14TH JUNE, 1906.

A CENTURY OF BRIDGE BUILDING AND THE GREAT SYDNEY BRIDGE COMPETITIONS, WITH A DESCRIPTION OF THE FOUNDATIONS OF THE ACCEPTED DESIGN.

(BY NORMAN SELFE, M.I.C.E.)

I.

HISTORICAL.

While many branches of engineering are of quite recent origin and others had no existence at all before the beginning of the nineteenth century, the dawn of bridge building is lost in the mists of antiquity.

The fact that London Bridge possesses an uninterrupted record of over nine hundred years, is sufficient to show that although the bridge engineer might not for many centuries have been very progressive, yet he has a venerable past. With the advent of the nineteenth century, however, things were altered, and the world has since witnessed such giant strides and marvellous developments in the theory and practice of bridge building as to practically create a new art.

This great advancement came about in two ways. In the first place, scientific education and training were then brought to bear on the principles involved in the stability of the structure; and secondly, new materials were placed in the hands of the constructor himself, of greater strength, and possessing other properties than those to which the hands of his older brethren had been confined.

In all ages of the world men have arisen qualified to lead by virtue of their intellectual imaginative or creative powers, and among these the great bridge builders of history must be placed. These men did not posses a fraction of the theoretical knowledge which is now within the reach of a junior student, but by a close observance of physical processes and results, and the possession of strong common sense, they advanced their art with the passing years, although their individual steps were often no doubt only small ones.

During the latter half of the eighteenth century, the foundations were laid of the science of constructive statics which has since been so extended and supplemented by a succession of able investigators that it now possesses a literature of its own. Consequently, where the older bridge builders could only learn by hard out-door experience—and thus put more material in a weak place simply because their previous efforts had there failed—their followers to-day sit down and calculate every strain or stress to be resisted in their structures—whether due to load, wind pressure, or temperature—before the work is begun. Thus mathematical precision is now substituted for clever guess work, in the apportionment of material to the ends in view.

From the earliest years until the middl of the eighteenth century, stone, brick, and timber practically had a monopoly as materials for the bridge builders' work. At this time the manufacture of iron in Britain had fallen off to only 18,000 tons a year—

four-fifths of the iron used in the country being imported from Sweden. With Dudley's use of pit coal in the smelting furnace, and the enterprise of ironmasters like the Darbys, of Colebrook Dale, a new iron era began in England, which witnessed the first iron bridge in the world. This was cast at Colebrook Dale, and set up over the Severn in the years 1776 to 1779.

About this period also there appears to have been a general movement both in Europe and America for building new bridges and reconstructing old ones. With increasing knowledge of the principles involved greater feats of construction were time after time accomplished to startle the world by their boldness and novelty. Among timber bridges that at Schaufhausen, in Switzerland, 364 feet in length (burnt by the French in April 1799) was a most notable example, with a span of 193 feet. Another bridge at Wittengen, also burnt, had a still greater span. The magnificient forests and suitable timber then becoming available in the United States to the enterprise of the young nation, it was only natural that its emulation of the Old World progress should produce local results. Thus we find a most notable bridge was built of timber by Wernwag in 1813 over the Schuylkill at Philadelphia, of the extraordinary span of 340 feet, while the Delaware Bridge at Trenton N.J. with spans of 200 feet was built by Burr in 1804, with a versed sine of 32 feet.

In older countries, however, Stone was still the favoured material. Old London Bridge (of which a rare engraving is shown) had at this time 20 openings, the widest being only about 35 feet span. In a proposal for its improvement presented to the Lord Mayor in 1746, the span of the widest arch was only 100 feet. Notwithstanding the progress that has since been made through the use of iron and steel, we cannot altogether regret its late introduction, as otherwise the world might have missed a number of monumental masonry bridges which have now had for nearly a century world wide renown.

In the early years of the 19th. Century the more imperishable material still asserted itself in great cities, and under the hands of the elder and younger Rennie both Waterloo and London Bridges were built to be examples for all time. The former with nine eliptic arches of 120 feet span was commenced in 1811 by the elder engineer, while the latter—recently widened—was commenced in 1824 by his son. London Bridge has a centre span of 152 feet, the next arches being 140 feet, and those at the abutments 130 feet. There are thus only five openings to replace the twenty of the old bridge which it superceded. As far as span goes London Bridge has since been completely beaten by the Dee Bridge at Chester with a 200 feet span, the keystone being 12 feet above the water.

To digress for a moment it will be interesting to compare this span of 200 feet with that of the Second Premium Design for the North Shore Bridge (First Competition) submitted by the Author; this has a clear span of 1800 feet and a clear headway of 180 feet, while another design for a steel arch bridge sent from England had a clear span of 2000 feet. The structure of London Bridge—1005 feet long—cost £425,000; the bridge across Sydney Harbour for which government received designs and tenders is 3000 feet long, it is also one and a half times as wide, and five times as high for headroom as London Bridge. Therefore under the same conditions and on the basis of plan area alone it would be worth say four and a half times as much as London's great structure, or nearly two millions of money. But inasmuch as the actual conditions involve greater span, greater height and unprecedented depth of foundations, it would really warrant a much greater proportionate expenditure. The tenders were however—owing to modern progress—very much lower than such proportionate rates.

As the first cast iron Bridge at Colebrook Dale was esteemed a successful experiment, Southwark Bridge followed, with three Cast Iron Arches; the centre span in this case being 240 feet, and the cost about £800,000.

About this time also a bridge was projected to cross the Thames with a Single Cast Iron Arch of 600 feet span, which led to a series of questions as to its feasibility being submitted to eminent men, for the information of Parliament.

Reading their reports in the light of present day experience is very interesting, Mr. John Playfair who was consulted, evidently had a poor opinion of theoretical men and said "the most valuable information in such a case is not to be expected from them," and "from men educated in the school of daily practice and experience the soundest opinions could be obtained."

In the present day a Bridge Builder, even with a life's practical experience, must have the highest theoretical knowledge at his command if he is to succeed.

The special properties of Wrought Iron and its increased production led to Cast Iron being supplanted, and the great 600 feet Cast Arch was never erected. Wrought iron then held its sway until the discoveries of Bessemer, Martin, and Thomas, between the years 1855 and 1880, provided a still superior material, and introduced the Steel Age of Bridge building.

The Wrought Iron age, however, coming at a time of great industrial activity, saw numbers of bridges of remarkable character erected that will always—even after they have ceased to exist—have an historic interest for engineers, as marking new epochs or phases in bridge design.

Telford the first President of the Institution of Civil Engineers commenced the Menai Suspension Bridge with a span of 570 feet (then thought marvellous) in 1819. The Freiburg Bridge in Switzerland, 1833-34, was a still greater advance to 870 feet span and was 167 feet above the water.

In Girder Bridges Stephenson made his notable departure, thirty years after Telford's work, by building the Britannia "Tubular Bridge" over the same Menai Straits with spans of 466 feet—the trains going through the inside of the girders; and he followed up the system by the erection of the Conway and the St. Lawrence Victoria Bridges on the same principle.

Brunel gave us a new type in the Saltash Royal Albert Bridge in 1857-1859. This was erected 102 feet above high water at a cost of £230,000—and the design was a novel form of parabolic Bow and Chain.

Owing to the facility with which it was found iron bridges could be constructed, hundreds of useful structures of less notable types and designs came rapidly into existence. Many of these were so unsymmetrical in their utilitarian simplicity that a great and fully justified outcry arose as to the way engineers were disfiguring cities and landscapes with their ugly works. Few would pretend to say for instance that the Blackfriars Railway Bridge at London, the Poughkeepsie Bridge over the Hudson in New York State, or the Hoogly Bridge in India are graceful structures—notwithstanding the admittedly scientific character of their designs.

This outcry against the appearance of many of the early iron bridges, practically contemporary with the introduction of steel into their construction, has been followed by a total change of practice. The man of taste in Art is now often associated with the mathematician and the constructive engineer in the design of great works, so that the economic fulfilment of requirements in the use of material is combined with aesthetic proportions, while at the same time full consideration is given to the harmony of the completed structure with its surroundings.

Between the years 1867 and 1874, utilitarian America built one of the most beautiful bridges that have yet come into existence—the celebrated three arched steel bridge over the Mississippi at St. Louis—at a cost of £1,307,000. This is practically the same amount as the tender for the selected design for the North Shore Bridge, although the latter is twice as long and twice as wide. The St Louis Bridge is however, double decked,—the railway being below—,but the centre span is only 520 feet, while that of the North Shore Bridge is 1200 feet in the clear. Captain Eads great Monument at St. Louis has however, shared the same fate as has overtaken Stevenson's "Tubular" and Brunels "Parabolic Girder" bridges and which also awaits the great Forth structure; for while they all mark epochs in bridge building, they have never been, and are not likely to be, repeated; bridge building has since made such progress as to leave them hopelessly behind from the economic standpoint.

America, of late years, has witnessed much experimental bridge building, and has seen many great works carried out as well as hundreds of shoddy structures.

These no doubt evidence the ingenuity and originality of that great people, but at the same time the solid and substantial character of English bridges has become proverbial. If, however, we desire to see the highest development of scientific design and faithful construction, combined with aesthetic considerations as applied to bridges, it seems certain we must go to Germany, France or Belgium.

No reference to late American bridges would be fair that omitted to mention the works of the two great German engineers the Roeblings—father and son. The former built the Niagara Railway Suspension Bridge—recently replaced by Mr. Buck with a single arch of 550 feet span, while the latter was the author of the world famed Brooklyn Bridge at New York which for a quarter of a Century held its position as the greatest bridge in the World; it has a centre span of 155 feet and a headway of 135 feet.

In the last quarter of the last Century the great Forth Bridge broke the record (which it still holds) with a span of 1700 feet, this however was exceeded in several designs for the Sydney Bridge—as before referred to.

Owing to the Main Compression members of the Forth Bridge lying in curves like the haunches of an arch, the general outline of that great structure does not present the abrupt and uncouth appearance which many Cantilever designs suggest; and situated as it is amid the wild scenery of the Forth its immensity does not dwarf the landscape. The late Advisory Board of the New South Wales Government however showed clearly that even if such a design had been an economical one it would not harmonise with the adjoining shores of Sydney Harbour.

In Germany public sentiment is too powerful to permit its Mediaeval Cities and classic rivers to be disgraced by hideous structures, and thus we find magnificent Arched bridges, with approaches and towers all in harmony with the surroundings, now span the Rhine, Danube and other Continental Rivers. (See illustrations of Bridges at Worms, Bonn, etc.).

Engineer Lindenthal of New York has a mighty proposal for bridging the Hudson river on the Suspension principle with a 3000 feet span, but the Tunnel now nearly completed under that River will probably put back this bridge project. Two or three other bridges, one of which is now completed, have been recently planned to cross the same esturay of the sea as the Brooklyn Bridge. There is a lofty Arched bridge of 541 feet span and 356 feet head room by French engineers at Truyere, and another over the Douro in Spain. There is an arch over the Kiel Canal and the Great Kaiser Wilhelm Arch at Mungsten—both designed and erected by the firms associated with the Author in the North Shore Bridge Competition; the latter has a span of 557 feet and rises 354 feet above the water in the Valley below.

The greatest span of arch bridge at present is 840 feet by Mr. Buck at Niagara Falls, but the possible limit is not reached. There were arch designs for the North Shore Bridge up to 2000 feet one of them a five jointed Arch—Motto "Funfgelenkbogen"—submitted by the Author's colleagues in the First Competition,—was most remarkable for novelty of design, being a three jointed arch carried on the ends of two jointed cantilevers.

With the whole world of Bridge engineers ever alive to meet new problems as they arise, and with each having a natural pride in his own and his country's work, it is easy to understand how great a stir was made in the camp of the bridge buider six years ago, when the Premier of New South Wales, Sir William Lyne, and the Hon. Minister for Works, Mr. E. W. O'Sullivan, publicly announced the intention of their Government to build the North Shore Bridge, for which Parliament had refused permission to private syndicates.

This interest was intensified when the Government of the State issued printed plans and conditions for the guidance of Competitors, and invited the whole world to send in designs and tenders.

Some disappointment was felt in America at one of the conditions, owing to the fact that the amount offered as premiums was only the comparatively small sum of fifteen hundred pounds, "Partly to recoup competitors for their trouble". This arose from the fact that the conditions insisted on the supply of the most complete details, working drawings, strain sheets, specifications, and schedules for every design—worth more in each case if the design was any good, than the whole amount of the two premiums. No provision was made for preliminary supply of sketch plans, to be followed by further particulars if the proposal was sufficiently approved of by Government to warrant further action. This of course entailed on each conscientious competitor an enormous outlay to which the two prizes of £1,000 and £500 respectively, bore only a small relation.

When Mr. Bruce Smith, as Minister for Works in 1891 invited designs for the comparatively unimportant Pyrmont bridge, only drawings general description and