Trends in the construction of concrete bridges

T. N. Subba Rao

The paper traces the history of concrete bridge construction in India, citing several outstanding examples of the various structural forms adopted through the years. It discusses in detail the construction technologies most suited for individual components of a bridge structure and the profound impact that prestressed concrete has made on Indian bridge construction. Specific aspects of prestressed concrete relevant to bridge construction, particularly launching techniques, grouting, sheathing and grouping of cables and the like, are treated in detail. Future trends in bridge construction and how developments abroad will affect concepts in India are indicated.

The oldest bridges still in service in the world are of stone masonry, and practically all of them are of the arch type.

Records and authentic information about the earliest bridges of the world are rare. The earliest reference is of a bridge across the Nile, built around 2650 B.C. But, the oldest surviving bridge is an arch structure over the River Meles at Izmir, Turkey, built around 850 B.C.

In India also, the oldest form of bridge is of the arch type, but in stone masonry. The famous Grand Trunk Road, built by Emperor Sher Shah in the sixteenth century, bears testimony to this fact. With the emergence of the British Empire in the eighteenth century, India gained access to the state-of-the-art of the West. Many major bridges were built during the days of British rule, mostly with steel decks, to carry the railway tracks across the mighty rivers of the Ganges, Jamuna, Godavari, Brahmaputra and others. The longest bridge built up to the end of the nineteenth century is the Upper Sone Railway Bridge (1899), which is 3.1km long and consists of 93 spans, each of approximately 30m. About the same time, another long railway bridge was built over the River Godavari, which is approximately 2.7km long. The superstructure of all the major bridges constructed in those days was of steel. For the substructure, either stone or brick masonry was used since reinforced concrete was practically unknown at that time.

Reinforced concrete bridges

The beginning of the twentieth century saw the introduction of modern concrete bridge design and construction. The use of concrete, both plain as well as reinforced, became more acceptable, obviating for spans up to 40m the total dependence on steel. The road bridges built during this period can be classified into the following categories:

1. simply-supported spans (in reinforced concrete):
   (a) solid slab .
   (b) hollow or voided slab
   (c) slab and beam
2. balanced cantilever with suspended spans (in reinfored concrete)
3. arch and bowstring girder (in plain or reinforced concrete)
4. continuous or framed structure (in reinforced concrete)

Simply-supported bridges: Solid slab simply-supported bridges were very common in the early 1920s for minor bridges and culverts. With this type, the span lengths were normally restricted to 10m. Because of the reduced depth of the deck, this type of bridge could be used advantageously in the case of submersible bridges. Later on, to effect economy and to reduce the dead load, hollow or voided slabs were introduced in many bridges.

A typical example of such a hollow slab simply-supported bridge is the Baru Rewa Bridge in Madhya Pradesh* (1931). This bridge has 7 spans of 10.44m each, supported on masonry piers, which are founded on brick masonry wells. This type of foundation was very common in those days.

* The bridge is illustrated amongst others on pages 7 to 11

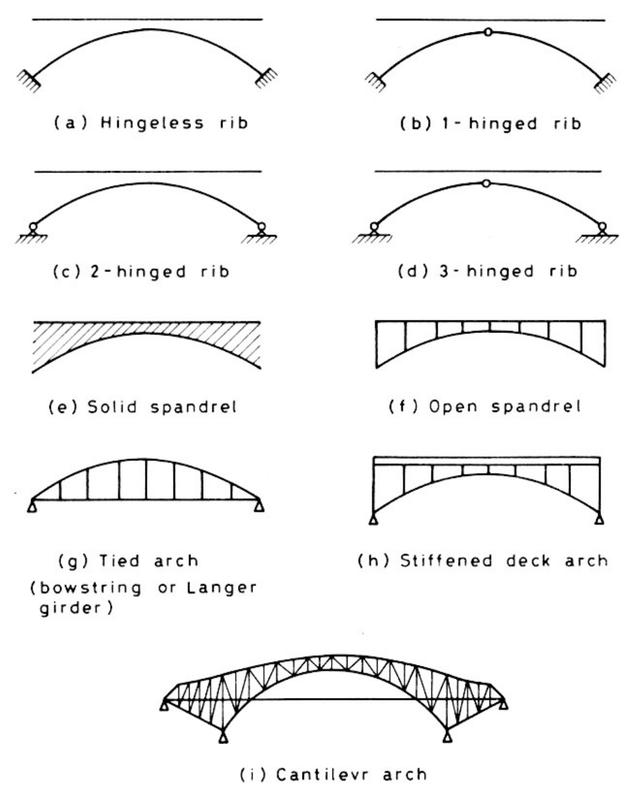


Figure 1. Different types of arch bridges

Another bridge of this type is the Kolhapur Bridge (1931) across the river Purna at Amravati, Maharashtra* with 4 spans of 10.4m each.

Balanced cantilever bridges: The reinforced concrete balanced cantilever bridge with suspended spans has the advantage of increasing the span length beyond 20m, which was earlier not possible with simply-supported or continuous reinforced concrete bridges. However, this type of bridge has a weak point in the articulation at the ends where the suspended span is supported. Defects at the articulations have been reported in most of the balanced cantilever bridges that have been built. Some examples of old balanced cantilever bridges are given below.

The Kitchinia Bridge* (1950), built on the Patna- Nawadah-Rajauli section of the national highway. has 3 spans of 28.5m each and two spans of 20.88m each. The suspended spans at the centre are 10.6m long.

Another bridge of this type is the Rohini Bridge* (1950) which has 2 spans of 29.3m, 1 span of 29m and 2 spans of 21.8m. The superstructure is supported on reinforced concrete wall type piers, which are founded on brick wells.

The Sarju Bridge* (1965) is a reinforced concrete balanced cantilever bridge, built over the Sarju river near Ayodhya. It has 19 spans of 48m each and 2 spans of 35m each, giving a total deck length of 978m.

Mention may also be made here of an interesting structure, the Kayenkulam Bridge* (1935) across the Karipuzha Canal on the Quilon-Alleppey road. It has a central span of 24.7m, which cantilevers 6.63m at both ends. The cantilevers are hollow and filled with sand to reduce the bending moment at the centre of the main span.

Arch and bowstring girder bridges: Most long-span concrete road bridges built in India before the World War and up to 1950 are of the arch type. The arch shape has the advantage of transmitting all the intermediate transverse loads to supports, primarily, by axial compressive forces, for which concrete is considered the most suitable material. For a fixed type of loading, it is possible to shape the arch in such a way as to avoid tension at all sections.

There are several variations of the arch shape such as the hingeless arch, the hinged (one, two or three hinges) arch, the filled spandrel arch, the open spandrel arch, the tied arch or bowstring, the stiffened-deck arch or the cantilevered arch, Figure 1.

The period between 1920 and 1950 witnessed the construction of many elegant and major arch bridges in India. One example is the Dum Dum Bridge* (1926), the first reinforced concrete bridge to be built over the circular canal in Calcutta. The total length of the bridge is 49m, and it consists of two reinforced concrete arches, each with a span of 24m.

Another example is the Bhandara Bridge* (1929). It crosses the Wainganga River at Bhandara, Maharashtra, and it consists of 18 spans of 26.22m each. Each span is a reinforced concrete barrel arch with masonry spandrels. The piers are of stone masonry, founded on reinforced concrete piles.

The Patalganga Bridge* (1935), located at Panvel near Bombay, has an overall length of 178m, and is spanned by 3 reinforced concrete bowstring girders, each of 30m. The bowstrings are realised through inclined 63.5-mm mild steel round hangers which participate as active intermediate members of the structural system, unlike the vertical suspenders of the conventional bowstring bridge.

A particularly elegant structure is the Coronation Bridge* (1941). This 168.90-m long arch bridge, crosses the Teesta River in northern Bengal at the border with Sikkim. The main arch has a clear span of 81.71m and a rise of 39.63m. The arch was cast by means of suspended shuttering from a temporary pylon erected adjacent to the springing.

Another example of the bowstring girder is the Alwaye Bridge* (1941), which crosses the Periyar River in Kerala. This bridge has three bowstring girders with spans of 45.12m each.

The Mand Bridge* (1946) is an interesting combination of the bowstring girder and arch. It has one reinforced concrete arch span of 50m of the bowstring type and five plain concrete arches with spans ranging from 17.7m to 19.5m.

* The bridge is illustrated amongst others on pages 7 to 11

Like the Patalganga Bridge, the Bonum River Bridge* (1949) is a bowstring girder structure with inclined hangers. It crosses the Bonum River on the Jharsuguda—Sambalpur Road in Orissa. The bridge has 6 bowstring girders, each with a span of 36.6m.

Continuous or framed structure bridges: Continuous or framed structure bridges in reinforced concrete came to be built after 1930. This type of bridge resulted in slender deck and pier sections, and it proved a very useful solution for submersible bridges where obstruction to the flow of water is one of the critical factors. Some bridges of this type built during this period are described below:

1. The Boya Bridge* (1935) is a 260.16-m long structure over the river Tochi in Waziristan (now in Pakistan). It has 25 spans, each of 10.16m. The deck is continuous over one group of 3 spans, another three groups of 4 spans each and a further two groups of 5 spans each.
2. The Loressa Nallah Bridge* (1936) has a reinforced concrete continuous beam-and-slab type of deck. It is one of the most sleek and elegant of structures of that time. It has 3 spans of 10.06m each and 2 cantilever spans of 2.44m at either end.
3. The Indravati Bridge in Orissa* (1942) is 160m long. It consists of 13 spans of either 13.10m or 10.37m each. The piers and deck slab are rigidly connected and designed as continuous frames in two groups of 4 spans each and one group of 5 spans. There is a cantilever at each end.
4. The Krishna Bridge* (1956) is a reinforced concrete multiportal type of structure across the river Krishna in Andhra Pradesh. It has 49 spans of 17m each and 2 spans of 14m each. Each portal unit consists of 4 continuous spans with a cantilever at either end.

Advent of prestressed concrete

The period following the Second World War saw significant developments in bridge engineering with prestressed concrete replacing conventional plain and reinforced concrete as a basic material. By then, prestressed concrete had already been used in various structures in Europe and other countries and was accepted widely by practising engineers.

Despite opposition and resistance from some senior engineers in India, Mr. J. C. Gammon successfully completed the first prestressed concrete structure in India—the Aero Hangar at Karachi in 1942. It has 7.5-m deep prestressed concrete beams. spanning a clear distance of 59.5m and supporting 39.7-m span barrel roof shells with a chord width of 10.7m. Encouraged with this application, the Indian Railways proceeded to construct three prestressed concrete railway bridges on the Assam Rail Link project in 1948. These bridges, having spans varying from 12.8m to 19.2m, were completed in a record time of four months and became the first of their type in India.

The first road bridge to be built in prestressed concrete in India is the Palar bridge located on the Madras-Dindigul Road on NH 45. Built in 1955, this bridge has 23 spans of 27.45m each with a carriageway of 6.71m. The deck of this bridge consists of four U-shaped precast prestressed concrete girders with a 150-mm thick in-situ reinforced concrete slab on top, Figure 2. The prestressing was done by the Magnel-Blaton system, using 8 cables, each made up of 32 wires of 5-mm diameter.

The first prestressed concrete semi-continuous submersible bridge to he built in India was over the Krishna River at Dcodurg in Karnataka*. This submersible bridge which is 540m long, has 18 spans of 30m each with expansion joints at approximately 180-m spacing. The superstructure consists of a three-cell trapezoidal box section, Figure 3, supported on teflon hearings over solid elliptical piers, which cause the least possible resistance to water flow in the submerged condition. The precast box units were match-cast vertically for ease of concreting, then rotated, transported, laid in position and joined by epoxy mortar while being supported over staging and on temporary bearings at the ends. The deck is simply-supported for self-weight but is made continuous for temperature effects and horizontal forces due to live loads by casting the gap between spans in-situ and lowering the deck over the main bearings. The prestressing was carried out from the front end only.

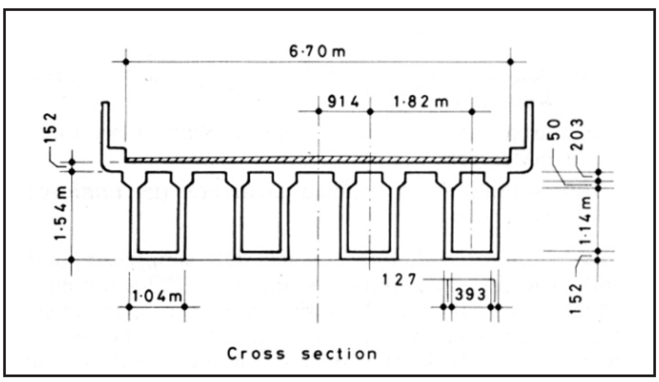


Figure 2. Cross section of Palar Bridge Superstructure

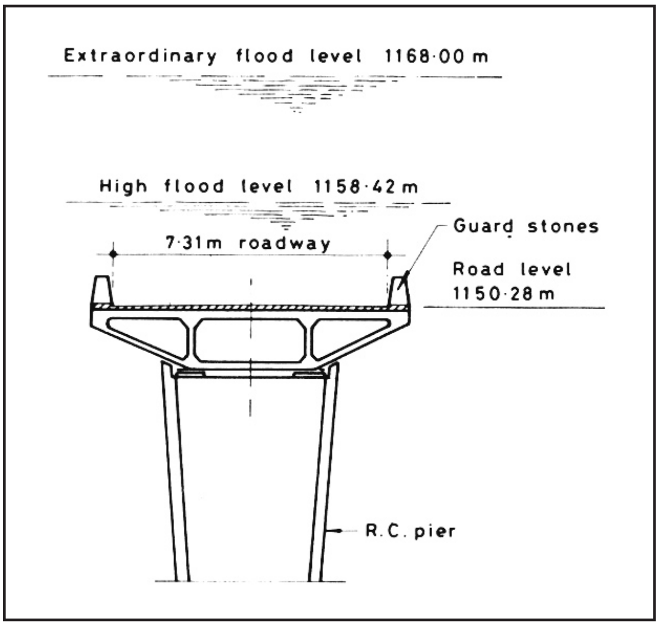


Figure 3. Cross section of semi-continuous submersible prestressed concrete bridge across Krishna River

* The bridge is illustrated amongst others on pages 7 to 11

The use of prestressed concrete made it possible for design engineers to adopt large spans and to minimise the number of foundations. The early prestressed concrete bridges were mostly simply-supported—as, for example, the Luni Bridge, Rajasthan*, built in 1968—with spans ranging from 25m to 47m. However, with the provision of suitable hammerheads (the Yamuna Bridge at Paontashib, Himachal Pradesh*, built in 1977) or V-shaped piers with hammerheads (the Gambhirkhad Bridge in Himachal Pradesh*, built in 1964) or twin piers with a hammerhead (the Salapur Bridge in Himachal Pradesh*, built in 1964) or a balanced cantilever with suspended spans (the Bhagirathi Bridge, West Bengal,* built in 1961) it became possible to increase the span lengths to about 80m.

Cantilevered construction

Although span lengths of about 80m can be obtained by the above systems. It became necessary in some cases to adopt even longer spans from 'considerations of navigational clearance, foundation difficulties, economy. etc. This led to the introduction of the cantilevered construction method.

In cantilevered construction the deck is invariably given a hollow box section in order to attain a high degree of torsional stiffness and improved transverse load distribution. The deck is monolithic with the pier, and construction advances on both sides either by casting the box section in-situ in segments, 3m to 4m long, with the aid of a travelling gantry and stitching the units by longitudinal prestressing or by precasting the box elements in a casting yard, then transporting, hoisting and placing them in position and finally stitching the elements together with an epoxy interface glue.

The first prestressed concrete bridge constructed in India by the cantilevered construction method was the Barak Bridge at Silchar in Assam*. Built in 1961, this bridge has a clear span of I22m. Initially, a suspension bridge of the same span was envisaged by the clients. However, construction work did not proceed after some work on the foundations had been done, and fresh tenders were called in 1958, stipulating the utilisation of the partially completed foundations of the pylons for the suspension bridge. The solution evolved was the adoption of a cantilever structure with the existing foundations sunk deeper and additional foundations provided on either bank with a view to absorbing the longitudinal forces. The cantilevers meet at the centre of the span through a pendulum hinge. The approach arm on either side rests on roller bearings and projects beyond in order to accommodate the simply-supported spans through articulation. The hearings are provided with shims, which were subsequently removed following progressive creep of the approach arm.

The precast segmental-type box construction with elements match-cast in the casting yard was first used on the Ganga Bridge at Ruxar, Bihar*, in 1971. The precasting bed made for this bridge was of the fixed type and extended 90m up to one T-arm length. The bed consisted of brick walls on either side, profiled to the shape of the soffit of the box girder. The soffit of the bottom slab of the box was supported by independent tubular staging.

The pier head for this bridge is a triangular unit. It was cast first and then subsequent units were match-cast on the bed. The pier head unit was lowered, side-shifted, lifted and transferred to the yard. Thereafter, the remaining units were easily lifted off the bed. The casting progressed until all the 36 units for one cantilever had been cast, but by the time the fourth element was made preparations were already afoot for casting the second pier head.

The precast units were lifted by a gantry and stacked in a numbered sequence. The elements were subsequently placed on a power-driven trolley running on rails over the completed deck length. After erection, the units were checked for alignment, the cables were threaded and prestress applied. A specially developed epoxy formulation provided the interface with the match-cast units.

Until prestress was applied the precast element was held in position with the help of a system of hydraulic jacks, placed over both the deck slab and the soffit slab. The pressure of the jacks was so regulated as to provide uniform compression on the epoxy joint.

Of the many outstanding cantilever bridges constructed in India with a single-box cross-section, three—the Lubha Bridge, the Bassein Creek Bridge, and the Ganga Bridge at Patna—are described below in some detail.

The Lubha Bridge (1961) is the longest single span prestressed concrete bridge in India. It has a central span of 130m with adjoining spans of 21m which are progressed into the rock strata on either bank and counterweighted against the rock mass through cast steel roller bearings, Figure 6.

The Bassein Creek Bridge* (1967) is 555m long. It has 2 spans of 48.5m each, 4 spans of 57.3m each and 2 spans of 114.6m each. The four central spans were cast in situ and mated at their centres to form a continuous deck of 361.6m. The deck rests on cast steel rocker and roller bearings. During construction, the deck was stabilised by the construction of temporary piers on either side with sand jacks on top. After the cantilevers had been completed and mated at the centre of the spans to form a continuous unit, the sand jacks were lowered.

The Ganga Bridge at Patna* (1982) is the longest river bridge in Asia. It is 5,575m long. It consists of 45 spans of 121.065m each and end spans of 63.53m each. The bridge supports a carriageway for four lanes of traffic (15m) with 2-m wide footpaths on either side. A power cable runs under the deck. The foundations consist of single circular wells of a large diameter. The wells are designed to take four lanes of traffic. The well steining is of reinforced concrete, whereas the bottom as well as the intermediate plugs are of "Colcrete" with a sand fill in between. The pier is &signed as a cellular reinforced concrete structure with horizontal and vertical diaphragms. The piers transmit the loads directly to the well steining. To

* The bridge is illustrated amongst others on pages 7 to 11

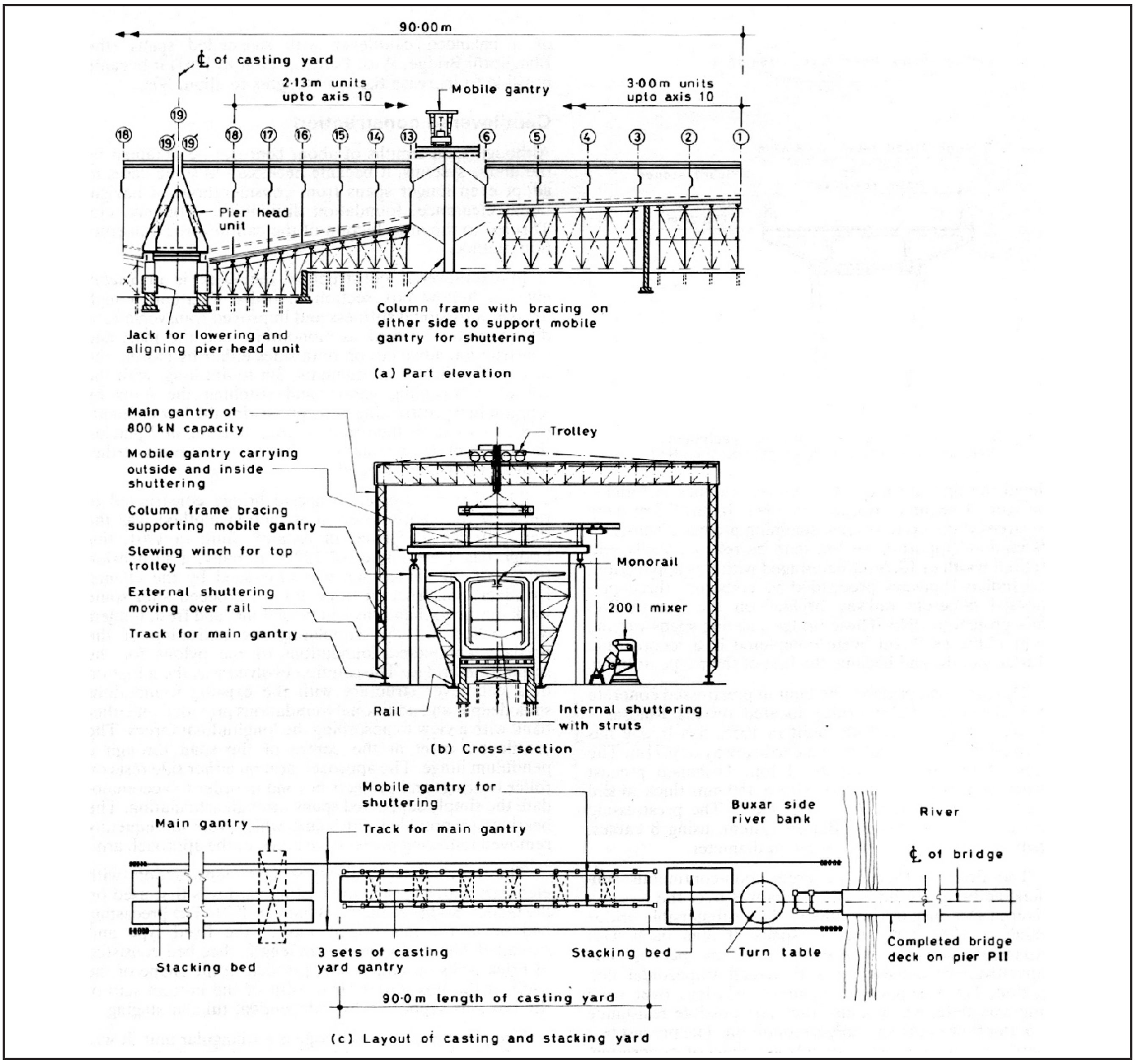


Figure 4. Layout of yard for casting and stacking precast units of Barak Bridge at Silchar

facilitate such a transfer, the top portion of the well steining is provided with a haunch of suitable geometry.

The superstructure of the Ganga Bridge consists of two single-cell boxes, supported independently on hollow piers, Figure 7. A major portion of the bridge deck was cast by the precast cantilevered method of construction and the remainder by in-situ cantilevered construction. Matchcast precast elements were erected by a travelling bed gantry for the dry spans and by a floating crane for the river spans. The Freyssinet system of prestressing was adopted for stressing the cables made up of 24 wires of 8-mm diameter each, for which the system of prestressing was improvised by threading two cables, each having 12 wires, into a single duct and prestressing them separately. The mating cantilevered arms were connected by forged steel pendulum bearings to provide smooth riding.

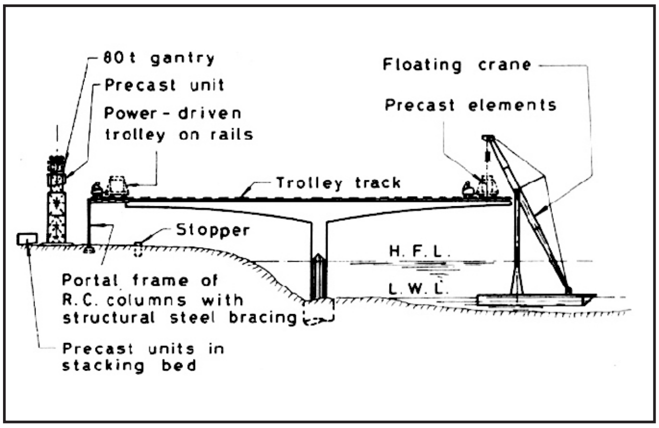


Figure 5. Precast element of Silchar Bridge in transit for launching over pier

* The bridge is illustrated amongst others on pages 7 to 11

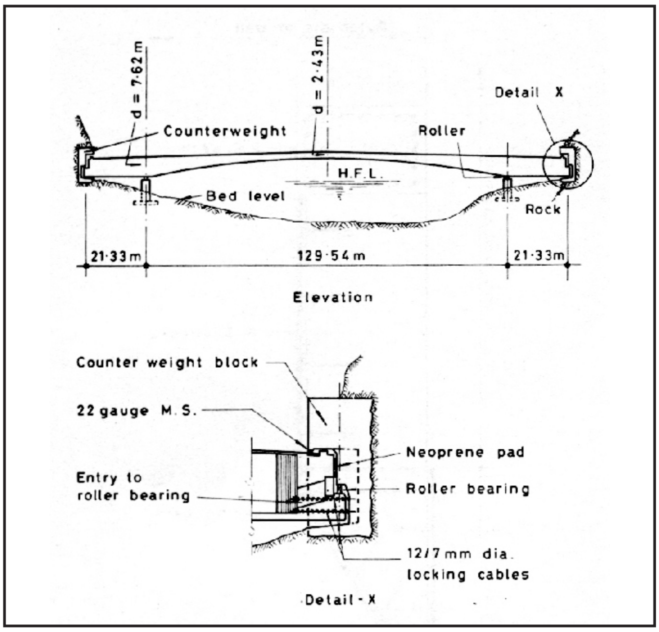


Figure 6. Profile of the Lubha Bridge

Methods of construction

Foundations: The construction of open foundations in shallow water is carried out by using sand bags or other types of cofferdams. Where the water level is high, shored timber-lined cofferdams are constructed. Sometimes, these are double-walled with a compacted clay fill in between. Where the depth of water is substantial, sheet piles have been adopted. These construction techniques are well known and do not signify any important breakthrough.

Piles are driven from a prepared island if the location is under water. If the depth of water is substantial, i.e. 6m to 9m, steel-framed decks, supported on pontoons and spudded into the river bed, are used. The pontoons are filled with water to increase stability before piling. The frame is transferred after dewatering the pontoon following completion of the piling at each location.

Sinking of caissons in India has an interesting background. Apart from using triangular shear legs with winches and grabs. there have been cases where bullocks have been used to lift the grab. The ground is sloped away from the caissons with a view to giving the bullocks facility to pull the weight more comfortably. Many jobs in the early 1940s and 1950s have adopted this solution. The shear leg solution is still used in isolated foundations and by small contractors, who can ill afford the cost of crane equipment. Their performance is obviously slow and not conducive to rapid completion of the job. Hence, mobile cranes and stationary derricks are now being used increasingly on most jobs. The adoption of a single circular dredge hole, the advent of longer spans with a reduced number of foundations, and the need for rapid completion of bridges have all dictated the need for mechanical sinking. In alluvial strata, this has been found to give excellent results. The caissons have a tendency to go out of plumb during the sinking operations, and to correct this eccentric kentledge, aided by eccentric sinking and other similar strategies, have been adopted. Sometimes, such kentledge is of the order of 800t. The need to ensure that the outer surface of the caisson is smooth and truly vertical, despite progressive shuttering of the surface, is vital for ease of sinking.

Sinking of caissons through hard strata, including rock, in locations where foundation depths are less than 30m demands working under compressed air conditions in the dry through the installation of pneumatic locks. Two systems, one with steam compressors and the other with diesel compressors, are in use. The latter system has been found to provide cooler conditions inside the lock, thus contributing to a higher turnover by the workmen inside the dredge hole. The air lock design adopted is also of two types. One type operates on the open-and-close door principle to discharge muck outside the lock without losing internal pressure, whereas the other has a monorail within the lock to lift the muck bucket and discharge it through an internal exit without any assistance from outside.

Caissons foundations are designed either for adequate grip in the sand below scour level or have to be sunk about half a metre into rock, aided by Torsteel bar anchorage, Figure 8. In some cases, pneumatic sinking is avoided by resorting to controlled blasting, aided by chiselling of the hard strata. In such cases, mild steel strakes are provided at the bottom of the well foundation covering the entire well curb and part of the well steining, Figure 9. It is advisable to provide a heavily reinforced ring beam just above the strake portion so as to arrest any crack in the concrete steining due to a change in the shielding characteristics.

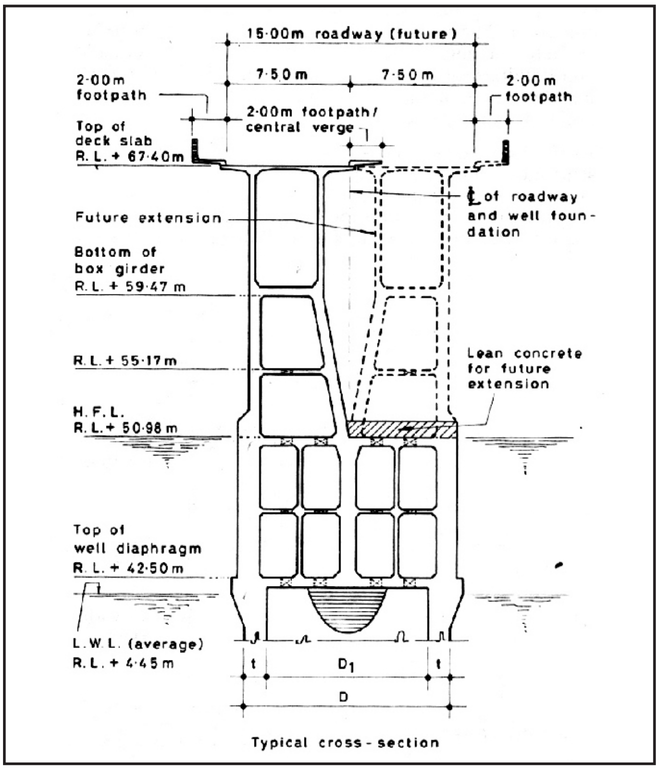


Figure 7. Typical cross section of pier for the Ganga Bridge at Patna

Piers: The piers for bridges are constructed using the usual form of shuttering. Where piers are not more than 6m high, they have sometimes been constructed in one operation. The piers have not been slipformed till today in India. mainly on account of the lack of suitable opportunities for utilising this technique. The technology for slipform construction is, nevertheless, available in India for both tapered and parallel profiles.

Deck: Even today, the superstructure is generally constructed on temporary timber centering. Square sections arc extended and joined by bolting to make up the requisite height and also to obtain the longitudinal and transverse stability. However, after 1960, for all major constructions steel pipes and clamps were used as centering. The most notable example was for the Kandroor Bridge, where the centering was fanned out from the foundation block up to a height of 46m. Box-type trestles, placed at approximately 6-m centres, are also adopted with girders spanning between them to support the form work for the deck on many jobs. Where the centering rests on sand, the base distribution plate is supported on timber planks running longitudinally and transversely. If the soil is poor, these plates are placed over timber piles and driven to a sufficient depth in order to carry safely the designed load.

The use of a launching truss, Figure 10, for launching prestressed concrete beams is very common. Trusses are made of either steel or aluminium, in the latter case the inward counterbalancing extension being of steel sections. Trusses are counter weighted with water during self launching of the truss. They arc capable of launching girders with spans up to 48m and weighing up to 180t. The girders are lowered either by hydraulic jacks or by sand jacks, the latter solution being favoured by workmen since it is quicker (15 minutes for 6-m height) and relatively safer to operate. The section of the truss is either rectangular or triangular. The advantage of the aluminium truss is that the deck need not be designed for the temporary transfer loading conditions of the truss itself, which for a span of 48m generally outweighs the transferred beam load.

Some spans have also been cast by a supporting truss placed below deck level, which is moved from span to span following casting and stressing. Wherever possible, beams have been cast in the yard, transported on trolleys to the span in question and thereafter lifted and placed in position by means of specially designed gantries, a typical example of which is shown in the photograph of the Vasista Bridge*. Alternatively, the beams are cast one at a time at the top level of the pier and side-shifted beam after beam into position; this activity proceeds on a number of spans simultaneously This procedure is made possible by the specific behaviour of most Indian rivers having a small flow under dry weather conditions.

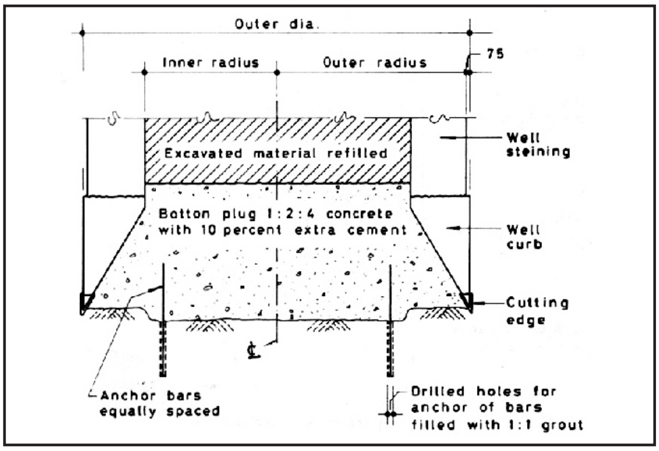


Figure 8. Cross section of typical caisson toundation

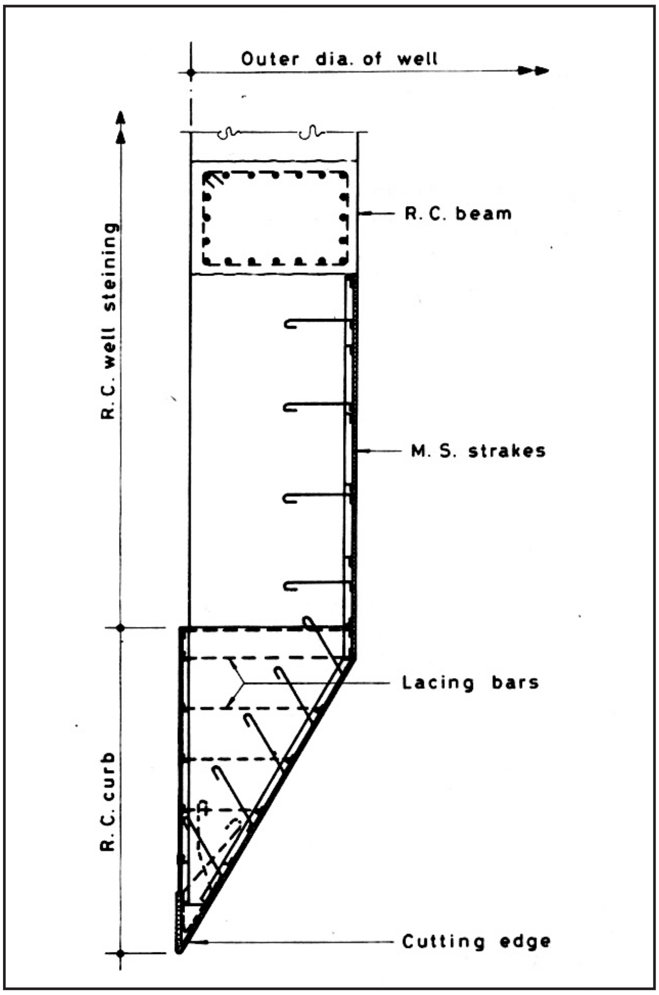
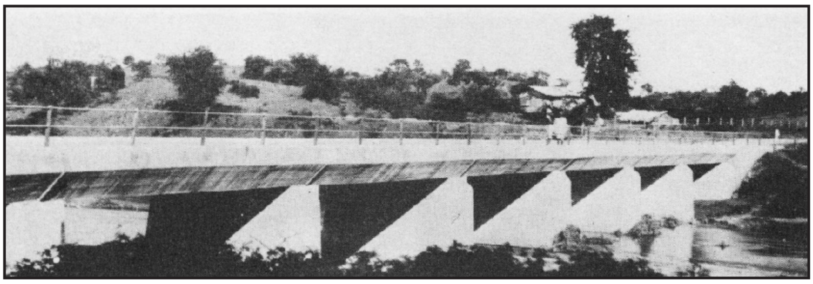


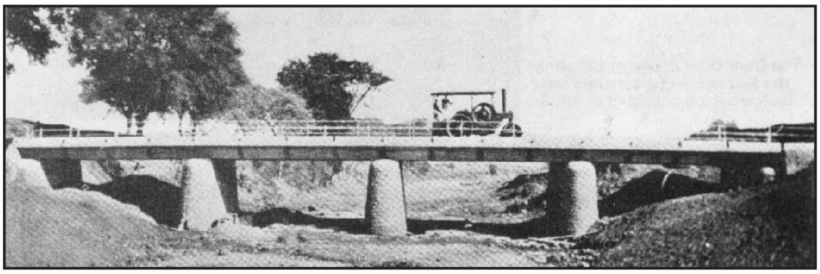
Figure 9. Provision of strakes in well foundation when caisson is sunk by controlled blasting

For the cantilevered system a cantilevered steel gantry, weighing approximately 40t, is used and both the inside shuttering for the box and the external shuttering move forward after each section (3m to 4.5m) has been stressed. The use of bed gantries and floating cranes for large bridges, like those across the Ganga at Patna and at Buxar, has already been mentioned.

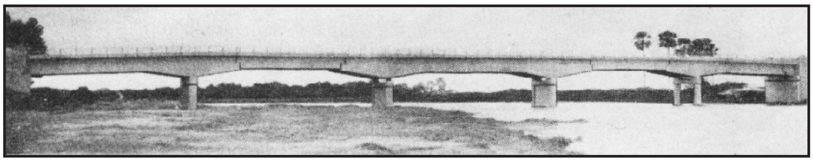
Push-launching has yet to be introduced in India. However, a variation of the push-launching system, using a central axial casting yard, was adopted to cast 10-m long segments of the cellular deck of a submersible bridge; the segments were then pushed across 3 spans on a longitudinal staging with rail skids.



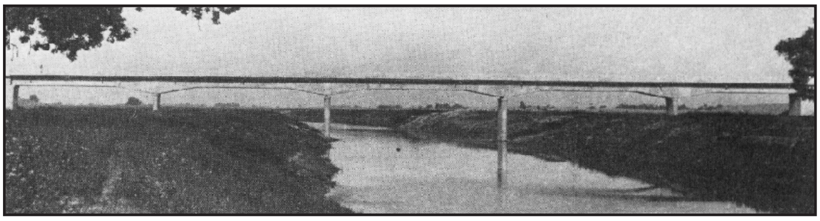
1 -
The Baru Rewa Bridge in Madhya Pradesh. A simply supported bridge with hollows in the slab, it has 7 spans of 10.44m each.



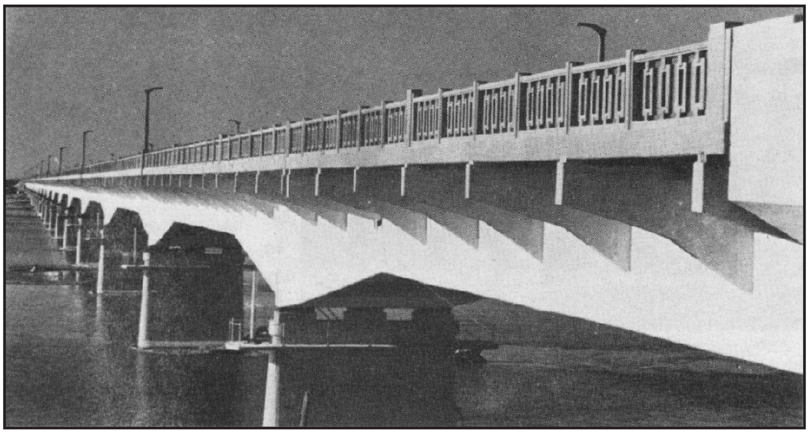
2 -
The Kolhapur Bridge over the river Purna at Amravati, another example of a bridge with hollows in the slab.



3 -
The Kitchinia Bridge on the Patna- Nawadah-Rajauli section of the national highway, an early example of a balanced cantilever bridge with suspended spans.

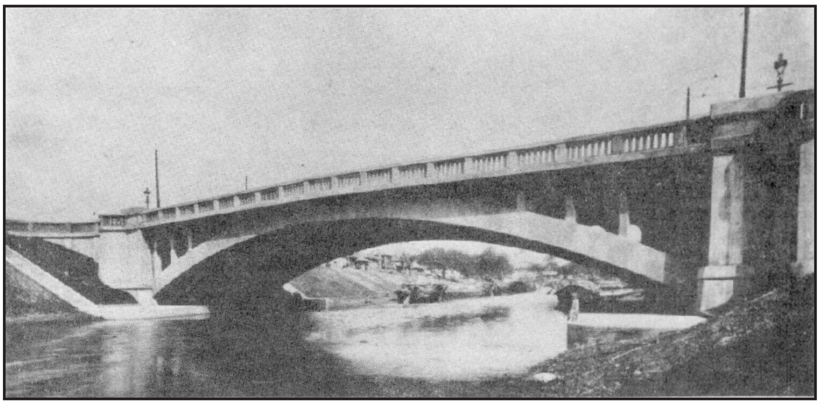


4 -
The Rohini Bridge, another balanced cantilever structure, with wall type piers.

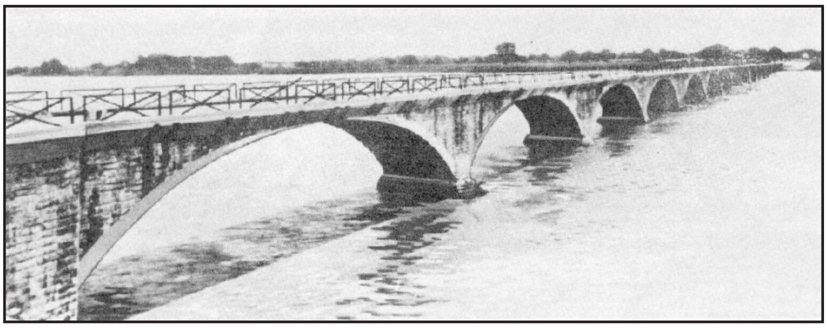


5 -
The Sarju Bridge near Ayodhya, is a balanced cantilever bridge with 19 spans of 48m each and end spans of 35m each.

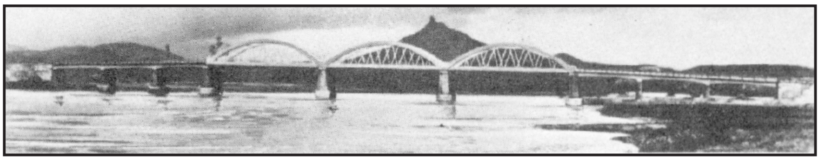
6 -
The Kayenkulum Bridge has hollows in the cantilevered sections which are filled with sand.



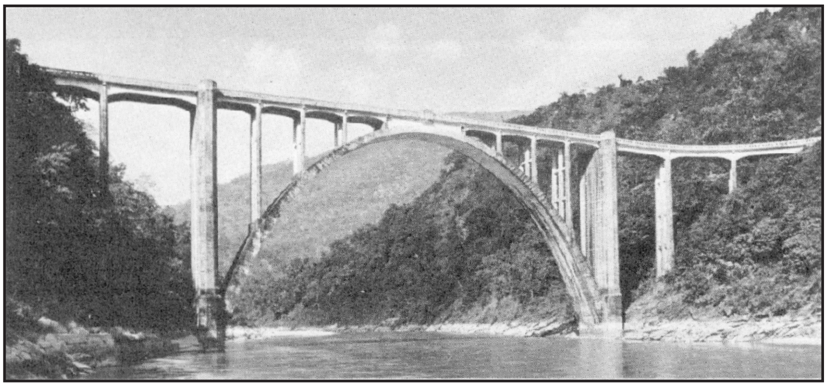
7 -
The Dum Dum Bridge at Calcutta, the first reinforced concrete arch bridge, which was built in 1926.



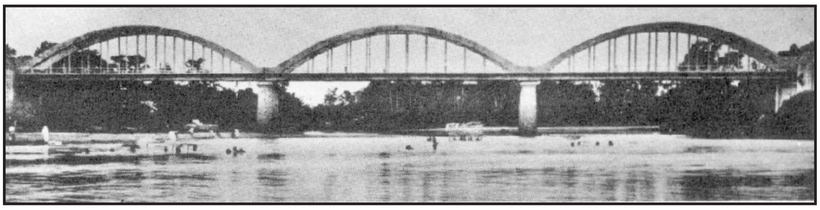
8 -
The bridge across Wainganga at Bhandara has reinforced concrete barrel arches with masonry spandrels.



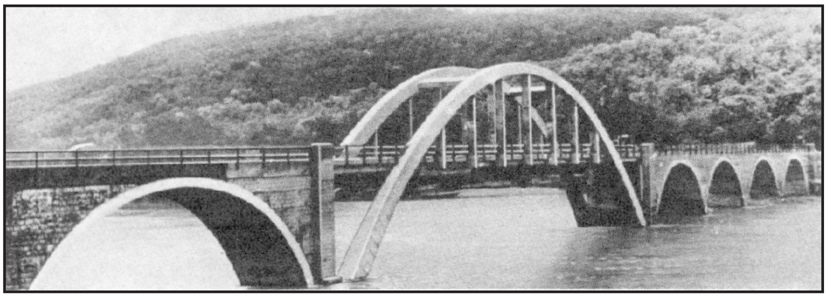
9 -
The Patalganga Bridge at Panvel, built in 1935, is an interesting example of a bowstring girder with inclined hangers.



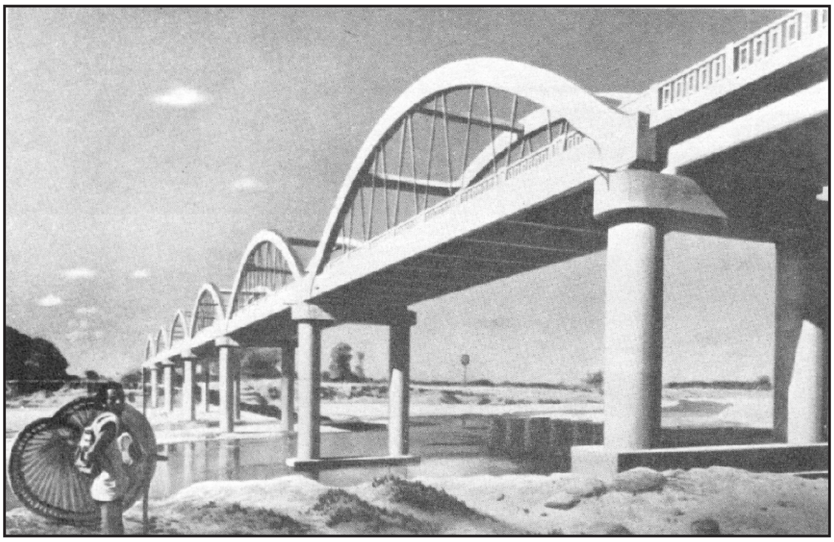
10 -
The Coronation Bridge across the Teesta, an elegant structure with the main arch spanning 81.71m.



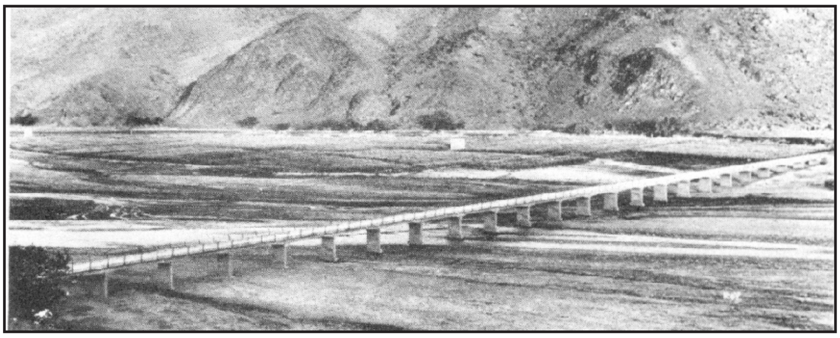
11 -
The Alwaye Bridge across the Periyar. Each bowstring girder spans 45.12m



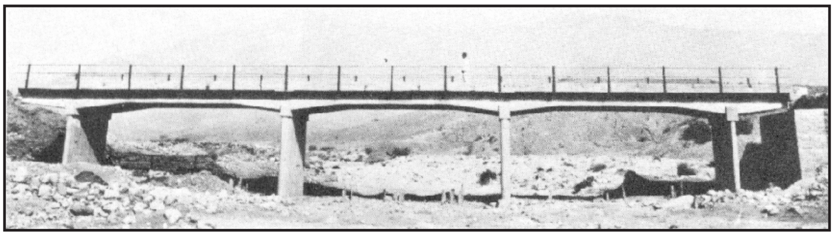
12 -
The Mand Bridge combines a bowstring girder or 50m span with side spans of plain concrete arches



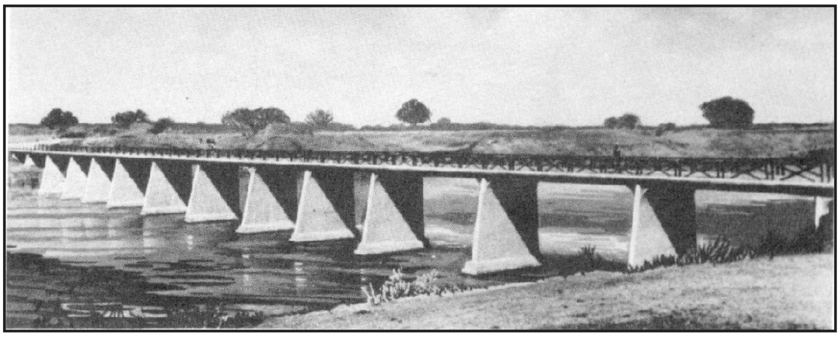
13 -
The Bonum River Bridge on the Jharsuguda-Sambalpur road has six bowstring girders with inclined hangers.



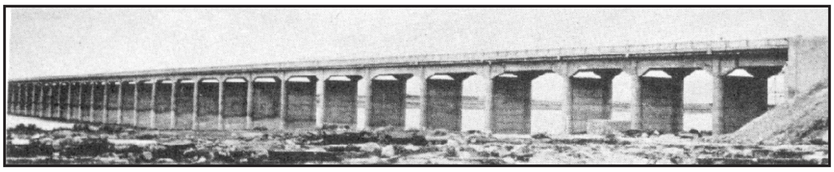
14 -
The Boya Bridge, a submersible structure with continuous spans.



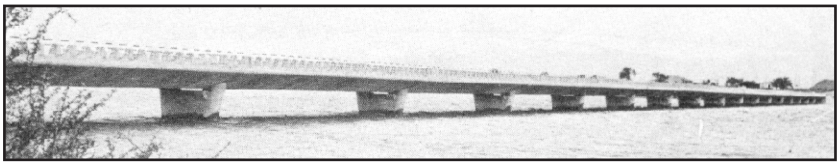
15 -
The Loressa Nallah Bridge, an elegant example of the continuous beam and slab type of superstructure.



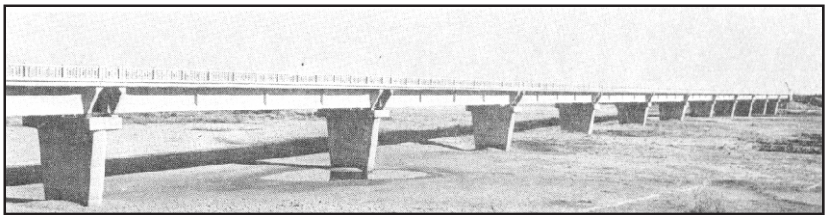
16 -
The Indravati Bridge in Orissa, an early example of a rigid frame bridge.



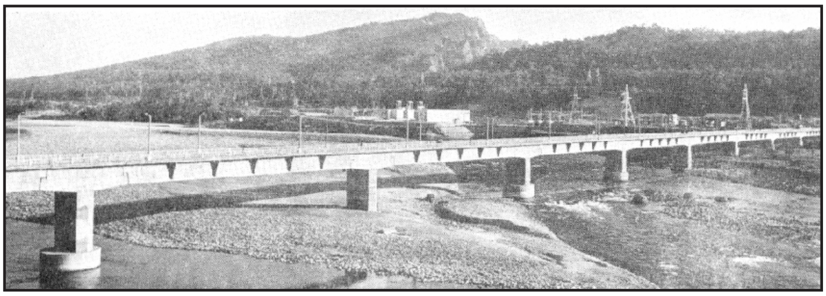
17 -
The Krishna Bridge in Andhra Pradesh is a multiportal type of structure.



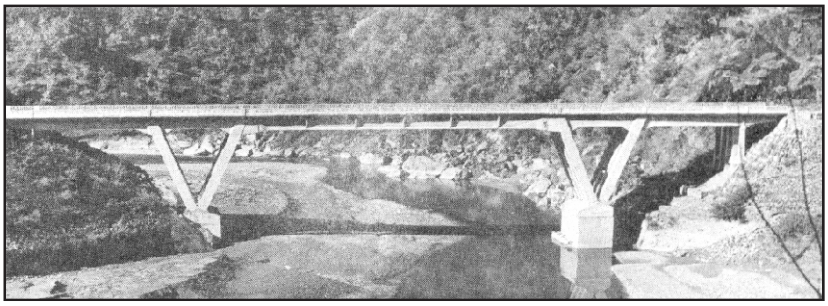
18 -
The Krishna Bridge at Deodurg, Karnataka, the first prestressed concrete semi-continuous prestressed concrete bridge built in India.



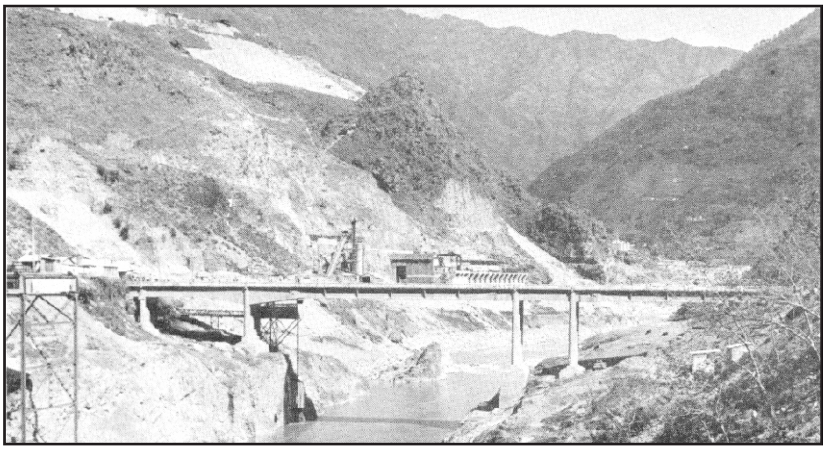
19 -
The Luni Bridge in Rajasthan, an example of simply supported spans in prestressed concrete built in 1968.



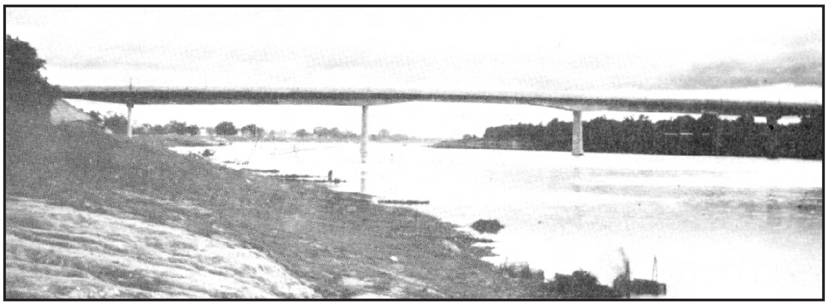
20 -
The Yamuna Bridge at Paontashib, an example of a prestressed concrete bridge with hammerheads on the piers.



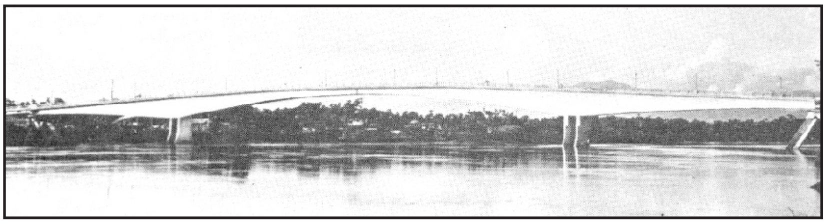
21 -
The Gambhirkhad Bridge in Himachal Pradesh, a prestressed concrete structure having V-shaped piers with hammerheads.



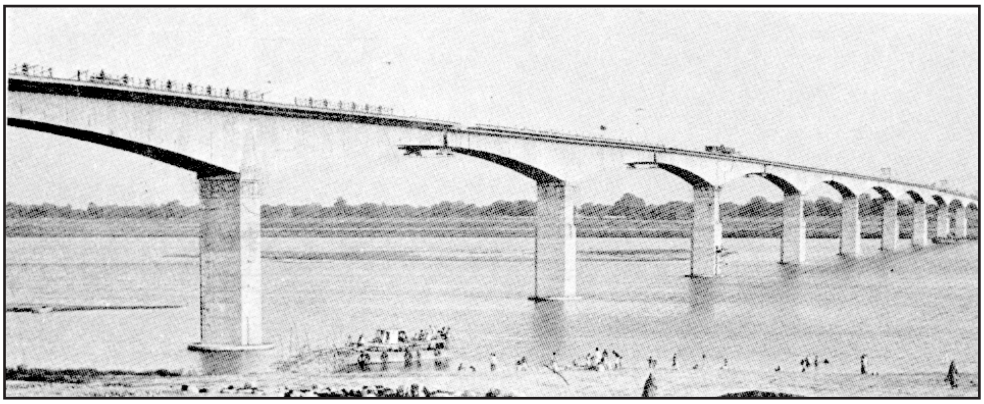
22 -
The Salapar Bridge in Himachal Pradesh, a prestressed concrete structure having twin piers with hammerheads.



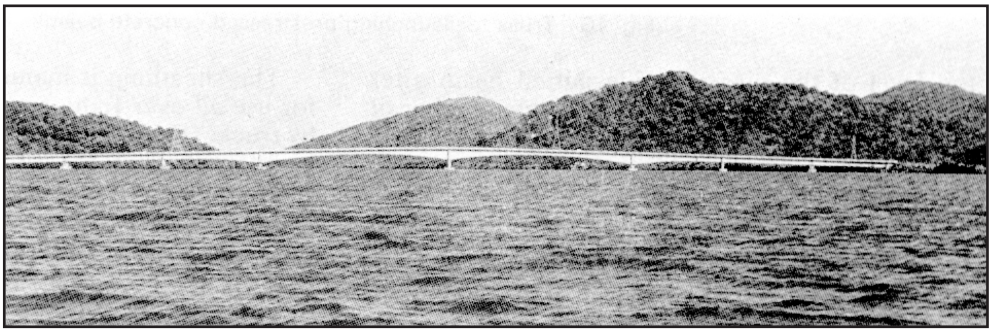
23 -
The Bhagirathi Bridge in West Bengal is a prestressed concrete structure, designed as a balanced cantilever with suspended spans.



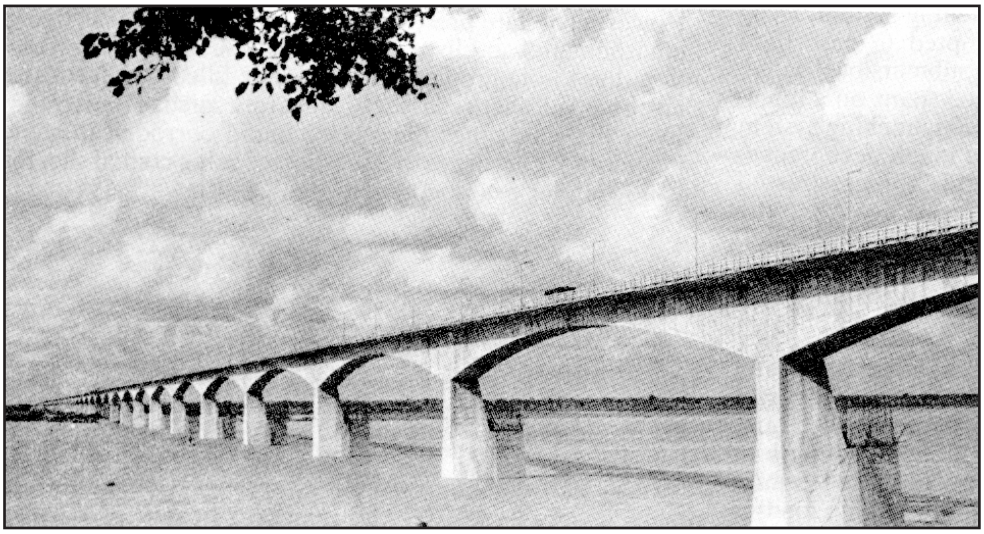
24 -
The Barak Bridge at Silchar, the first prestressed concrete bridge in India to be built by the cantilever method, has a clear span of 122m.



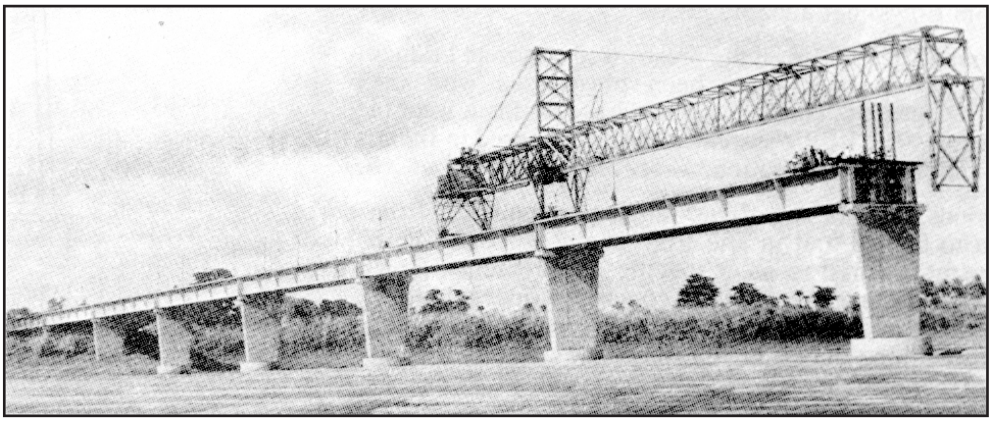
25 -
The Ganga Bridge at Buxar, built by the cantilever method using precast segmental units.



26 -
The Bassein Creek Bridge near Bombay, a 555m long structure, in which the four central spans (two of 114.6 each and two of 57.3m each) were cast in-situ by the cantilever method and then mated at their centres to form a continuous deck.



27 -
The Ganga Bridge at Patna, the longest river bridge in Asia, is 5,575m long. A prestressed concrete structure comprising of 45 spans of 121.065m each and end spans of 63.53m each, it was built by the cantilevered method, partly in-situ and partly with precast segmental units.



28 -
The Vasista Bridge, showing a typical gantry for launching precast prestressed concrete girders.

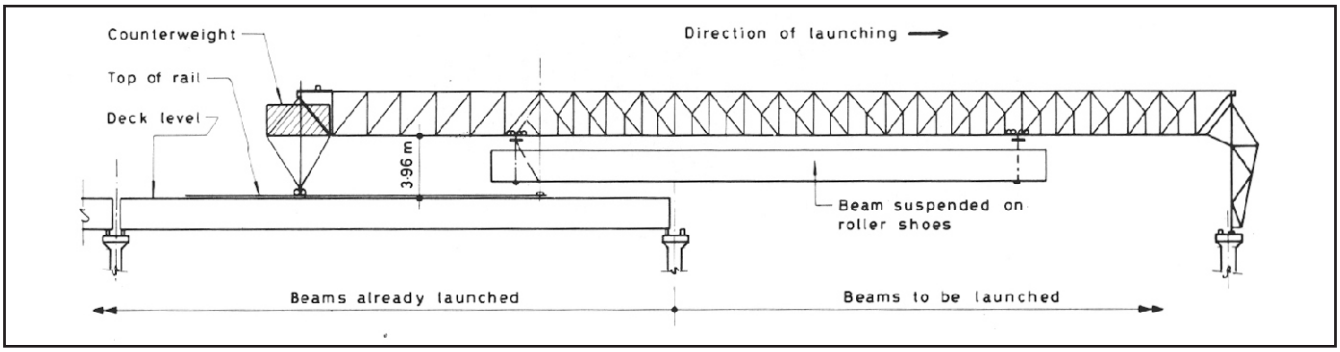


Figure 10. Truss for launching prestressed concrete beams

The push-launching system with a nose truss has so far not found much acceptance, mainly because the current Indian code for prestressed concrete does not permit partial prestressing. Also, the dead load to live load ratios for Indian bridges are such that continuous structures are not economical for medium spans up to 45m, for which range the push-launching system is best suited.

Prestressing : All the systems of prestressing currently used in India are manufactured in toto indigenously with foreign collaboration. High tensile steel wires of 5-mm, 7-mm and 8-mm diameter, having an ultimate strength in the range of 180kg/mm^2 to 150kg/mm^2 , and also 9.5-mm, 12.7-mm and 15.2-mm strands, having a breaking load of 10.4t, 18.7t and 26.7t, respectively, are also being manufactured in India.

Where cables made up of 24 wires of either 7-mm or 8-mm diameter are used, the cable is split in the proximity of the anchorages and anchored to two 12/7-mm or 12/8-mm Freyssinet anchorages.

About 80 percent of all the prestressed concrete bridges constructed in India have been prestressed with the Freyssinet system. The CCL system has also been used in a few cases. The BBRV system, although licensed in India, has hardly found application.

Various types of sheathing, ranging in thickness from 0.2mm to 0.3mm and in size from 25mm to 70mm have been manufactured to meet specific requirements. However, the first three prestressed concrete bridges, built in 1948 by the Indian Railways, were constructed without the use of sheathing ducts. At that time, the cables (12 wires each of 5-mm diameter) were coated with bitumen and wrapped in sisalcraft paper. The sheathing is manufactured at a centralised depot for use all over India and transported to the site of work by truck. However, on major projects, a sheathing factory is established at the site itself. The cables for all the simply-supported bridges are threaded prior to casting the beam. However, in the case of cantilevered construction, the cable is threaded progressively. To help retain the duct profile and trajectory, a rigid steel tube is inserted in the sheathing during the casting of each segment and subsequently removed.

The grouting of cables is carried out after prestressing. The grouting has not always been carried out very satisfactorily in the past, but this has not led to major problems because of the high ambient temperatures in India. However, of late prestressed concrete beams in corrosive environments and in coastal areas have shown deterioration due to the grout not having fully filled the ducts and ensured sufficient passivity of wires against corrosion. Even the sheathings have been found corroded in some beams and, therefore, the question of using coated sheaths is now under examination.

The grout used for prestressed concrete is usually of neat cement with a water-cement ratio varying from 0.40 to 0.50. Neither is the grout chilled nor is iced water used for the mix although ambient temperatures are quite often as high as 40°C.

The procedure normally adopted for grouting is to clean the duct with compressed air, flush it out with water and then grout the cable from one end with a view to displacing the water and keeping the nose of the grout wet. The flushing with water also helps to bring down the temperature inside the ducts and to avoid bleeding of the grout. Vent pipes are provided in the case of drooping cables, as required for cantilevered construction, at approximately 10-m intervals to ensure removal of entrapped air during grouting.

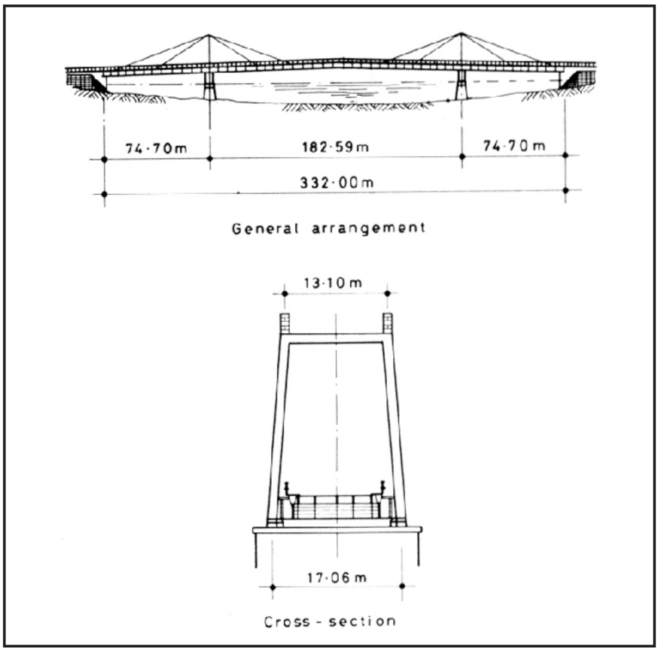


Figure 11. Details of the Stromsund Bridge, Sweden

The grouting procedure is now receiving serious attention from the agencies accepting tenders and executing the project because the defects due to corrosion are becoming increasingly apparent. These problems have also helped bring about a greater awareness of various techniques for non-destructive testing that can be carried out with the equipment available in Indian research laboratories so that the condition of the prestressing steel can be verified in-situ.

The grouping of cables up to a maximum of four is generally permitted but, as a result of observations carried out on beams showing distress, this procedure is now being discontinued and individual cables of higher strength are being preferred.

The looping of cables to deck level from the centre of the span of a simply-supported beam is permitted, and approximately 30 to 40 percent of the total number of cables are likewise anchored and the consequential benefits on the shear capacity of the section exploited. The equipment used for grouting comprises of hand-operated pumps for short spans up to 25m and electrically-operated pumps for longer spans, the latter having become a codal requirement of late.

Aesthetics

There is no specification in India making aesthetic approval mandatory before the choice of type of bridge for a location is decided upon. Also, specific solutions are involved for each location, considering our wide rivers. Nevertheless, certain rules are observed with a view to maintaining profiles and giving the bridge a reasonably good appearance. The concept that form should follow function is given emphasis. What the user looks for is invariably not what appears below the deck but at the deck level itself.

From this angle, the construction of the wearing coat, expansion joints, road kerb, footpath. railing and the transition from the approach road to the bridge all became important. It is by no means unheard of in India for cattle to cross a bridge and jump over the railing, thus highlighting the importance of railing height. Again, there is the instance of a lorry and a bus colliding recently on a major 4-lane bridge near Bombay with the result that they both jumped the kerb, crossed the footpath, crashed through the railing and plunged into the river, causing the loss of many lives. This.particular instance resulted in a public outcry against the specifications used by engineers for constructing the deck. Until the level of thinking of the masses is raised through audio-visual media and other means, an immediate solution as to what is beautiful and what is safe and how both should be integrated to give a meaningful, and yet beautiful, structure is an open question. It should not be presumed that Indian structural engineers are not conscious of the need for graceful lines and form. The difficulty lies in the fact that they are constrained by the specifictions and there are social environments to be complied with.

Modern solutions

Recent years have witnessed some major breakthroughs in bridge technology, involving a high degree of skill and innovation. The new types of bridges that have been evolved, viz. cable-stayed, space-frame, floating and lightweight concrete bridges and the like, are providing fresh concepts for exploitation.

The economics for various span lengths favour the following types of construction:

1. up to 25m in reinforced concrete
2. over 25m and up to 50m in prestressed concrete or with continuous spans in reinforced concrete
3. over 50m and up to 75m with semi-continuous spans in prestressed concrete
4. over 75m and up to 140m by cantilevered construction in prestressed concrete
5. over 140m as cable-stayed bridges.

The concept of cable-stayed bridges originated from the application of external inclined cables. The first modern cable-stayed bridge to be built is the Stromsund Bridge in Sweden in 1955, which is shown diagramatically in Figure 11. Modern cable-stayed bridges have a three dimensional system consisting of stiffening girders, transverse and longitudinal bracings, orthotropic type deck, and supporting components such as towers in compression and inclined cables in tension. Cable-stayed bridges could have the cable systems. pylon types and deck profiles shown in Figures 12, 13 and 14, respectively, all of which provide many possibilities to meet the individual requirements of each location without overlooking aesthetic perceptions.

Many cable-stayed bridges have been built in Europe, U.S.A. and other countries with spans as large as 404m with a steel deck and 320m with a concrete deck. Particulars of the world's longest cable-stayed bridges are given in Table I. and some of the outstanding cable-stayed bridges built in concrete are described below.

The bridge over Lake Maracaibo (Rafael Urdanetal in Venezuela: This 8.85-km long bridge (1962) spans the Lake Maracaibo in Venezuela and is one of the world's outstanding prestressed concrete structures. It includes five main spans of 235m each, soaring 45.1m above the lake's navigation channels. The deck is supported by inclined cables, Figure 15.

Each 235-m span consists of two 95-m cast-in-place decks at either end and a 46.6-m suspended prefabricated deck. The cantilevered span is supported by inclined ropes, suspended

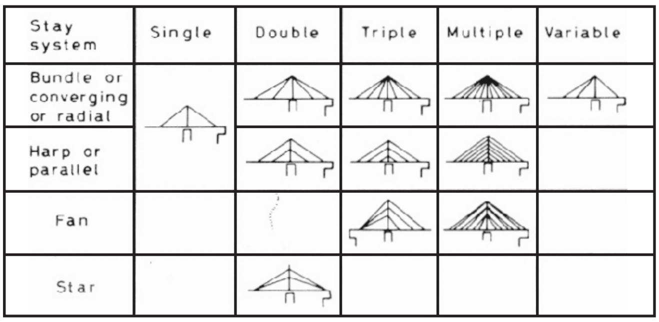


Figure 12. Cable arrangement for cable stayed bridges

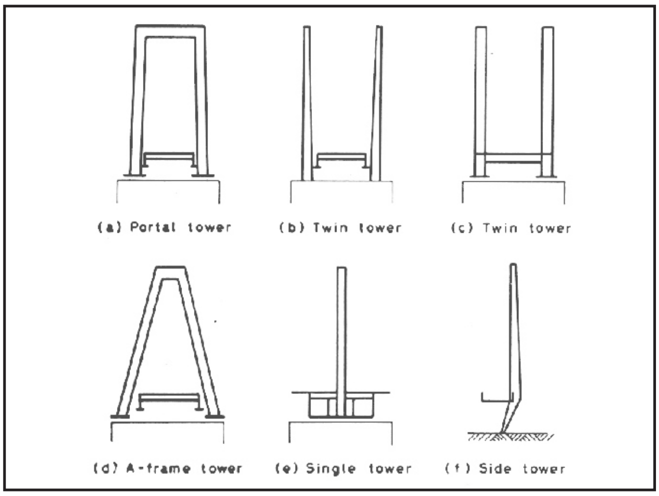


Figure 13. Pylon types for cable-stayed bridges

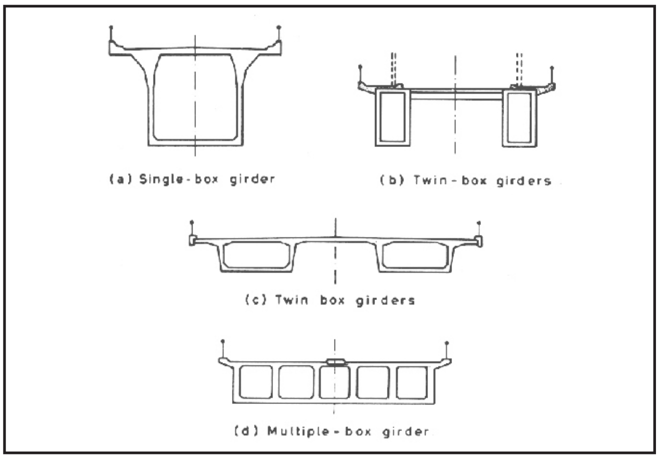


Figure 14. Deck profiles for cable-staved bridges

from the top of 93-m high four-legged piers which comprise two inclined A-frames linked at the top by a transverse girder. To exclude any possible damage resulting from differential settlement of the bridge piers and towers or from earthquake vibrations, the central spans were made statically determinate, Figure 16.

Wadi Kuf Bridge, Spiac, Libya: This three-span bridge (1972) is a part of the new highway near Libya's Mediterranean shore, linking Tunis and Egypt. The bridge has a central span of 282m, which is flanked by 97.5-m side spans to give a total length of 477m. Concrete was selected because of its rigidity, tolerance to extreme day-and-night temperature variations, and stability against seismic disturbances in the area.

The A-frame portal and inclined pier legs support a single-box girder of varying depth with a single pair of forestay and backstay cables, Figure 17. The inclined legs are attached to the deck at points 97.5m from the tower by means of an inclined transverse prestressed concrete box beam, 6.5m deep and 2.5m wide. The main girder extends a further 16m beyond the cables to support a 55-m suspended span. The overall deck width of 12.9m consists of a 10.51-m wide roadway, flanked by two sidewalks each of 1.05m width. The bridge deck is of cellular construction and consists of top and bottom slabs integrated with the longitudinal beams and a number of transverse diaphgragms.

The main side-span cantilever extends to the abutments, where it is anchored down through very large doublehinged rockers. The single suspended span is formed from two precast I-beams lifted directly into position.

Cable-stayed bridges in India

Cable-stayed bridges arc now being constructed in India, and the Second Hooghly Bridge at Calcutta is the first of this kind. The bridge consists of a central span of 457.2m with an end span of 182.9m on either side, Figure 18. The pylons rest on cellular concrete caissons, the larger one located at midspan being 24m in diameter. The steel strakes were fabricated on a tilting platform, slipped into the river at high tide, transported, grounded and sunk a couple of metres at their location before the annular spaces provided in the strakes are filled with concrete and extended further with the progressive sinking of the caisson. The pylons are in steel and the deck is of composite construction.

The first all-concrete cable-stayed bridge will be at Akkar in Sikkim, Figure 19. Its pylons have already been completed, and work on the deck just initiated. It is expected to be completed in 1985.

Future trends in India

India now stands at the threshold of its Seventh Five-Year Plan, which is scheduled to commence in 1985. The civil engineering component of this plan will exceed Rs 132,000 crores, which is

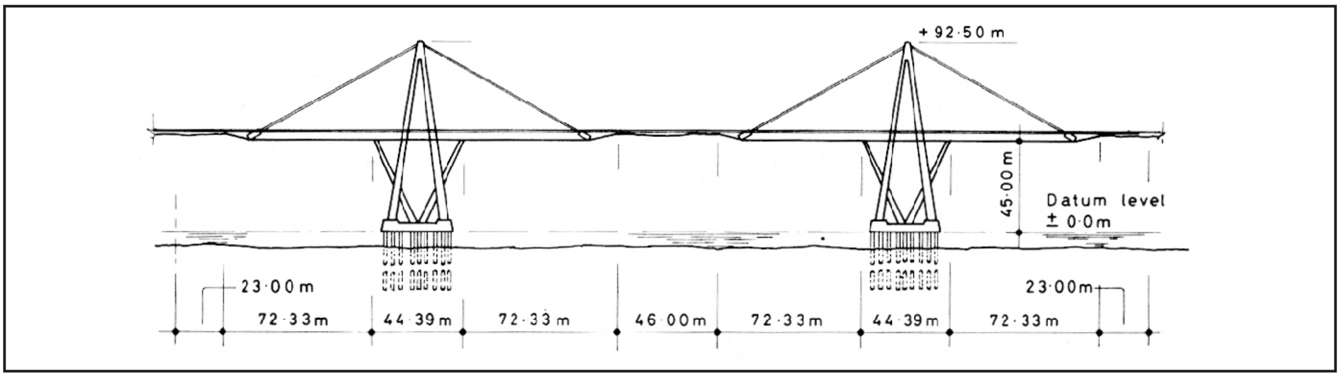


Figure 15. Elevation of Lake Maracaibo Bridge in Venezulea

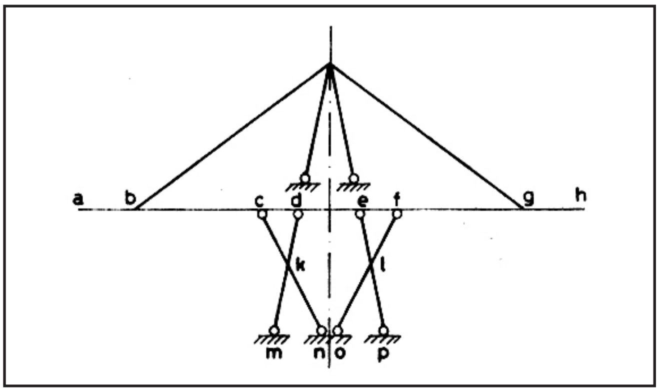


Figure 16. Diagrammatic arrangement for making centrai Spares of Lake Maracaibo Bridge statically determine

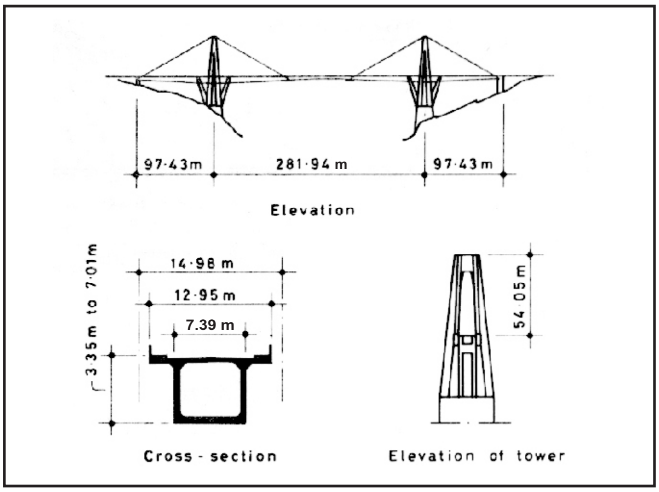


Figure 17. Details of tower and deck of the Wadi Kuf Bridge Libya

more than the entire budgetary investment of all the preceding six Plans put together. The emphasis will be on completing projects on schedule and curtailment to the maximum extent possible of expenditure under the escalation clause now incorporated in contracts. This will necessarily lead to higher inputs of machinery on projects and to a reduction in the labour content, which presently accounts for about 30 percent of the project cost. The availability of computer facilities of a fairly advanced type will help in optimising structures and also in building with confidence the more complicated ones, like cable-stayed bridges. With materials accounting for nearly 40 to 50 percent of the total cost of a structure in India, it is apparent that the need to conserve materials by improved structural forms and design techniques is a must.

The planning to make available all materials of construction in sufficient quantities through indigenous production of these items has been already initiated in the Sixth Plan period, and the augmented industry will be on stream when the Seventh Plan takes off. The opportunity for ensuring necessary machinery inputs having been ensured through advanced plant production programmes at the national level, it would be reasonable to expect projects to be completed on sehedule, except where progress on works may be affected because of wage demands and other industrial disputes.There are nearly 22 labour laws applicable to the construction industry in India, which require to be consolidated and properly oriented to meet the emerging challenges. The Government of India is aware of this problem and the necessary groundwork is under way.

With regard to design concepts, partial prestressing and the limit state method will gain increasing acceptance, and these concepts will help improve the performance characteristics of structures. These concepts have already been incorporated in the codes of the Indian Standards Institution for building works and are now being reviewed to ensure that their application will lead to satisfactory behaviour of bridge structures.

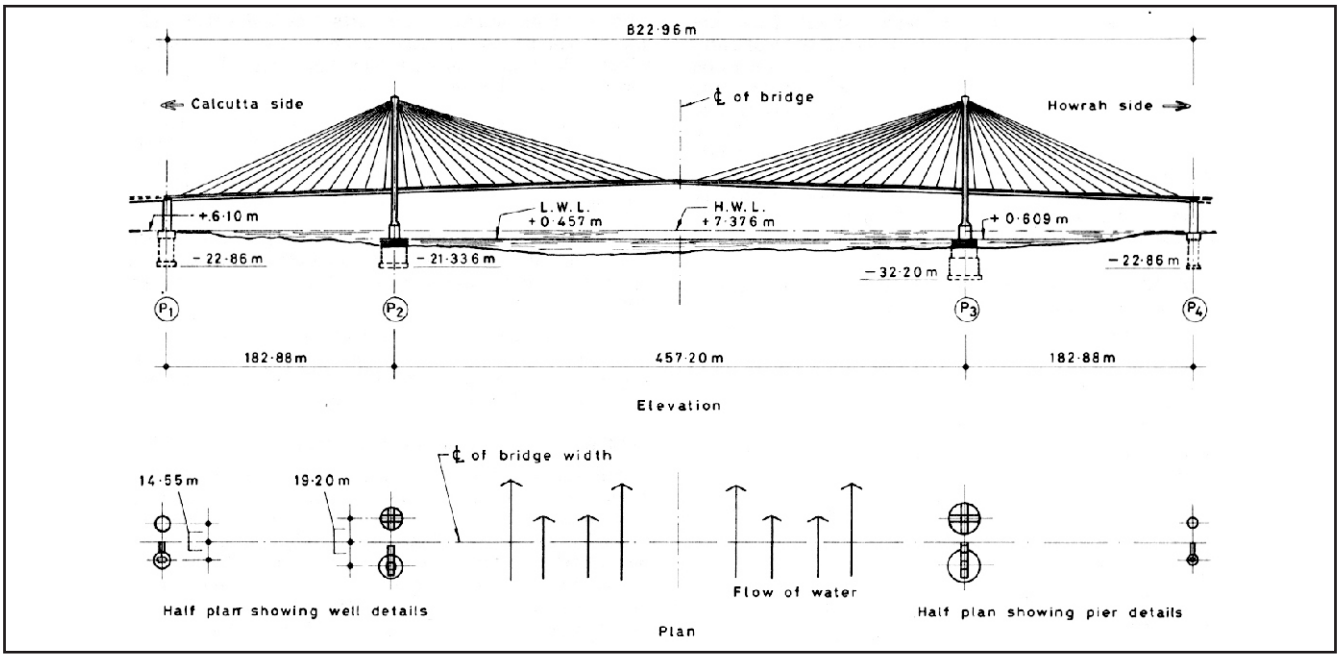


Figure 18. Details of Second Hooghly Bridge at Calcutta

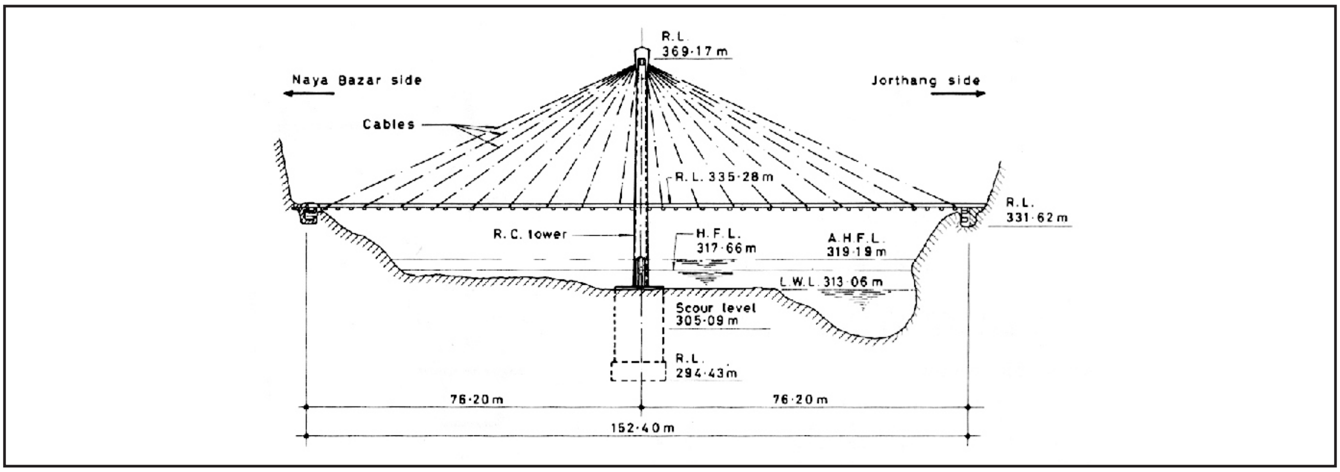


Figure 19. Details of bridge at Akkar in Sikkim, the first cablestayed bridge to be built in concrete in India

The present deck width for two-lane bridges in India is 7.5m. It is likely that this will be increased to 9m, and possibly even more, to provide a standard three-lane width of deck since the present two lanes make overtaking difficult on increasingly congested highways. A major development in this context is the construction of six-lane highways, proposed under World Bank support, between Ahmedabad and Baroda (92km), Jullundur and Panipat (250km) and Calcutta and Durgapur (65km). These are super-express highways with only a few clover leaf entry and exit points connecting the most important towns en route. These highways will gradually be extended, and new links will also be taken up to meet the considerable increase in traffic projected in the Seventh Plan. There will also be extension and widening of the secondary highways and rural roads. A programme is in hand to increase the carrying capacity of the Indian road network so that it can meet uniformly the load requirements contemplated in the specifications for national, state and rural roads with different priority requirements, militarily and otherwise.

Cable-stayed bridges will now find more favour with longer spans in the range of 200m to 300m. Push-launching systems, with continuous decks and consequently improved expansion joints, will also find increased usage. A beginning may possibly be made with longer prestressed spans for railway bridges. Truss-type solutions for road bridges may be tried before long, especially where the superimposed loads are uniform, as in the case of bridges carrying water pipes.

Table 1. The world's longest cable-stayed bridges

Name and country	Span m	Year
Steel		
Saint-Nazaire, France	404	1975
Luling, U.S.A.	376	1980
Duisburg-Neuenkamp, West Germany	350	1970
West Gate, Australia	336	1974
Brazo Largo, Argentina	330	1976
Zarate, Argentina	330	1976
Kohlbrand, West Germany	325	1974
Knee. West Germany	320	1969
Concrete		
Brotonne, France	320	1976
Wadi Kuf, Libya	282	1972
Tiel, Holland	267	1975
Manuel Belgrano, Argentine	245	1973
Rafael Urdaneta, Venezuela	235	1962
Polcevera. Italy	208	1967

The use of crash barriers and improved transition to bridge approaches, as also aesthetics of railing and bridge concepts, will find greater emphasis. Steam curing of precast elements, rarely adopted in India due to high ambient temperatures, will nevertheless find a place. The accent will be on adopting techniques of construction which will promote speed rather than material conservation or too much sophistication.

A greater awareness regarding the performance of existing structures, their maintenance, and rectification of defects observed, not the least the effects of aggressive environment on them, will become a major activity, adequately supported by research. Better interaction between universities, research institutes and the industry will manifest itself, so that applied research sponsored by industry is given priority consideration. A beginning may be made with the use of lightweight concrete, fibre-reinforced concrete and polymer concrete. There is already an awareness of these materials and research on a low key is in progress.

Trends abroad and their impact

Cantilevered construction heralded long span bridges, commencing with the Coblenz Bridge (1956) which has a main span of 208m. This span length was subsequently exceeded in the case of the Urato Bridge in Japan, which has a span of 230m. It is now fairly well established that a maximum span of 300m can he achieved by this method of construction, although the economics of construction may not always justify this solution. However, the transition from cantilevered construction to cable-stayed bridges, starting with spans of around 180m, has now been well established. Commencing with the first cable-stayed solution for the Maracaibo Bridge with a span of 236m, bridges with longer spans have been built, the maximum achieved so far being 320m for the Brotonne Bridge. The realisation of spans up to 500m is already contemplated. It may be mentioned in passing that for the Messina Straits Bridge a span of 1,350m has been proposed. Invariably, the pylons of all cable-stayed bridges constructed of late have been with slipformcd concrete, which makes for much better performance. It should not be presumed that the earlier concepts of arch bridges and bowstring-hanger bridges are now antiquated and no more viable. The construction of the Kirk Island Bridge in Yugoslovia with a main span of 390m in 1980 is an excellent example of choosing the appropriate solution in selected locations without overlooking aesthetic perceptions. Spans of 200m are feasible with the bowstring deck where site conditions are best suited for its adoption.

The stressed ribbon bridge possesses certain advantages, and a footbridge of this type has already been built and tested in Switzerland. A similar one was proposed by Dr Finsterwalder for the Bosphorus crossing before a suspension bridge was chosen. This concept is capable of large spans and depends mainly on the performance of the cable with a very shallow sag between the piers. Lightweight concrete has already been used in Europe and has the potential for greater application in future for all types of bridges, especially for long-span decks where its application is most effective. The use of floating bridges, especially in the U.S.A., is significant. Although they cannot have much application in India, as a structural approach to a particular location, they merit mention. The best known construction of this type is the Second Lake Washington Bridge at Seattle, U.S.A., which is 2,437.8m long and has special arrangements to meet the requirements of floatation and movement at the junctions of each of the floating units.

The use of a three-dimensional concrete truss is finding an important place in the design of bridges. Basically, this technique cuts down the self-weight of the bridge deck and, thereby, makes the project more economical. Also, because of its lower weight, larger elements can be precast and erected more efficiently. A recent example of the construction of a major bridge using the space frame technique is the bridge joining Bubiyan Island with the mainland of Kuwait. The bridge, 2.4km long, consists of 58 spans each of 40m and one central span of 54m over the navigable channel. The main innovation in this bridge is the three-dimensional triangular prestressed concrete truss. The deck comprises of two slabs linked by a truss formed by a series of indentical triangles, Figure 20. The truss configuration has reduced the quantity of concrete by as much as 20 percent and prestressing steel by 30 percent as compared with a conventional concrete box girder.

In the field of materials development, apart from lightweight concrete mentioned above, high capacity cables of 2500t and the use of almost no-relaxation steel (less than 2 percent) have opened up new prospects with regard to optimisation of steel in bridges. Protection against corrosion, especially on cable-stayed bridges, has also undergone considerable reassessment. The latest approach is to use a polyurethene flexible coating on the cables. Likewise, much attention is being paid to the material used for forming cable ducts and grouting composites, especially in areas with an aggressive environment. The adoption of long, continuous bridges with a provision for sophisticated arrangements at the requisite expansion joints (like DEMAG joints) has come to stay. The

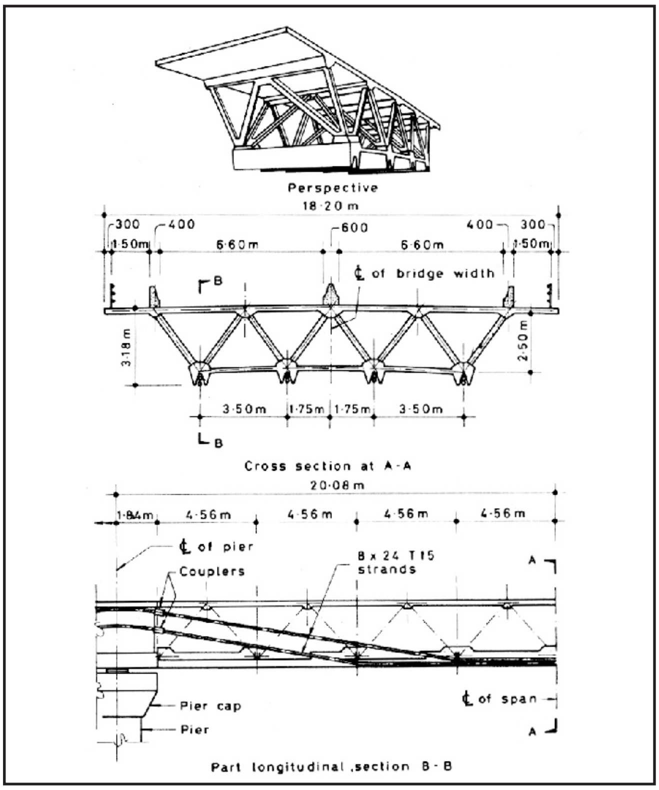


Figure 20. Details of the space frame truss used for the Bubiyan Island Bridge, Kuwait

problems created by expansion joints in locations where freezing is expected and also in the tropics where monsoon water drainage through such joints creates a problem have greatly contributed towards a preference for continuous bridges. The use of factory-made precast units to obtain a neat form finish and superior grade concrete, free from blemish, will be preferred. Model testing of bridges is gaining increasing acceptability, as also computerised solutions for designing most bridges. These techniques are bound to percolate into the Indian environment. As such, increasing use should be made of our laboratories and also of computer programmes, available internationally for solving even the most complicated problems, in order to obtain a clear insight into the structural behaviour of the system chosen.

It can be stated with confidence that Indian technology is somewhat conservative in approach and constrained by codes and practices that are vigorously enforced, thereby restricting the introduction of new forms of construction, like cable-stayed bridges, with a totally Indian content and approach. It is hoped that the rapidity with which such new structural forms and solutions are being increasingly adopted abroad will greatly help stimulate construction of similar works in India before long.

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T.N. Subba Rao. BE, CEng, FISI, FICE (UK), FI Struct E (UK), FIE (Ind), Managing Director, Gammon India Limited, Bombay.
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