Bolgoda Bridge, 5th Mile, Panadura-Nambapana Road.

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Metal bridges date from the time of the industrial revolution in England and have been in common use only during the past 160 years. In the days when the metallurgy of iron was little known, cast iron was popular and the compressive factor was taken advantage of. The first metal bridge was an arch of cast iron constructed in the year 1775 at Colebrook Dale over the Severn, with a span of 100 feet, roadway 26 feet and rise of versine 45 feet.

About five years later, the heavy cast iron beam bridges came into use with narrow compression and broad tension flanges complete with stiffeners and all cast together.

Wrought iron beams were produced in 1832, but the construction of wrought iron lattice bridges did not commence until 1853.

The industrial activity and the developments in machinery led to the production of heavy plates in mills, and 1857 saw the first plate girder bridges. When plate girders of wrought iron had become possible the field of metallurgy extended to the production of mild steel.

Improvement of material alone, however, did not result in the development of structures. Designers had to formulate stress diagrams and evolve suitable frames with struts and ties in various planes to produce equilibrium. That was successfully done before long; but the problem of fabrication and construction remained unsurmountable until some famous contractors by virtue of their boldness, patience and resourcefulness materialised the structures conceived by the designers.

The designers were master minds in evolving grace with dignity, strength with rigidity. As is
natural, the scope for recognition was wider in those days, and the early designers became famous.

Of the Contractors the name of Sir William Arrol & Co., Ltd. was as famous in the eighties as it is to-day. The originality displayed by this great Firm of the North of Britain made structures great and small possible; and the invention in 1875 of a machine to drill all the component plates and angles of the booms of heavy girders opened the field to great undertakings. The designers were at last to be satisfied. Concentrated attention led to the development and improvement of plant and the invention of new types. Invention followed invention for surmounting difficulties of construction and the Firm produced such gigantic structures as the Tay Bridge, the Tower Bridge (the heaviest yet made) and the Forth Bridge—one of the largest cantilever structures in the world.

Mild steel was first used in the year 1880 and the Forth Bridge was the finest bridge of importance to be constructed with this metal. Since then great achievements have been made and mild steel has been a boon to Engineers the world over.

The early designers created structures of enduring beauty and character. In designing modern structures however small we apply the experience of the past: every step forward in design is evolved from proved experience in the past.

It is the execution of ennobling structures of such varied character in principles of design, function and form that has to be learnt by new members of the profession who are but diminutive dwarfs beside the old giants; for example one may mention the Forth Bridge with a total span of 8295 feet, 60,000 tons of steel, and cantilevers of 680 feet; the Tay viaduct of 10,711 feet and 27,370 tons of steel; the Scherze roller lift bridge; the Wear bridge at Sunderland of 330 feet river spans and 9,000 tons of steel in all; the Tower Bridge with a central opening of 200 feet and two open leaves weighing 1,200 tons each, marvels of engineering—the more to be marvelled at considering the difficulties of the day in labour, materials and machinery for fabrication and construction.
In the present day the aims of design are subject to political and economical considerations in many of our undertakings. That designers are not wanting is proved by the Sydney Bridge, that glowing example of design and craftsmanship.

**DESIGN—SINGULAR FOR CEYLON.**

The subject of the paper, however, is a particular design of singular type at present in Ceylon: a venture in bridge construction not lacking in boldness, but with function and economy duly considered.

Utilising the opportunity afforded by Government's Five-year plan for roads to be carried out with assistance from the Road Fund the Ministry of Transport in Great Britain has recently issued a Circular emphasizing the value and importance of right proportions and artistic character in highway bridges. I would like to quote in full an article on the Circular which appeared in the Surveyor of 1st March, 1935, but content myself by giving the gist of some of the comments which were particularly striking.

Mr. Hore-Belisha urges that special care should be taken to see that new bridges and re-constructed bridges are of pleasing design and suitable to their surroundings. It is possible for a bridge to comply with regulations prescribed for the strength of such structures and yet fall short of the legitimate expectations of the public in the matter of architectural design and suitability to its surroundings.

He adds that there is no reason to assume that the provision of bridges pleasing in themselves and harmonious with their settings will add to the cost of construction and experience confirms that bridges are more frequently criticised for undue elaboration than for well-proportioned simplicity.

As far as records show, the first bridge of the type adopted for Bolgoda was the Dalginross bridge at Comrie also constructed by the Firm of Sir William Arrol & Co., Ltd. The bridge was of a novel type of construction and the design was known as "constrained cantilevers" from the method devised for connecting the ends of the cantilevers where they meet at the centre of the waterway by a "pendulum link."
The bridge at Comrie had four main girders of this type at 6 feet 4 inches centres placed under the roadway. They are 18 inches deep at the abutments, 44 feet at the piers and 16 inches at centre of the middle span. The opening between abutments was 200 feet, divided into two side spans of 55 feet and a centre span of 90 feet.

The width of roadway was 20 feet between kerbs with a footway of 5 feet width on each side. The road was on a slight grade to the centre to conform aesthetically with the outline of the arches formed by the cantilevers.

The Dalginross Bridge referred to above was the first of this type in the British Isles. The latest one is perhaps the bridge of similar design and features at Fladbury. The latter bridge was completed in July, 1933, by the Worcestershire County Council over the river Avon, at Fladbury. The Bridge replaced an old wrought iron structure of lattice design built in 1887. The change was therefore effected after 46 years.

In this case the design of constrained cantilevers was adopted because of the countryside and the desirability to harmonise with the surroundings, an example of aesthetics in Engineering design. The steelwork was finally painted in shades of green to blend with the natural vegetation of the banks.

Fladbury Bridge is not only the latest bridge of the cantilever type, but also the first modern steel bridge built by the County Council. The British Steelworks Association was consulted as to details of the newest practice in steel construction.

The total span is 200 feet between faces of abutments as against the same opening of the Comrie bridge, and 180 feet of the Bolgoda Bridge, the central span between centres of piers being 100 feet 3 inches, against 90 feet of the Bolgoda Bridge. The carriage way is 18 feet as in Bolgoda but the Fladbury Bridge has two foot-paths of 4 feet each.

At Fladbury the centre pier cylinders are 12 feet diameter steel cylinders sunk 10 feet to 12 feet below river bed into clay, and filled with a hearting of mass concrete. The largest cylinder sunk by the Public Works Department in Ceylon is 10 feet diameter and this is found to be econo-
mical from the point of view of handling and construction. Steel cylinders were not considered suitable at Bolgoda as the water was subject to brackishness, and corrosion at average water level would accelerate the deterioration of the metal.

The abutments at Fladbury were built on piles. At Bolgoda cylinders were decided upon as likely to be more suitable.

THE STEELWORK AND SUPERSTRUCTURE.

An authority on Engineering construction has stated that concerning all types of bridges the importance of selecting an appropriate form increases with the length of the span; the choice of design is then narrowed, a correct decision becomes more difficult, and an error in judgment or departure from the exact form which may be best for the purpose in view, tells with great effect.

One of the advantages of cantilever bridge construction is that it allows of erection over wide rivers or ravines without expensive temporary staging.

All the above and similar considerations were weighed and compared before the design for the new bridge at Bolgoda was finally adopted.

It will be seen from the drawings that the steelwork consists of two pairs of main cantilever plate girders. The girders are supported at their deepest section, which is 6 feet, on special cast iron bearings, and connected at the centre of the main span by a pendulum link as in the Comrie Bridge. They are held in position at the abutments by specially designed bearing ends.

The main girders are of simple design, 6 feet at the deepest point and 2 feet at the ends. Their flanges consist of mild steel plates designed as for ordinary plate girders, diminishing in thickness towards the extremities according to stress conditions. Tall gusseted Tee irons have been arranged on both faces of girders, spaced to provide adequate stiffening at the most effective points.

Roadway.

The width of roadway is 17 feet clear between kerbs, the centres of the main girders being 19 feet
9 inches. The width of roadway is the standard approved by the Ceylon Transport Commission for bridges providing two lines of traffic. The roadway has a cross camber of 1 inch in 8 feet and a longitudinal camber following the lines of the steel work and the formation of the arched cantilever opening.

In designing the surface of roadway special attention has been paid to the nature of the traffic which it will carry. It provides both for transport vehicles of 50 years ago which are still in use and for modern vehicles.

A few years ago when fast traffic came into use and the surface treatment of roads with tar emulsions became universal, it was observed that the ordinary tar macadam had its drawbacks in bridge platforms.

Heavily laden carts to and from the principal towns created furrows in their wheel tracks and reduced the ordinary macadam road to a corrugated platform. The impact of heavy and swift moving vehicles on such a surface causes tremendous impact stresses and undue vibration of the structure. Therefore granite sett paving was introduced on bridges.

The setts were of stone 9 inches by 5 inches by 4 inches thick. Their weight alone added to the area of steel required. Setts while being good enough in far off places proved unsatisfactory in principal bridges where the bullock carts created definite lines of wheel tracks. Victoria Bridge in Colombo provides a good example of such conditions. The wear is great and such as to show that the traffic coming into Colombo has done more harm than the outgoing traffic, indicating that the heavier vehicles are those that come daily into town with food products, timber and other articles.

The roadway in the Bolgoda Bridge therefore has iron paving. The wheel tracks are paved with "Tripedal Castings" for a width of 2 feet for each wheel line. The castings are to be imported from Messrs Iron Roads, J.td., and set in special Asphaltum prepared for the purpose by Messrs Socony Corporation, Ltd.
The question of temperature on the iron surface has been considered as far as knowledge permits. Experience alone will test and prove the design.

The area between the Cast Iron Sections will be surfaced with 2 inches thickness of special Steel-Crete cement wearing surface, the specification of which furnished by the manufacturers is as follows:—

(A) The wearing surface shall be of a total thickness of 2 inches laid over the cement concrete slab.

The wearing surface shall be laid in two thicknesses consisting of:—

(i). $1\frac{1}{2}$ inch thick granolithic surface composed of two parts granite chips, one part sand and one part cement, with the latter of which has previously been incorporated grey Steel-Crete equivalent to half the weight of cement used.

(ii). A finishing coat of $\frac{1}{2}$ inch thick Steel-Crete rendering composed of two parts of sand and one part of cement with Steel-Crete equivalent to the weight of cement used.

(B) When rendering has been formed to required camber sprinkle evenly over the surface of the whole area a mixture of 2 lbs. cement and 2 lbs. Steel-Crete per square yard of area and thoroughly trowel the surface with a steel float until the required finish is obtained. When surface is sufficiently set cover over with clear fresh water for a week. Brush off surface and when dry paint with two coats road tar as in macadam roads.

The edge of roadway along the steel girders is finished with well dressed stone kerbing of standard profile.

The iron paving and the Steel-Crete wearing surface are bedded on cement concrete filling 4 : 2 : 1 mixture in steel troughing 4 inches deep rolled by Messrs Motherwell & Co. The troughing is supported at 9 feet, centres by built-up plate cross girders spanning the main girders.

**Cross Girders.**

It will be observed that, contrary to the general practice the cross girders are not mounted on the
main girders: this is because of the camber of the latter, the varying thickness of flange plates, and difficulties in erection and painting of the steel surfaces in confined formations. The arrangement also enables the cross girders to act as an integral part of the stiffening arrangement for the structure. At the shallow ends of the Cantilevers the ends of the cross girders are themselves reduced in depth.

Sway bracing is provided by broad flanged built-up cross beams.

In the choice of depth of girder and dimensions of sections market widths of rolled steel plates have been kept in view. The deepest web plate is limited to 6 feet and the positions of the joints in the main girders have been designed to afford the maximum economy in plate length, sections convenient for transport, ease of fabrication, erection and assembly, and also with relation to the stiffening points so as not to foul the vertical stiffeners that are indispensible.

The handrailings in a bridge of this type has to be of suitable section and shape to harmonise with the general lines and afford reasonable protection to fast moving heavy vehicles. Recently the ordinary gas tubing attached to the lattice bars of Victoria Bridge were wrenched out by a 'bus that strayed off the track and rode the pavement of the bridge.

No attempt is made in the design of the handrailings to provide a buffer for such adventurous vehicles, but the railing will give the normal protection intended for vehicles using the roadway.

Main Girders: the pendulum link.

As already stated there are only two main girders to each span, making four cantilever girders for the whole bridge supported on four cast iron rocker bearings on the four pier cylinders.

The ends of the cantilevers are connected by a pendulum link. The mechanism constrains the ends to deflect together and enables the smooth passage of vehicles from one cantilever span to the other without shock or impact at the joint. The link is designed as a strut, pin jointed at ends,
capable of taking maximum shear at the section and consists of a mild steel flat 4 inches by 1 inch by 2 feet long with 1\(\frac{3}{4}\) inch diameter pins.

While constraining the cantilever ends to deflect together vertically, the mechanism being pin-jointed offers no constraint to bending at the joint.

Any other method of fixing would have upset the assumption of cantilever design altogether by converting the main girders into a rigid arch or one pin-jointed at the crown.

A space of 1\(\frac{1}{2}\) inch is allowed between the ends of the girders; and in order to permit movement and expansion the edges of the roadway are provided with C.I. traffic tread plates across the bridge, the maximum clearance between the plates being one inch.

The cantilever ends at abutments are not fixed. Provision is made for expansion and moderate movement vertically to prevent the rigid arch formation.

The bottom flange of the end of the girder is held in alignment by mild steel clip plates 1 foot 3 inches by 8 inches by 2 inches thick on either side of it.

These clip plates are secured to the bed plates by 7/8 inch diameter bolts counter-sunk and feathered at underside of bed-plate. The bed-plate is held down by four 1\(\frac{1}{2}\) inch diameter holding down bolts.

The maximum pull at each girder on bolts has been reckoned at 21.65 tons, and the system of bearing girders in the abutment capping has been designed to meet that.

The weight of each main girder is 13 tons, and that of each cast iron bearing exclusive of bolts, &c. 3 tons. The weight of the total steelwork supported on the pier caps is 146 tons on each pier. The total load when bridge is fully loaded is 73 tons on cap of each cylinder.

The maximum bearing pressure at the base of each cylinder for the piers is 4 tons per square foot assuming the level of rock as shown on drawing and recorded by borings.
An advantage of the design from the aspect of corrosion is the exposure of the minimum area of the steelwork to the action of the weather. The only areas exposed are the top flanges and the outer faces of the main girders, the remainder of the steelwork being under cover by the bridge roadway itself.

STANDARD OF LOADING.

According to the standard of traffic permitted on roads by this department the bridge would be classified among those for 6 ton traffic, that is those capable of taking a train of trucks extending over the full length of bridge with 5 ton axle loads at 6 feet centres and another train 70 feet long passing in the contrary direction. For concentrated loads a single 10-ton steam roller is reckoned at centre of span of cross girder with its hind wheels over the girder.

This standard of loading is higher than that adopted by the Crown Agents for Colonial Bridges, in which only 8-ton trucks are taken with 4-ton axle loads at 10 feet centres.

The standard adopted by the Department is equal to that of the British Standard for Road Bridges where the trucks or trailers are 134-tons with axles of 64-tons at 10 feet centres. The Ministry of Transport Standard is however higher as it provides for 13-ton trailers with axles at 8 feet centres and trailers 10 feet apart and includes a 50% allowance for impact.

The limiting stresses for the steel in this bridge are well within the British Standard Specification for Steel Bridges, No. 153, part. 3 1923—where for steel in tension it is 8 tons per square inch, compression less according to the form of section, and shear 5 tons per square inch.

British Standard Specification No: 153 is now under revision and it is understood that one of the amendments will be the raising of the permissible stresses for new steel.

THE ABUTMENTS AND PIERS.

The foundations of piers and abutments are of cement concrete cylinders 10 feet diameter below water level. Above water level the piers consist
of 8 feet diameter cylinders, but the abutments and wings are of concrete on deep reinforced concrete capping over the cylinder foundations.

The cylinder rings are 1 foot thick with concrete of 1:2:4 composition. All cylinders are to be sunk to rock foundation. The heating for the lowermost 6 feet depth and the uppermost 6 feet depth is to be of 4:2:1 concrete, and for the intermediate depth it is to be of 6:3:1 concrete with 30% plums.

The cylinder caps are connected together by steel girders which receive the holding down bolts of the main bearings.

Precast concrete flood diaphragms are provided between cylinders to a depth of 6 feet, between the levels of flood and normal water. The entire steelwork inclusive of bearings will be above H.F.L.

The head room at centre of archway of the central span is 9 feet and would permit the passage of paddle-boats and other vessels not requiring more than that clearance.

The width of the roadway is 26 feet at the approaches which are to be realigned and regraded to conform to the new bridge levels.

The cost of steelwork and bridge platform is estimated at Rs. 85,000, and the foundations, abutments and approaches at Rs. 200,000. As the bridge is still under construction it is not possible to give final figures.

ACKNOWLEDGEMENTS.

The drawings forming part of the paper have been prepared specially for the purpose and are not working drawings. As the bridge is under construction a perspective of the bridge has been drawn with the kind permission of the Senior Architect Mr. Wynne-Jones by his Assistant Architect Mr. Shirley d'Alwis.

My thanks are due to the Director of Public Works for granting permission to read the paper and have access to official documents and to Mr. Wynne-Jones and Mr. Shirley d'Alwis for the perspective which admirably portrays what the bridge will look like when completed.
This passage from "the Stones of Venice" presenting Ruskin's appreciation of a designer's difficulties may prove interesting and form a fitting conclusion to the description of a new departure in Engineering design in Ceylon:

"Suppose for instance, we are present at the building of a bridge, the bricklayers or masons have had their centering erected for them, and that centering was put together by a carpenter, who had the line of its curve traced for him by the Architect. The masons are dexterously handling and fitting their bricks, or, by the help of machinery, carefully adjusting stones which are numbered for their places. There is probably in their quickness of eye and readiness of hand something admirable, but that is not what I ask the reader to admire, not the carpentering, nor the bricklaying nor anything that he can presently see and understand, but the choice of the curve, and the shaping of the numbered stones, and the apportionment of that number. There were many things to be known and thought upon before these were decided. The man who chose the curve and numbered the stones had to know the times and tides of the river, and the strength of its floods, and the height and flow of them, and the soil of the banks, and the endurance of it, and the weight of the stones he had to build with and the kind of traffic that day by day would be carried over his bridge—all this especially and the great general laws of force and weight, and their working; and in the choice of the curve and numbering of stones are expressed not only his knowledge of these, but such ingenuity and firmness as he had in applying special means to overcome the special difficulties about this bridge. There is no saying how much wit how much depth of thought, how much fancy, presence of mind, courage, and fixed resolution there may have gone to the placing of a single stone of it."