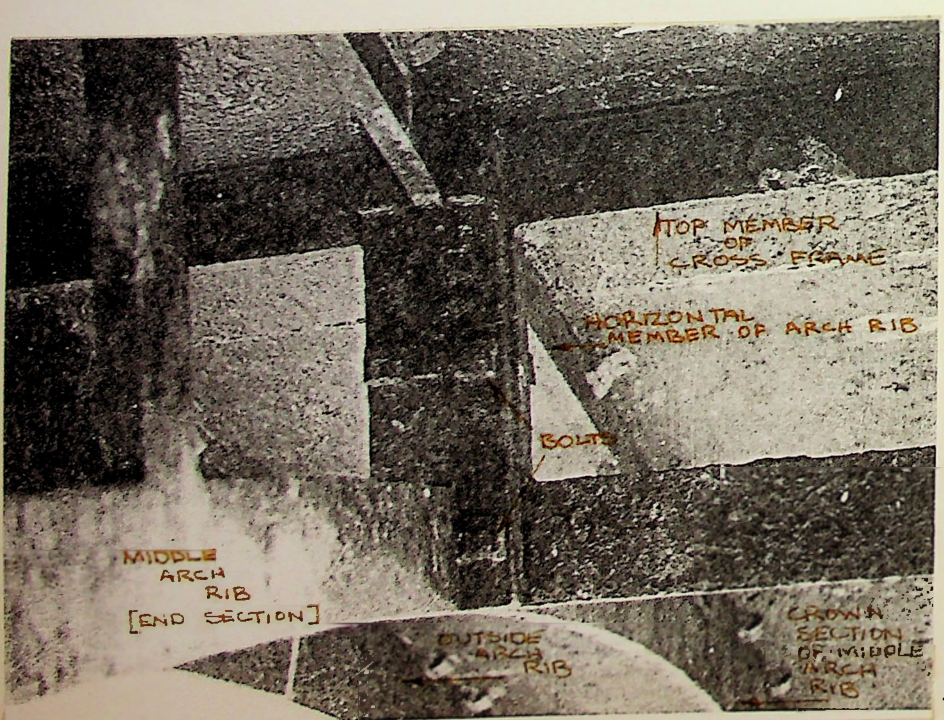
In 1796, at Buildwas in Shropshire, Thomas Telford Father of Civil engineering put up his first iron bridge which was cast by the Coalbrookdale Company. Compared to the "Iron Bridge", Telfords bridge contained half the amount of iron in the structure even though the span was greater by 30 ft. As with the "Iron Bridge", the main problem was to span the river Severn in a single arch so as not to interfere with river traffic. Although it was replaced with the advent of heavier road traffic in 1905, this was Telford's first experiment in Iron and it encouraged him to use it more and more.

His design was markedly different from that of the "Iron Bridge", each of its ribs were cast in only three pieces connected together by bolting through transverse plates like the Pont Cyssylte 1805 arch ribs (Figure14). The ribs suggest that Telford was thinking of timber framing, and an interesting comparison can be seen in the Schaffhausen Bridge (Figure13). His bridge being only 18 ft. wide had three 'bearing ribs' of 130 ft. span and 17 ft. rise. On the outside faces two 'suspender ribs' sprang from about 12 ft. lower and, having a rise of 34 ft. they crossed the bearing ribs (as some of the Schaffausen Bridges struts crossed the line of the road). The outer bearing ribs were connected to the suspender ribs by struts, ties and bracing, and the road was supported on flanged cast iron plates bolted to the bearing ribs.

As the main arch strength was in the outer ribs the plates were really spanning 18 ft. and it was therfore, like Schaffausen, a system which could not be used for a much wider bridge. The bearing ribs were only 15 ins. x $2\frac{1}{2}$ ins. in section and the suspender ribs 18 ins. x $2\frac{5}{8}$ ins., the whole weight of iron being 173 tons. It was all cast iron except for the bolts, fixings and maybe the guard-rails. It was Telford's intention that he eliminate the problem which arose at the "Iron Bridge" in Coal-brookdale namely the thrust of the large abutements in towards the river, not being allieviated by the large arch. He designed a low rise arch in order to resist the pressure he feared might be exerted on the high east abutement by unstable ground.

He was aware of the criticism that 'by connecting ribs of different lengths and curvature, they are exposed to different degrees of expansion and contraction', but he never saw aby trouble from this. It is curious to note, that this was a unique design which he chose never to repeat.

The abutements, although never quite free from movement, are still standing as built today, but the iron-work cracked and was deformed by heavy traffic loads in the late 19th century, and had to be replaced by steel girders in 1905.



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ST LOUIS BRIDGE

ADVENT OF STEEL

Because of developments in the processing of steel i.e. the Bessemer Converter in 1856 which burnt off impurities by blowing air through molten iron, and subsequent improvements thw world price of steel dropped by 75% in 1870 and this began a completely new phase in bridge building.

Steel was to herald a new freedom in bridge designing; it would be the foundation stone for suspension bridges, cantilevers, arches and trusses, it was stronger than any piece of wrought or cast iron. It was ductile rather than brittle, and could be rolled, cast or drawn into many different shapes -blocks, tubes or girders or wires.

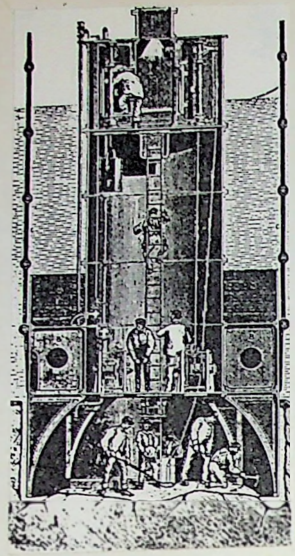
The very first bridge to have incorporated steel in its make up, was a 334 foot suspension span over the Danube Canal at Vienna and was opened as early as 1828. Steel was used for the eyebars.

However in the early days of steel the most significant developments occured in the U.S.A. where fierce competition for bridge building was beginning. Organisations like the old Keystone, Phoenix and Baltimore Bridge Companies were all in competition to win contracts for their pre-fabricated iron designs.

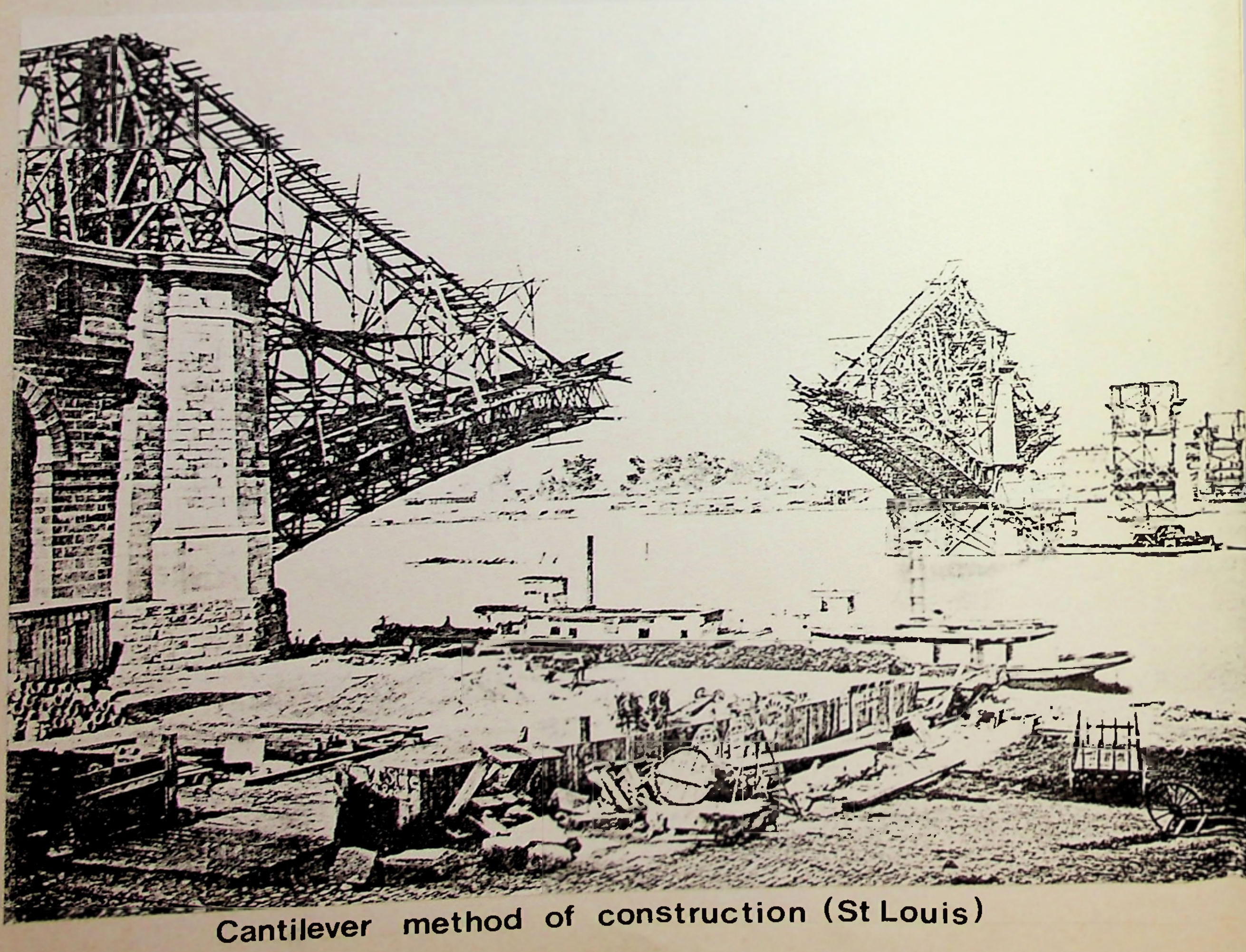
STEEL ARCHES:

The first major development in steel arch bridge building was in St. Louis Missouri, St. Louis on the banks of the Mississippi was becoming a major crossing point of the river. In 1850 the townspeople of St. Louis decided the Mississippi had to be bridged. For 15 years, designs were tendered for the bridge by some of the leading engineers of the time. It was eventually given to Captain James Buchanan Eades who had been a steamboat engineer on the river all his life and knew its characteristics which the previous candidates did not realise. His proposal was fro a steel arch bridge of 3-500ft.arches supported on two piers and the end abutements foundations to be rested on solid rock way below the mud and sand of the river bed.

Eades battled with innovations and lack of previous experience for the six years of construction. His decision to use steel for the arches was one of the major developments he made, then only in their infancy. Other developments were his



Caisson

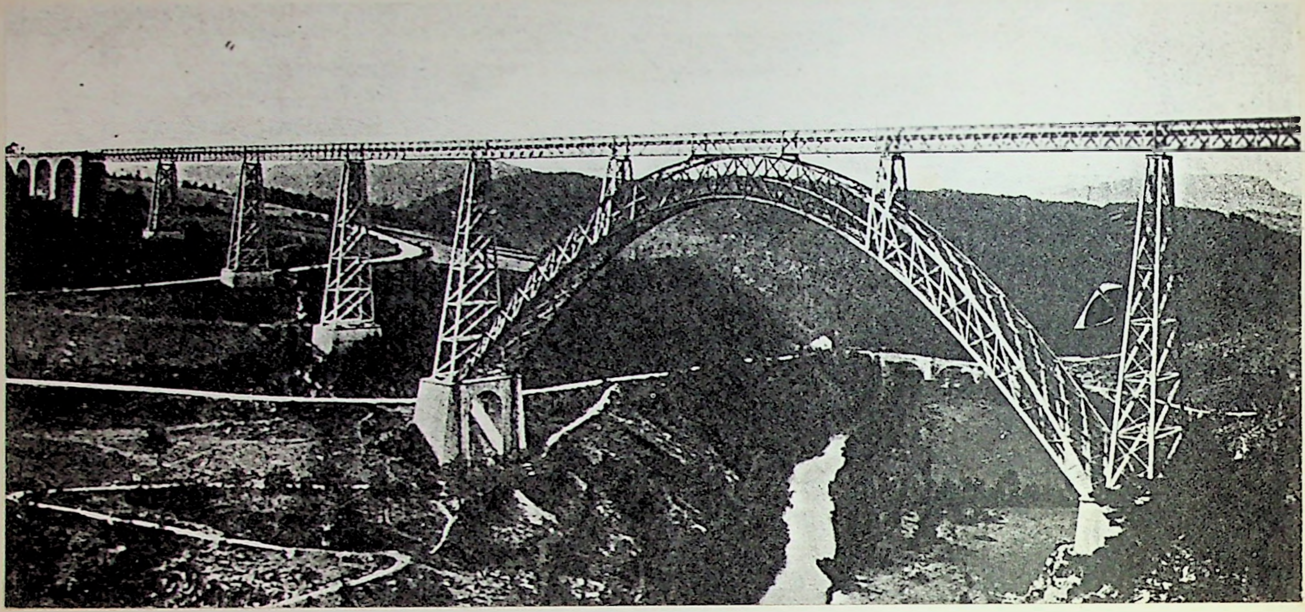


Cantilever method of construction (St Louis) use of pneumatic caissons (water tight box for founding piers) for the foundations at tremendous depths, and the method of constructing the arches without centering. This was done by cantilevering the arch sections out towards each other, supported on cables stretched from temporary towers. The huge pneumatic caissons were floated into place and as they were dug into the river the masonry was laid in the caisson. When they reached rock, the shafts and working spaces were filled with concrete. Because of the great depth of the foundations the pressure inside the caissons was such that many of the workmen developed what they called then 'caisson disease' now known as 'the bends', it resulted from a build up of nitrogen in the bloodstream due to too rapid decompression. Some 15 men died and many others were paralysed from this 'caisson disease'.

Eades overcame this by giving his own family doctor the job of prescribing a work rate and diet and slow decompression for the workers. The results proved successful and when the last and deepest foundation was laid 136 ft. below high water only one man died and that was from his own neglect.

Eades' exacting requirements for the steel tubes for the arch ribs were the bane of his suppliers. He even designed his own machine for testing every one. He in his perfectionism was responsible for the improvement in steel making generally. The bridge was opened in 1874 and today it still stands, indeed it now carries loads which were never designed for in Eades own time. It was the first bridge to have major use of steel (an alloy steel comparable to present day high strength steel) and one of the first significant steel structures of any kind. It was the first bridge to use hollow tubular members, its three spans were substantially longer than any other bridge at the time, besides suspension bridges; it is claimed to be the first bridge of its kind to use the cantilever method of construction, and it was designed so as any part could be removed for repair or replacement.

In Europe the development of railways and the growth of industry was slower than in the U.S. or Great Britain. In France in particular the accessibility of raw materials was poor. They were mainly in very inaccessible places, and no transport from major centre to centre was available as from Lyons or Limoges where the mining of the Massif Central could be exploited.



EIFFEL'S GARABIT VIADUCT

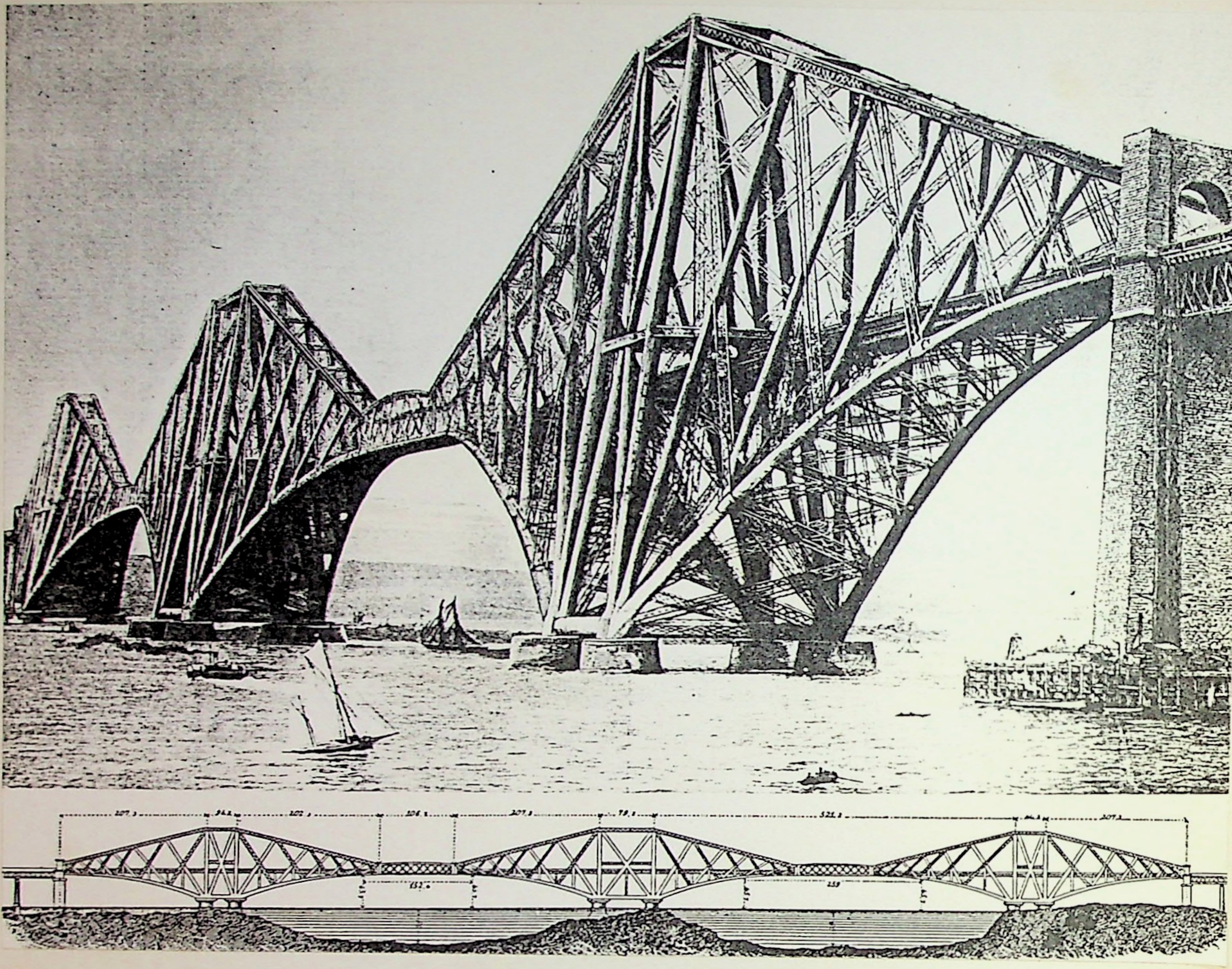
TYNE BRIDGE

In 1879 Alexandre Gustave Eiffel who was to become world famous for his tower in Paris 1889 had been constructing many fine viaducts along the difficult gorges from mining areas to Lyons and Limoges. He had been constructing iron pylons and truss decks to stand up to fierce winds which were prevelant in the valleys of the area. In the early stages he even designed and set up several meteorological stations to study the problems.

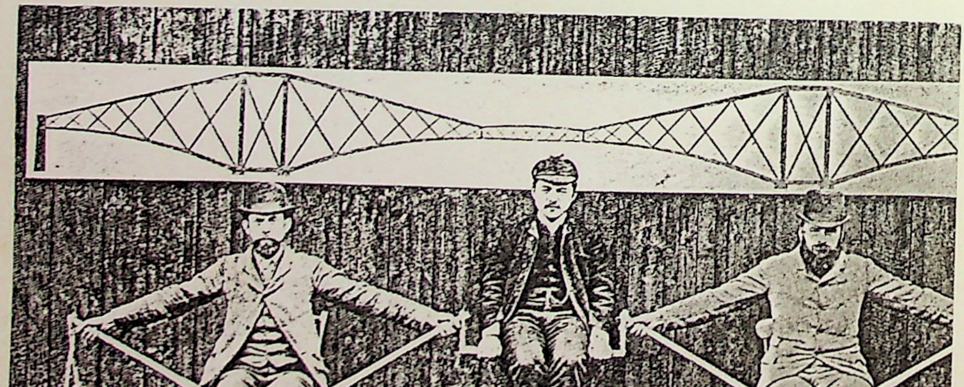
He was consulted by the government of this time who were planning a new and difficult link from the southern Massif Central to the main Paris - Marseilles line. Eiffel proposed that one rather long roundabout could be avoided by constructing a 400 foot high viaduct over the River Trugere.

Thus heralded one of the finest examples of a metal arch bridge ever constructed. For the huge 530 foot parabolic arch Eiffel used iron. The cross-section of this arch is particularly clever in its design. At the crown of the arch, the truss is narrow and deep to support the deck truss carrying the railway. Towards the abutements the section becomes wider and shallower to counteract the overturning effects of the side winds. The ends of the arch rest on hinges which allow for expansion and contraction of the steel with changes in weather conditions. This 'two hinged' concept can be seen in many steel arch bridges which followed this, and can be particularly well demonstrated in the Tyne Bridge in Newcastle.

One interesting comparison to this bridge and Eade's St. Louis Bridge was the method of construction both using the cantilever method.



Forth Rail Bridge



Sir Benjamin Baker (seated centre) demonstrates the cantilever principle, with the help of two of his assistants.

CANTILEVER

It was not until the advent of steel that the cantilever principle became really feasible as a form for long spans. It was railways that provided the first great stimulus for this kind of bridge.

The first spectacular success for the cantilever system was the Firth of Forth railway Bridge. When it was completed in 1890 its size and design were unprecedented. The astonishing fact of the bridge is that it has remained in active service since (95 years), and is the second longest cantilever span in the world.

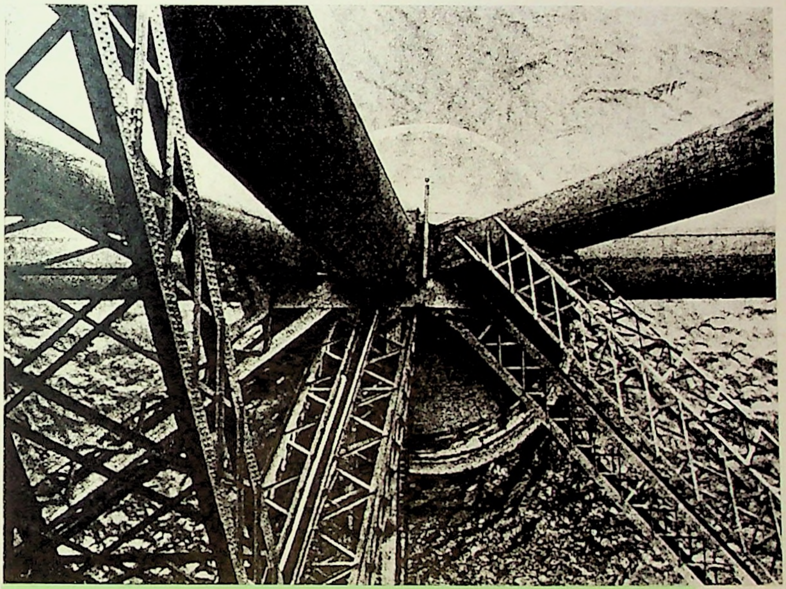
It was a structural masterpiece, with its 3 great pairs of trussed cantilevers reaching out 207 m. from each anchored foot and carrying simply - supported central spans of another 106 m. to leave two clear waterways of 520 m.

Responsible for its design was Benjamin Baker, a member of Sir John Fowler engineering office in London, and had been advocating cantilevers for long spans, in lectures and articles for years.

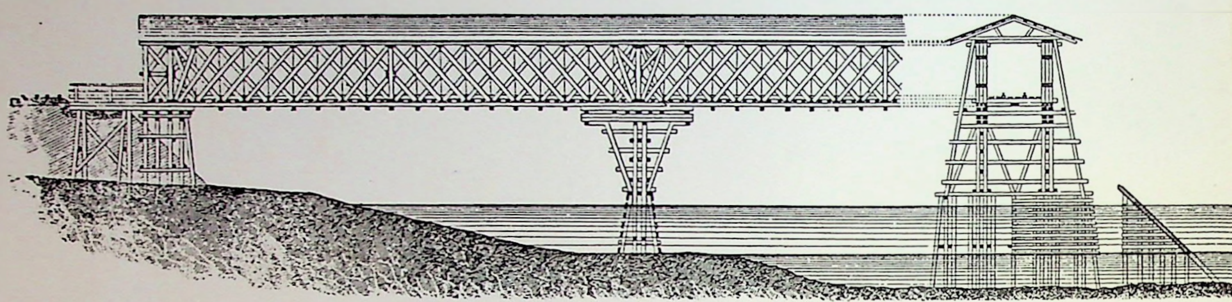
In 1881 Baker and Fowler submitted a new plan for the Forth Railway Bridge and on the strength of their proposals were made engineers in-chief. Fowler had already worked on the famous Stockton and Darlington railway and was at the time President of the Institute of Civil Engineers.

Apart from the cantilevered-suspended span principles of the Forth Bridge, its most impressive feature is its sheer size. Into the bridge went 58,000 tons of open hearth steel and although the effect is spectacular the bridge has been criticised for being 'unnecessily' strong. Baker and Fowler were, in fact extremely cautious on two aspects of their design. First with the Tay Bridge disaster fresh in the public memory, the effects of side winds had to be catered for. After many experiments it was decided that the bridge should be able to withstand wind pressures that, by todays standards would be considered unnecessarily high, even in a part of the world subject to gales. Second, since steel was such a relatively new material, the margins the designers allowed themselves were very generous, especially for the parts of the bridge that could be subject to fatigue from the repeated vibration of passing trains.

The bridge was officially opened on March 4th 1890 by the Prince of Wales (later Edward VII) and was seen as a triumph of Victorian engineering and a symbol of Scotland's greatness. Benjamin Baker was knighted, Sir John Fowler received a baronetry.



Detail at the foot of one of the main cantilever arms of the Forth Rail Bridge.



The 'Town Lattice'system. 15

The ugliness of a truss bridge at Sciotoville Ohio.

TRUSSES

Major Gen. William Smith was an American army engineer, who in the 1870's set out to build the first all steel bridge in the world, for the Chicago, Alton and St. Louis railroad at Glasgow, over the Missouri river. It consisted of five Whipple trusses and was so conventional that it was largely ignored by the public.

Squire Whipple was the first practical designer to arrive at a sufficiently clear quantative understanding of the truss design. His truss was provided with crossed diagonals only near the centre of the span, where the spearing action that tended to deform the individual panels was likely to change its direction as the load passed.

The Glasgow bridge and most other early steel trusses were required by the railways. Most of these were very plain in design, the longer the bridge the more seperate truss units were applied. There were 7 bridges of this nature built over the river Missouri in 1880, by a prolific designer George S. Morrison. The longest of these was the 1675 foot bridge at Sioux City with four 400 ft. spans. Plain trusses of many types were built the world over - like the Hawksbury River Bridge, Australia of 1889 or the Attock Bridge over the Indus in Pakistan, completed in 1883.

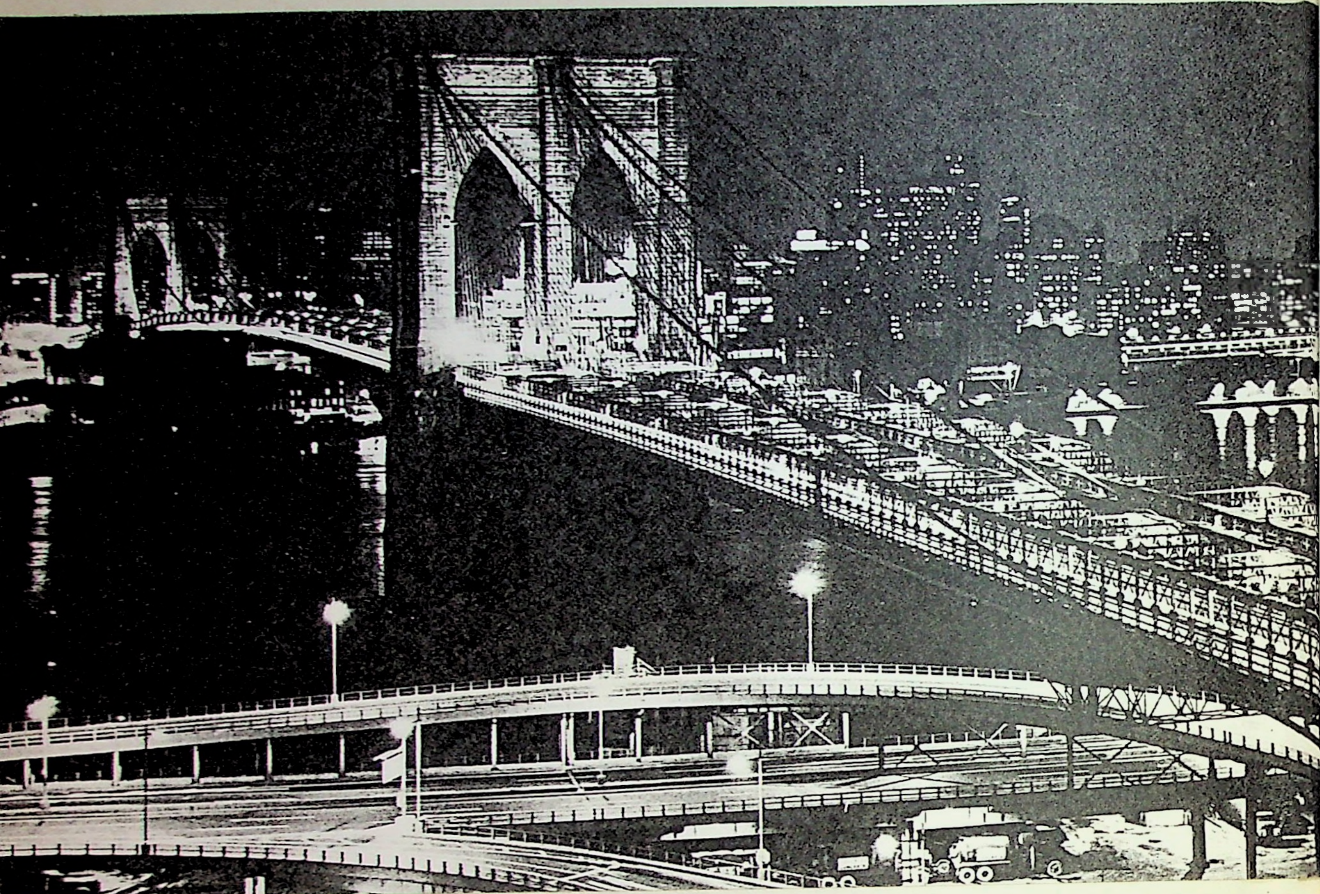
In building truss bridges of more than one span however it was realised that the spans could be made longer and stronger if the truss units were joined together to form one continuous structure. Since each span can then act to anchor or balance the load in its neighbour, a continuous truss girder bridge acts as a cantilever on adjacent spans.

In Ireland an interesting and glowing example was the Boyne Bridge built in 1855 by Sir John McNeill. The Town Lattice (Figure15) patented in 1820, was the final step in the evolution of wood, truss and with it the arch disappeared altogether. Using the Town Lattice truss system, its two side spans of 140 feet each were, druing erection, built continuous with the central 267 foot span. The bridge was completed by seperating the spans : but later, when it was realised how much stronger a continuous structure was, they were rivited back together again.

The other type of truss bridge was a logical step from the 'pure' continuous truss i.e. the combination of the truss and cantilever system, this was also developed in America. A truss acts like a simple beam with compression force in its top chord and tension in its lower chord. In a cantilever on the other hand the stresses are reversed, so the way some of these bridges work is not always obvious. They were found however to be more economical and capable of longer spans than the individual truss system explained previous.

This system was largely developed in Europe but as always is the case in the United States the obstacles were bigger and better so the spans of the bridges had to be longer so it was really here where the principles applied and worked best.

One of the first bridges to combine these two principles was a bridge which I have had the pleasure of crossing and admiring namely the Poughkeepsie Bridge over the Hudson. The deck to the Central Western and New England Railroad was supported on alternating trusses and cantilevers. The heavy trusses acted as counterbalances for the projecting cantilevers arms. The inscription on the bridge showed that it was designed by a Thomas Curtis Clarke who says on it "It may not be a thing of beauty but we hope that it may be a joy forever to its stockholders".



THE BROOKLYN BRIDGE

SUSPENSION BRIDGES

Since 1929 all the worlds longest spans have been suspension bridges. Links of wrought iron pinned together to form a chain, were the basis of the suspension bridge as it emerged in the Industrial Revolution and was exemplified in Sir Samuel Brown's Union and Telford's Menai Suspension Bridge.

The suspension bridge story is largely an American one, although much of the early experimental work was carried out in France and the U.K. The American story is largely due to the work of two men namely Colonel Charles Ellet and John Agustus Roebling. The latter designed the bridge which probably is the most famous and written about bridge in the world, namely Brooklyn Bridge over the East River in New York.

Many people were sceptical at the idea of a 1,600 foot suspension bridge being built. Roebling wrote "The completed structure will be not only the greatest work of the continent, and of the age. As a great work of art and as a successful specimen of advanced bridge engineering, this structure will forever testify to the energy, enterprise and wealth of that economy which shall secure its erection".

His plan was for huge monumental masonry towers, bearing for the first time, steel cables from which would be suspended a strong iron truss. This stiffening would be strong enough to hold itself up, without the cables. "The bridge would sink in the centre but would not fall".

Roebling died before work even started on the bridge in tragic circumstances. His son Vushington Roebling was the obvious successor to the project. Like Captain Eades then in the middle of constructing the St. Louis Bridge Roebling Jnr. had been to Europe to study the pneumatic caisson method for digging foundations. He also had the benefit of Eades own experience.

To support the 280 foot towers the Brooklyn caissons had to be enormous. They took the form of huge partitioned boxes 108 feet by 168 feet in which gangs of workmen could work under compressed air, excavating the river bed, so the caisson would probably sink to solid rock under its own weight plus that of masonry laid inside.

The major setback of the construction which was dogged with ill-luck from the beginning, was the ill-fatal "caisson disease" as talked about in Eades' St. Louis Bridge. It eventually got Roebling himself and he was confined to a house in sight of the bridge for the rest of its completion.

He was hampered by the steel wire suppliers not supplying to his exacting specifications. Also with the bridge nearly complete in 1881 Roebling had to add an extra 1,000 tons of extra steelwork to carry a railway.

It never carried a steam train, but this alteration has made it last to this day with ever increasing loads without any structural changes.

The Brooklyn Bridge the world's longest span, at nearly1,600 feet and the first suspension bridge with steel cables, was also the first bridge over the East River and was thus a milestone in the history of the city of New York.

These were still the early days of building in steel, and despite the success of the Brooklyn Bridge, the suspension principle was not proven as the best for the long spans, and especially not for railways. The Firth of Forth Rail Bridge and later Quebec cantilevers were still regarded as the world's longest from 1889 to 1929. However just after the turn of the century the technology of wire cable suspension systems seemed to get better, and the second bridge over the East River was the Williamsbury, with its unique steel towers, its 1,800 foot span which was designed by Lefferts L. Buck who specialised in arches and it represented the ultimate in truss stiffening with its 40 foot panels.

CONCLUSION

In this study we have seen the major developments in bridge building from Perronet's arch bridges to Roebling's Brooklyn bridge.

Most of the bridges mentioned or their builders were responsible for the advancement of civil engineering as it is today.

Gone are the romantic stories of the individual bridges construction, gone are the single names responsible for their design.

Present day bridges though no less important result from teamwork and theory applications, gone is the adventurous concept of people like Perronet, Eiffel, Prichard, Telford, Darby, Eades and Roebling.

Appreciation for a bridge was no doubt greater in ages past than it is today when objects of convenience are expected and demanded by the public. The knowledge and skill of todays bridge builders is almost infinitely greater today than it was a century ago, yet the place of the bridge builder in the community is nowhere near as great. Nevertheless the personal satisfaction derived from the opening of a new bridge is just as gratifying to the onlookers and the creators themselves.

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