Bridges: The Spectacular Feat of Indian Engineering

By R.R.Bhandari

Promoters of railways in India faced a major challenge in crossing the wide rivers, which changed their course dramatically with seasons. The climatic conditions vary considerably and so does the flow through the rivers. The volume of water register seasonal variations of magnitude unknown in other parts of the world. The varying character of the river-bed soil further aggravates the problem. Most rivers pass through alluvial soil devoid of rocks. To quote Charles Greaves, one of the early engineers visiting India in 1852:

"The whole of the Bengal plain is nothing but a sea of mud, there is hardly a stone as big as coconut or a hill as high as a house. It is wonder having regard to the softness or looseness of the soil that Calcutta remained where it was."

Early Railway Engineers in India had to innovate and devise special methods for constructing bridges to overcome the problems presented by the terrain and non-availability of proven material of European origin at the work-site.

Large bridges were, and continued to be, a major problem. The rivers of northern India are fed mainly by the Himalayan snow and discharged their waters into the Bay of Bengal in the vicinity of Calcutta. In doing so, they traverse hundreds of miles of almost flat land largely composed of silt deposited over the centuries. The other source of water feeding these rivers is the monsoon rain, falling between the months of June and September each year. During the dry period, the rivers shrink to a sluggish, steady flow in the course of which silt is deposited on the bed. When the monsoon rain come, the flow increases to a flood and the river bed having been raised by silt deposit during the dry period, rises correspondingly with each monsoon. The inevitable happens; the rivers overtop their high banks, be they natural or man-made, and find a new route across the flat land. When the floods subside, the river may have shifted from its original route and gouged a new channel. There is no easy solution to the problem. Building higher and stronger banks would merely postpone the day when the flow could no longer be contained and the ensuing disaster would be all the worse.

James Meadows Rendel, the great consulting engineer, associated with railways in India from its very inception commented in 1854:

"There are engineering difficulties to contend with in India, which people at home cannot possibly conceive. Yet I am bound to say that the works executed by *East Indian Railways* (EIR) are equal to any of the kind done in this country; several large bridges have been built over river streams and rivers near Hooghly, and on exceedingly treacherous, sinking and shifting ground. Yet no failures have happened nor have any major accidents taken place, although since the planning of railway, heavier flood have risen in Bengal than have been witnessed since the days of Clive."

Difficulties in bridging the major rivers could favour a particular track alignment and sometimes even the *terminus*. A bridge over river Hooghly was the most difficult engineering problem faced by railway men of that era.

Mr. Simms, the Consulting Engineer to the Government of India, sent out by the Court of Directors of East India Company in early 1850 finally decided to place the terminus for the EIR line on the right bank at Howrah, although he had previously, in May 1846, submitted a recommendation of a contrary tenor. In April 1950, he wrote:

"In May 1846, I expressed myself in favour of bringing the railway into the heart of the town; and it is therefore due to myself now to state that when that report was penned, there appeared to be every probability of an abundance of money to carry out the whole of the railway project from Calcutta to Delhi, with bridges spanning the great rivers, the Yamuna, Sone and the Hooghly; and therefore in so magnificent a project, the extra outlay (large as it would necessarily be) to make so great a work quite complete by bringing the railway into the heart of the town, would, under such circumstances, be quite unworthy of consideration in comparison with the whole cost of the undertaking".

Rowland Macdonald Stephenson, the promoter of East Indian Railway Company had to compromise on the decision of choosing a terminus for his railway, thus Howrah was chosen instead of Calcutta. The bridge over Hooghly is an interesting story. An organisation calling itself `Steam Ferry Bridge Association of Calcutta' initiated building a *Floating Bridge* across the river. All the material including two floating bridges were delivered at Calcutta in 1842, but because of a dispute with Bengal Marine Board, the project had to be abandoned. A different design of `Floating Bridge' more in the shape of a *pontoon bridge* was however constructed a few years later by Sir Bradford Leslie. The roadway, 30 ft wide and 2000 ft long was supported on twenty-six *flat bottomed iron pontoons*, each 80 ft. long by 26 ft wide, placed 50 ft apart and moored by heavy chains to a cable carried across the river from bank to blank. On each side of the river two of the pontoons were movable, giving a 155 ft wide opening for the passage of the ships. At each end of the roadway was a 110 ft long platform, one end resting on the shore, the other on a pontoon. By this means, the 22 ft rise and fall of the tide could be accommodated. This system continued for 30 long years and all the material meant for Calcutta moved from Howrah through the `Floating Bridge'. A connection to Calcutta by rail was established 24 miles northwest of Calcutta, giving East Indian Railway a direct link, via the Eastern Bengal Railway. This Bridge, the Jubilee Bridge named after the Golden Jubilee of Queen Victoria was formally opened by the Viceroy on 21st February 1887.

Colonel J.P. Kennedy, promoter of Bombay Baroda and Central India Railway (BB&CI) suggested a line connecting Bombay with the territories of Northern Konkan, Surat, Bharuch, Gujarat, Khandesh, Rajasthan, Malwa, Sind, Punjab and the north-west provinces. Opponents of this proposal suggested that there are two grave impediments viz.

1) It will be very difficult to cross the broad estuaries close to the sea and the spurs coming down from the Sahyadri range, and

2) There are near impassable river streams in Tapti Valley.
Kennedy replied (excerpts from his report of 1854) thus:

"It is far from my intention to undervalue the obstacle that rivers and nullahs are likely to oppose to Indian railway construction; all that I maintain is, that the rivers and nullahs in these districts are like the rivers and nullahs in other districts of India, and that the engineer who is not prepared to deal with such obstacles had better turn his back upon India altogether. They are assuredly the chief subject requiring fore- thought and caution in the execution of public works in this country, and upon the mode in which we deal with them will depend the broad questions of whether our railway operations shall succeed or fail; whether the results from them shall be a profit or loss or whether their execution shall be rapid or slow.

So strongly did I feel the importance of this subject and the danger of adopting in India any of the costly and dilatory principles which have caused so much ruin and delay elsewhere, that I ventured to recommend, formerly, in my official reports to Government, the *temporary* omission of bridges altogether on the larger class of Indian rivers, rather than damage the character of Indian railway investments by risking the interests of the shareholders for the construction of those great masonry viaducts of former days. Our more recent practice, however, and the improvements and experience of the last few years, in our iron structures of this class, fully justify me in saying that no such inconvenience to our traffic, as a temporary omission of the larger bridges, will be now required, if we can obtain iron at a reasonable rate, and that point the investigations made by this company have placed beyond the shadow of a doubt; still, however, the bridging of rivers will be vital point in Indian railway construction."

On getting iron at reasonable price, Kennedy suggested;

"If we construct our viaducts, rails, etc., of native iron of our own manufacture, we may calculate on executing our railroad at an average rate of pound 4011 per mile. That if we adopt the same principle of construction, but purchase our iron in the English or other market, we may calculate on expending pound 7053 per mile; and if we use brickwork or masonry viaducts, with English iron rails, our outlay would be pound 8769 per mile.

Hence, then, the very first preparation that I should earnestly recommend to enable us to secure the most successful result in our future railway operations would be, the immediate establishment by our company of a native iron foundry."

Kennedy suggested building an integrated iron and steel plant though mentioned it as *iron foundry*, the typical English modesty. Alas! the iron foundry never came up under the auspices of his BB&CI Railway Company.

From the foregoing, it will be evident that bridges played a major role in deciding the alignment of many a rail-lines in India. Some of the peculiarities of bridges on Indian system, to be covered in greater details later are briefed thus:

Training of Rivers

Rivers in India behave drastically in rainy season. They change their course over a period of time depending upon the topography and terrain of the country and the rainfall pattern. Railway Engineers mastered the art of training the rivers, which changed course sometimes by miles. Never before in the history of railways, the engineers had come across such problems and their ingenuity, dedication and hard work provided the solutions.

Foundations of the bridges

The foundations of many of these large structures presented difficulties and problems peculiar to India. The usual method of founding the abutment and piers of large bridges in the sandy beds, extending often to unknown depths of great rivers, could not be followed due to sub-soil conditions of the foundation bed. In most of the early constructions, well foundation was adopted by sinking cylinders or wells of brickwork either singly or in groups on which the pier sub-structure was built. This system though novel to civil engineers in other parts of the world, was being practiced in India for centuries in a systematic and improved way. Nearly all the ancient bridges of upper India were formed by this method. Recognizing the suitability of this method, the practice of well sinking foundation was further developed by the Americans and they became the masters of *pneumatic caisson*.

Near coastal areas for clayey strata the system of ‘screw piles’ with cast iron outer shell filled with sand was successfully used as bridge foundation system.

Use of Local Material and Craftsmanship

Looking to the advantages of local materials like stones, etc. the masonry structure was used in a big way for construction of piers and abutments of the bridges. For superstructure, Indian Engineers preferred massive use of ‘early’ mild steel, particularly for large bridges as these were the only materials capable of producing the required long spans.
Extract from Col. J.P. Kennedy's writing in 1854 highlight the use of iron superstructure and screw-piles made by local smiths of Surat.
"Examination of the Tapti and Narbada justifies me in recommending that these rivers should be bridged by an iron superstructure, supported on iron-piers. The bridging of these two rivers will be the most serious operations we shall have to encounter in executing our works. We have had some *screw-piles* made by the ordinary smiths in Surat, to try their capacity, and the result of this, and other operations of a like tendency, has been very satisfactory, showing that, we may calculate upon good service from the native mechanics of India."

Architecture of the bridges

The railway bridges gave rise to a new architecture based on engineering and science rather than empirical knowledge. Bridges are the most spectacular of all railway engineering works. In size, materials and position they made an unparalleled impact on landscape. Some of the bridges may remind us of such earlier works as the Roman aqueducts, but on the whole they represent a new, architectural form unconnected with local traditions, though a few architects tried to merge the local art prominently at the bridge approaches.

Innovation

Early bridge engineers were highly innovative. They developed techniques to face the difficulties and challenges squarely. Some of them documented their experiences for the benefit of their brethren. Amongst the earliest technical papers published in India, bridges and river training there-of had lion's share. The author had come across many such articles. Briefs of some of these articles published from 1866 to 1876 give a glimpse of this rich literature:

* 1866; *Geo. Broadrick* of East Indian Railway; 18 pages and 1 photograph describe the construction of Tonse Bridge near Allahabad consisting of lattice girders of 150 feet span and piers on 12 wells each.

* 1870; *Edward W. Stoney* of Madras Railway; describes construction of Pennair Bridge, 1680 ft long, 24 spans of 64 ft each, and superstructure made of wrought iron plate girders.

* 1870; *Imrie Bell* of Delhi Railway; describes the Yamuna Bridge at Sirsawa near Ambala and the innovation - use of `sand pump' in sinking of wells, sinking 6 ft in 8 hours.

* 1870; *Alexander Robert Terry* of Great Indian Peninsula Railway; restoration of the Mhow Ke Mullee Viaduct on Bhore Ghat line washed in a violent storm in 1867 and construction of a new viaduct from 1868 to 1870.

* 1872; *George Woodbridge* of Oudh and Rohilkhand Railway; a memorandum of a hand dredger for sinking wells, invented and patented by W. Bull, Resident Engineer of ORR.

* 1873; *R.T. Ives*, Engineer of Public Works Department, Punjab; describes his patented excavator used on the Beas Bridge Works on the Sind, Punjab and Delhi Railway.
* 1874; *W. Bull* of Oudh and Rohilkhand Railway; describes his very simple fixed clay cutter.

* 1874; *Edward Byrne*, M.I.C.E; an analysis of factors causing disasters on some of the well-known bridges in India.

* 1874; *C.H.G. Jenkinson* of Rajputana State Railway; an analysis of Warren, Whipple Murphy and other types of trusses for bridges and their suitability for metre gauge lines.

* 1874; *W.H. Pitt* of P.W.D., Bombay, suggests his design for a dredger for deep well digging.

* 1876; author not mentioned; the floods of 1871 damaged a number of piers of Yamuna Bridge, Sutlej Bridge and Beas Bridge, the author gives some river training works undertaken on these rivers.

These are only a sample to show the enthusiasm of railway engineers of that time on river training and bridge works, something novel for them on the Indian soil.

Bridges were the most spectacular of railway engineering and architecture on Indian Railways a century ago and it continues to be at the close of this millennium. To illustrate this statement, an example:

The bridge over river Sone near Arrah had a chequered history. Construction was started in 1856, was disrupted during the risings of 1857 and was completed in 1862. The opening ceremony was performed by Lord Elgin, the Viceroy, who paid tribute to the achievement with the words: 'this magnificent bridge was exceeded in magnitude by only one bridge in the world'. It was indeed a triumph for the pioneer bridge builders in India. It remained the longest bridge in the Indian subcontinent, till it was eclipsed by the Upper Sone Bridge in the twentieth century. The bridge was designed by James Meadows Rendel, the consultants and the distinguished architect Sir Matthew Digby Wyatt, both associated with EIR. The total length of the bridge is 4726 ft, made up of 28 decked wrought iron spans, each 150 ft long, or 162 ft from centre to centre of piers, which are each 12 ft thick, carried on three brick wells of 18 ft diameter, sunk to a depth of 32 ft below low-water into a stiff bed of yellow clay. Re-produced below is the beautiful account of this bridge written by Captain Davidson in 1868:

"The Sone River, rising in the elevated districts of Central India, traverses the plains of South Bihar, and discharges itself into the Ganges, near Patna, after draining an area of nearly 23,000 square miles. Its extreme discharge in floods is said to be about 1.3/4 million cubic ft per second. The chief peculiarity of the river is the great width of its channel in the lower reaches. For the greater part of 100 miles it is over 2 miles wide, and reaches as much as 3 miles. This wide expanse of bed, through which during eight or nine months of the year only a narrow stream meanders, consists entirely of fine sand, appearing to the traveller like the surface of a great sandy desert. During the season of floods, the depth of water carried averages barely 20 ft, and it seldom exceeds 30 ft in the deepest parts. The whole width of the immense channel is, moreover, rarely completely covered. After careful examination of this formidable obstacle to the railway, a narrow point not far removed from the natural direction of the line was selected. Here the river was only about 4000 ft in width; and the banks were high and composed of clay, a bed of clay was also found by borings to underlie the sand across the whole width of the bed. It was at first proposed to construct a bridge of brick arches; but after some discussions, it was finally decided to adopt brick foundation-wells, with piers of similar material to support a superstructure of wrought-iron girders, each of 150 ft span, carrying the rails on the top, and having an ordinary roadway below. The foundation of the first pier sunk in the year 1856 was composed of a group of twelve brick wells, each 10 ft in diameter, laid close together in two rows of five, with additional wells at either end for the cutwaters. Initial work on the bridge was well in hand, when in July 1857, the native regiments at Danapur mutinied, and marching towards the west, overran the works. 'The resident engineers, their wives and children, together with inspectors and overseers and their families, escaped in the iron boats belonging to the railway company to Danapur, and the mutineers left nothing untouched that was destructible; then continuing their march along the line they came to Arrah, where Mr. Boyle, the resident engineer, had fortified a house. To it the European residents, 16 in number, with 45 Sikhs, retreated, and bravely defended themselves for a week against immense odds.

Work at the bridge site was of course suspended, and could not be resumed until November 1858, when operations had practically to be commenced *de novo*. The design for the pier foundations was now modified, and in place of the cluster of small 10-feet wells originally intended, the piers were founded on three wells, each 18 ft in diameter, built on very strong wrought-iron curbs, having vertical iron rods attached to them connected with horizontal rings of iron built at intervals into the brickwork. The foundation-wells were sunk into the riverbed to an average depth of 32 ft below low water, entering into a bed of stiff clay, and by the year 1860 construction work on all the piers was in full progress. As soon as the piers were completed, the girders were rapidly erected by the aid of a timber staging; and the bridge was virtually finished by the end of the year 1861, its final completion being unfortunately delayed by the loss of certain portions of the iron work in transit, so that it was not ready for traffic until the end of 1862. Lord Elgin, Viceroy and Governor-General, soon afterwards, in February 1863, officially opened the section of main line as far as Mughalsarai. The initial cost of constructing the Sone Bridge, which was completed for a double line of rails including protective works is given as 33 lakhs of rupees."

There are about 116,000 bridges of all types and spans on Indian Railways making an average of two bridges per route km. A rough break-up of the total is:

Girder bridges	20%
Arch bridges	19%
Slab culverts	23%
Pipe culverts	19%
Other types	19%

About 50% of these bridges are more than 100 years old. Though more than 1000 bridges are rebuilt/rehabilitated every year, the backlog is enormous. Old railway bridges are facing following types of problems:

- Aging and fatigue consideration
- Increased loading standards for axle load
- Increased longitudinal loads
- Rebuilding metre gauge bridges for broad gauge work.
- Replacement of Early Steel Girders provided prior to 1905.
- Corrosion problems in coastal areas.

Annual budget of Indian Railways for rebuilding/rehabilitation is of the order of Rs. 800 million.

Most of the girder bridges are of steel; some of them being of early steel with heterogeneous composition and need constant attention for their upkeep.

Most of the arch bridges are old and were built with brick or stone masonry in lime mortar. That includes the first major bridge on Indian Railways - the Dapoorie Viaduct, linking Bombay Island with the mainland of Thana; built by the Great Indian Peninsula Railway in 1854, this bridge of twenty-two stone arches still carries the mainline traffic.

First pre-stressed concrete (PRC) bridge in India was built in 1948 for Assam Rail Link Project near Siliguri. PRC bridges are now being built in large numbers.

Indian Railways have been pioneers in construction of long span bridges. Rail-cum-Road Bridge on river Yamuna near Delhi was built in 1864. In late 1950s river Ganga was bridged at Mokameh and the river Brahmaputra at Pandu. The longest railway bridge on Indian Railways is on river Sone at Dehri-on-Sone and consists of 93 spans of 30.5 m each. A bridge consisting of 18 spans of 120 m each and 2 spans of 30.5 m each is being constructed over river Brahmaputra at Joghighopa in Assam. This will be the longest span bridge on Indian Railways in coming years.

Chronological development of loading standards for design of railway bridges in India for the 5 ft 6 in gauge (BG) is tabulated below:

a) Vertical loads (expressed as axle load or load per axle; and *load per ft or metre run*)

Year	Engine (Axle load)	Trailing Load (Axle load; *load per ft run*)	Maximum Tractive Force
1875	Heavy 12 t	8 t	
	Light 7.5 t	7.5 t	
1882	12 t	8 t	
1886	14 t	9 t	
1892	15 t	1.2t/ft	
1903	18 t	14 t and *1.2 t/ft*	
1908	1903 standards + 25%	1903 standards + 25%	
1926	Heavy Mineral (HM) 28t	*2.3 t/ft*	
	Main Line (ML) 22.5 t	*2.3 t/ft*	*47.6 t*
	Branch Line (BL) 17 t	*1.5 t/ft*	
1964	HM Standards abolished		
1975	Revised Broad Gauge Standard (RBG) 22.5 t	*7.67 tonnes/m*	*75 t*
1987	Modified Broad Gauge (MBG) 25.0 t	*8.25 tonnes/m*	*100 t*
1995	Heavy Mineral (HM) Loading 30 t – for HM routes to be identified by Railway Board	*12 tonnes/m*	*135 t*

b) Longitudinal loads:

Prior to 1923: no mention.

1923: tractive effort (TE) and brake force (BF) to be considered in the direction of moving train as per some formulae given in these standards.

1933: revised formulae for TE and BF given.

Indian Railways are proud to have associated with some of the most renowned bridge engineers ever born. This author will refer them at many places. To name a few will be in order at this stage:

Mr. J.R.Bell
Sir Francis J.E.Spring
Sir Robert Gales
Mr. G.Lacey
Sir C.E.Inglis
Shri H.K.L.Sethi

BRIDGING THE MIGHTY BRAHMAPUTRA AT JOGIGHOPA

The most striking feature of the picturesque northeastern region, the land of hills and rivers, is the all-pervasive presence of the majestic Brahmaputra. This masculine river not only splits the state of Assam along its length but also cuts off the seven sister states of the north east from the rest of the country. The river having a catchment area of 3.8 lakh square km flows in the most unpredictable manner, occupying 12 to 16 km of space at places and poses a challenge to the bridge engineers.

Even though the first railway line in Assam came up in 1881, Brahmaputra was not bridged by the British. It was only in 1958 when construction of the first rail-cum-road bridge at Saraighat near Guwahati was started and this 1.30 km long rail-cum-road bridge was completed in 1962, followed by a 3-km road bridge at Bhomoraguri near Tezpur in 1987 and now a 2.30 km rail-cum-road bridge at Jogighopa has been completed in 1998 as a part of a142 km new line connecting existing Railway Station at Jogighopa on north bank with Kamakhya Railway station on the south bank of this mighty river.

The 2.3 km long rail-cum-road bridge, third in the series across mighty Brahmaputra, is situated near Jogighopa, 150 km west of Guwahati, in the Bongaigaon district of the state of Assam. Built at a cost of Rs.300 crores (excluding the cost of approaches) and jointly funded by the Ministry of Railways, Ministry of Surface Transport and North Eastern Council, the bridge connects National Highway No.31 B on the North Bank and National Highway No.37 on the South Bank. Along with the construction of a 142 km long railway line, this bridge shall provide an alternative and more stable link to Guwahati on the South Bank of Brahmaputra traversing through the Goalpara and Kamrup districts of Assam.

SALIENT FEATURES

Jogighopa Bridge has a span configuration of 17 spans of 125 m each, one span of 94.60 m and 2 shore spans of 32.60 m each. The superstructure of the bridge consists of 1.85 m high and 11.50 m wide double Warren-type open-web steel girders. The roadway is on upper deck and the railway line is on the lower deck. All the foundations are well foundations. Abutments are supported on twin circular wells of 6 m diameter having common well cap. Seventeen foundation wells are of double D type with plan dimensions of 11 m x 17 m. Two foundations, namely P17 and P18, are 18 meters diameter circular wells with a central diaphragm. These two well are founded on uneven rock bed and anchored with the rock by 12 piles of 1.5 metre diameter. All other wells are founded on dense sand. For separation of the road and rail traffic immediately beyond the main bridge, two road viaducts have been constructed. The north viaduct is 422 m long and the south viaduct is 660 m long. The substructure consists of hollow circular piers supported on pile foundations.

The construction of such foundation even though finally limited to two numbers has thrown a large number of problems from the design stage to the completion stage. The challenges met with were in respect of design, well sinking, pile driving, soil stabilization by jet grouping around the well base, rock anchoring and plug concreting. The foundations namely P: 17 and P: 18, had to be founded on undulating bedrock. To overcome the difficult and typical foundation conditions encountered at these two locations, a special foundation system comprising large diameter well with the anchor piles through the well steining was evolved. The design of these foundations comprised circular wells of 18 m diameter, with 12 anchor piles of 1.5 metre diameter through the well steining into the bed rock going 10 metres inside the rock and fully bonded into the well steining. In addition to the internal piles, 8 external piles of 1.5 m diameter were also constructed at pier No.17. These piles have been integrated with the well cap by a common well-pile cap.

SUPER STRUCTURE

Simply supported span with 121.6 m between centers of bearing has been adopted. Continuous spans or balanced cantilever spans were not considered suitable due to high seismicity of the area. The girders carry two lanes of BG railway track on lower deck and a 7.5 m wide two-road carriage way with two footpaths on the upper deck accommodated between girders. At present, single BG railway track has been laid centrally with provision for future doubling. Road deck is composite with steel floor system. The height of the girders is 18.5 m and they are spaced at 11.5m c/c.

The superstructure is made of double warren type open web steel girders. Top and bottom booms are parallel to each other. The main girder members are made up of high tensile steel. Each girder has 16 panels of 7.6 m length. Northern side has roller bearings and southern side has rocker bearings. The net requirement of fabricated mild steel. Was 10,345 MT and that of fabricated high tensile steel was 18,640 MT. Each 120-metre span weighed around 1600 MT.

BRIDGES ON RIVER GODAVARI AT RAJAHMUNDRY

The Godavari, largest river in South India takes her origin in Western ghats near Nasik after flowing about 1000 km across Deccan plateau it emerges in the plain of over Godavari Delta after flowing about 30 km from Rajahmundry. It joins the Bay of Bengal after flowing further 60 km down stream. The maximum discharge is around 3 million cusecs and maximum observed velocity 5m/Sec.

FIRST GODAVARI BRIDGE

The first railway bridge at Rajahmundry was built by Mr. F. T. G. Walton in 1900 when 56 spans of 45.7 m under slung girders were carried on masonry piers and one land span of 12.2 m at Kovvur end i.e., overall length of the bridge is 2950m. Certain technical decisions taken by Walton in 1900 still hold good even for today's engineers.

SECOND GODAVARI BRIDGE

Doubling of track between Chennai-Howrah was taken up during the Third Five Year Plan period. Most of the route had been doubled leaving behind only small stretch between Kovvur- Rajahmundry in Vijayawada- Visakhapatnam Sector wherein three kilometers long river has to be bridged. During 1964, the construction of second Godavari Bridge was sanctioned as a part of doubling of track between Kovvur- Rajahmundry and the work was taken up. There was a persistent demand from local public for construction of a road bridge between Kovvur- Rajahmundry and the State Government came out with a proposal to add a road deck over the rail bridge under construction as a part of doubling and thus the longest Road-cum-Rail bridge in the Asia and South East Asia on the river Godavari came into existence.

The second Godavari bridge at Rail-cum-Road type is thee kilometers consisting of 27 spans of 91.4 m and 7 spans of 45.72 m of which 6 spans of 45.72m are in 6 Deg. Curve at long Rajahmundry end to negotiate the built up area and it had many technical features during construction.

The following are salient technical features of special interest in the construction of Rail-cum-Road Bridge.

(i) Formation of sand bar-cum-islands in lieu of caissons.
(ii) Pneumatic sinking of wells with imported air locks.

THIRD GODAVARI BRIDGE

The construction of third Godavari Railway Bridge is another feather in the cap of Indian engineers. It is perhaps for the first time anywhere in the world that a bowstring arch girder using concrete has been constructed for such a long span of 97.55m, and that too for the Railway loading.

STEEL CONCRETE ALTERNATIVE FOR SUPERSTRUCTURE.

Although originally the third Godavari railway bridge superstructure was conceived as steel, this was re-examined due to growing popularity of concrete deck bridge in Indian railways. While, in the past individual; spans have 24.4m was adopted using concrete and 45m in Vasai Creek bridge and 53m in Thane Creek bridge, it was, therefore, decided to explore the possibility of PSC bridge with suitable design for 97.55m span. Pre-qualification bid of three firms were found suitable for the steel girder option and two for concrete. Based on the design criteria adopted for other PSC bridges using International Codes such as BS: 5400 and UIC Codes, draft design criteria were prepared and circulated to pre-qualified firms, RDSO and Railway Board. Based on the comments received from them, the design criteria were finalized. Proof Consultants recommended the design offered by M/s. Hindustan Construction Company Ltd., Mumbai consisting of bowstring type concrete arch of span 92.552 m with prestressed concrete box girder to act as tie.

The bowstring arch girder was found to be technically and financially suitable. While the width of the arch is constant at 800mm, its depth varies parabolically from 1150mm at mid span and 1700mm at the ends where the arch meets the tie-girder. The deck is supported from the arch by means of 12 bars of hangers enclosed in HDPE ducts to protect them. While the arch is of reinforced concrete of M-45 grade. The pre-stressing system used for the permanent stressing of girder as well as temporary pre-stressing during construction is BBRV system that used bottom heading. Each girder is supported on pot bearings of 1050t capacity. While three sets of bearings have been imported from Switzerland, remaining bearings were manufactured by M/s. BBR (India) ltd., Bangalore. Stringent quality control measures were adopted while accepting materials for manufacture of hangers and bearings.

YAMUNA BRIDGE

Yamuna Bridge, no. 249, is a rail-cum-road bridge having railway on top and roadway underneath, on Delhi-Ghaziabad section. There are 12 spans of 200 ft and 2 spans of 45 ft each. Through triangulated girders with double-decker arrangement on deep-well foundation. Down line (also known as north line) was opened to traffic in 1866 and Up line (south line) in 1913. Regirdering of north line was done in 1933. The peculiarity of the foundation of this bridge is that the tock was found a few feet below the bed of river over a considerable length and piers are resting on rock except pier No.6 & 7. During the floods of 1978 and 1988, both rail and road traffic was suspended for short periods as bearings were submerged in floodwaters. Since the bridge has outlived its life, a new bridge in lieu of above bridge has been sanctioned at a cost of Rs.72 crore for which model study is currently in progress

Another bridge over river Yamuna is bridge No.30 at Naini on Allahabad-Mughalsarai section. This bridge was commissioned in 1865. This bridge and Yamuna bridge at Delhi are hundred percent identical to each other.

MALVIYA BRIDGE:

This mighty bridge (no. 11), on river Ganga is an **open web double rail cum road type** with 7 spans of 350 ft and 9 spans of 110 ft long was the first bridge of its type constructed in Indian sub-continent by the engineers of O&R Railway. It was opened to traffic in the year 1885. This bridge is having well foundation in brick masonry ranging from a depth of 70 feet to 160 feet for the main spans and from 60 feet to 110 feet for secondary spans.

GARMUKTESHWAR BRIDGE

This bridge is also over river Ganga, located on Moradabad- Ghaziabad section of the Northern Railway and is at 409-km down stream from the source of origin of river Ganga. The bridge was constructed in 1901. It is consisting of 11 spans of 61 m each and is for single line. At the time of construction of bridge, river within a width of 7-8 km was flowing. The Railway line on either side of the bridge is having curves towards upstream side. These curves were purposely provided to touch holy place of Garmukteshwar. Immediately after construction of the bridge, the river started shifting towards left and an embayment took place behind the left guide bund in 1903. At that time 600 feet long neutral spur was provided. River straightened itself and no serious problem was faced till 1947. During the flood of 1948, an onward problem again started. To safeguard the bridge, river training work had been further strengthened after getting a study conducted by the University of Roorkee in 1997.

Being built of early steel, regirdering work has been sanctioned. Fabrication work of girders is in progress in Engineering Workshop, Manmad of the Central Railway. It will be a challenging task to do the regirdering work without disrupting the railway traffic.

REOND KHUD BRIDGE

Just beyond Kangra station the line crosses the Reond Khud having a depth of more than 200 feet. The bridge (no. 459) is unique in India. Perhaps it is only steel bridge of its kind. Main span is of 180 ft of three-pinned steel arch while the end spans are plate girders of 40 ft span, provided on either side of the bridge. Braithwaite and Construction Company fabricated the girder at their works in Mumbai. M/s. Rendel, Palmer and Tritton finalized design and drawing work. The bridge is for narrow gauge line opened in 1927 for the Kangra Valley Railway. Main span of the bridge was constructed by projecting cantilever portion on either side of the bridge and then after connected in the center with the central pin. To ensure safety of the workers, during the construction stage, cotton net was provided to give support to person accidentally falling down while erecting the girder. The whole erection work was completed in six weeks time.