Major bridges on Konkan Railway : Approach to design and standardisation

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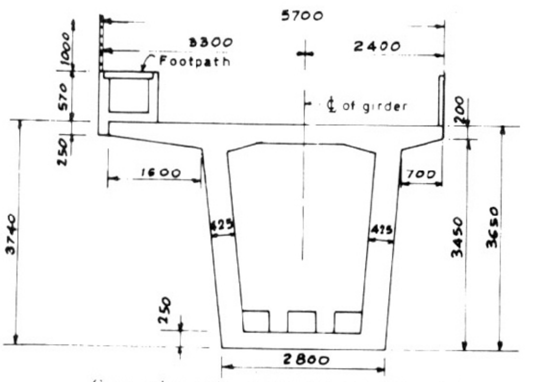
The Konkan Railway Project involves construction of 143 major bridges and 1670 minor bridges and the estimated cost of these bridges alone comes to Rs. 378 crores. Planning and design of these bridges had to be done keeping in view the requirements of safety, economy and durability as well as constructability and speed of construction. The latter aspects had to be given careful attention as the project is required to be completed in a tight time frame of 4 ½ years. To avoid delays in finalization of tenders and award of contracts it was decided to invite tenders based on Corporation's designs instead of allowing for bidder's designs. The article briefly explains the general approach adopted in standardising the design of the bridges and viaducts on the Konkan Railway.

There are as many as 143 major bridges and 1670 minor bridges on the Konkan Railway. Major bridge locations present highly variable site conditions along the length of this line. In the state of Maharashtra a large number of bridges have to cross deep valleys with pier heights upto 65 m. Fortunately, here the founding strata is suitable for open foundations on hard rock. In the state of Goa and Karnataka the line has to cross major rivers within tidal zones necessitating longer bridges with deep foundations. At a number of locations the alignment crosses National Highway No. 17 and other important roads which require construction of road over and road under bridges.

At the outset, Konkan Railway decided to adopt concrete decks for all these bridges so as to have uniform track structure (comprising 1540 inonoblock prestressed concrete (PSC) sleepers per km with 52 kg 90 UTS long-welded rails and 250 mm ballast cushion) all along the route. Keeping in view the objective of running high speed trains on this route, footpaths are being provided on all the major bridges on one side of the track.

Table 1: Major bridges on Konkan Railway - Superstructure details

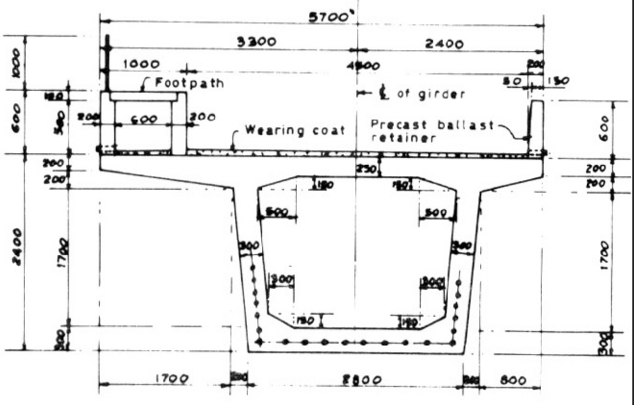
Sr. No.	Clear spam m	Overall length m	Structural details	Deck system Girders/Span	No. of Spam
1.	49.5	53.5	PSC post tensioned box girder -precast	One girder	14
2.	30.5	33.0	PSC post-tensioned box girder -precast	One girder	125
3	20.0	22.8	PSC post-tensioned T-girder - precast	Three girders	491
4	20.0	22.8	PSC pretensioned T-girder - precast	Three girders	
5	15.0	17.8	PSC post-tensioned T-girder -precast	Three girders	44
6	15.0	16.5	RC T-beam and slab - cast in-situ	-	4
7	12.2	14.1	PSC post-tensioned T-girder - precast	Two girders; Separate I beam for footpath	138 (7 and 8 together)
8	12.2	14.1	PSC post-tensioned T-girder - precast	Two girders with integrated footpath	
9	10.0	11.5	PSC pretensioned T-girder -precast	Three Girders	nil
10	10.0	11.5	RC slab - cast in-situ	-	122



Cross-section at mid-span of 53.5m span PSC box girder

Table of materials (per span)

	53.5 m box girder	30.5 m box girder
Concrete	325 m^3 (M-45)	125 m^3 (M-40)
HYSD steel	40 t	15 t
HT steel	16 t	6.5 t
No. of cables	23 Nos, 12T 15	21 Nos, 12T 13



Cross-section at mid-span of 30.5m span PSC box girder

Figure 1. Cross-sections of PSC box girders

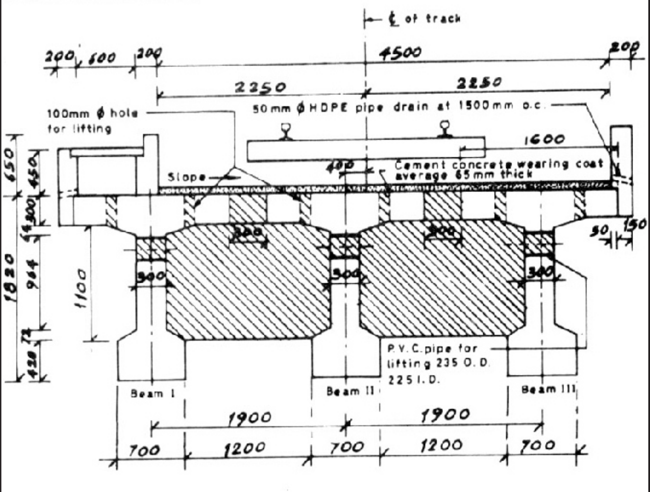


Table of materials (per span)

Concrete	95.7 m^3 (M-45)
HYSD steel	12 t
HT steel	3.2 t
No. of strands	180 Nos, 12.7 mm diameter

Figure 2. Pre-tensioned PSC girder having 22.8m overall span

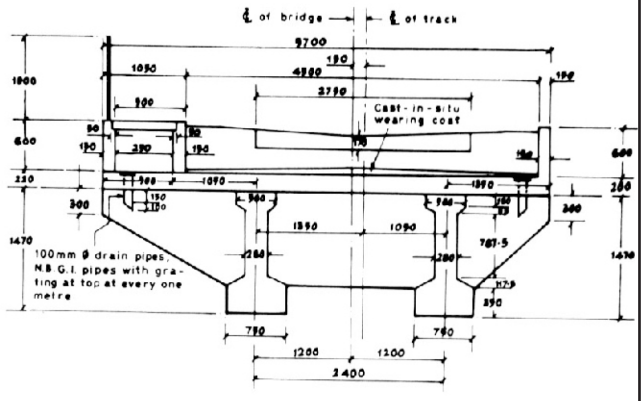


Table of materials (per span)

Concrete	40.5 m^3 (M-40)
HYSD steel	5.25 t
HT steel	1.05 t
No. of cables	14 Nos, 6T 13

Figure 3. Post-tensioned PSC girder having 14.1m overall span

Minor bridges on the alignment also present a special feature in the sense that many of these bridges have to be provided as low level bridges with substantial earth overburden on top.

Keeping in view the quantum of work involved in designing these bridges it was necessary to standardize various components of the bridges. But at the same time, the objective of economising these structures by adopting optimal configurations could not be lost sight of. During the progress of the project typical problems of bridge design were encountered and on many occasions these were tackled in an innovative manner to achieve economy in construction.

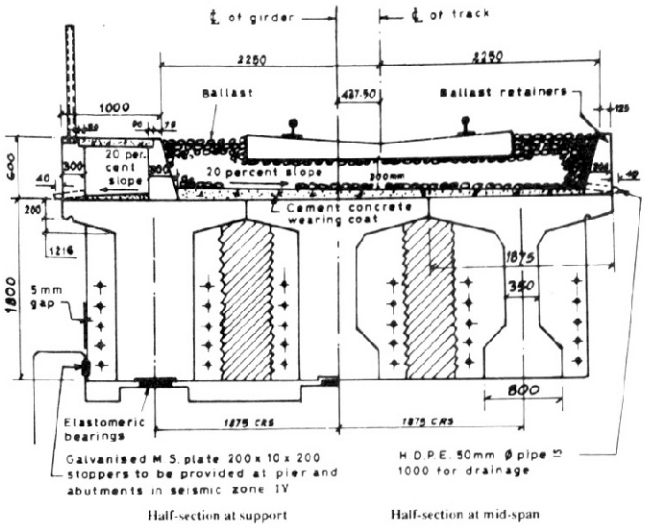


Table of materials (per span)

Concrete	93.5 m^3 (M-40)
HYSD steel	12 t
HT steel	3.6 t
No. of cables	15 Nos, 12T 13

Figure 4. Post-tensioned PSC girder having 22.8m overall span

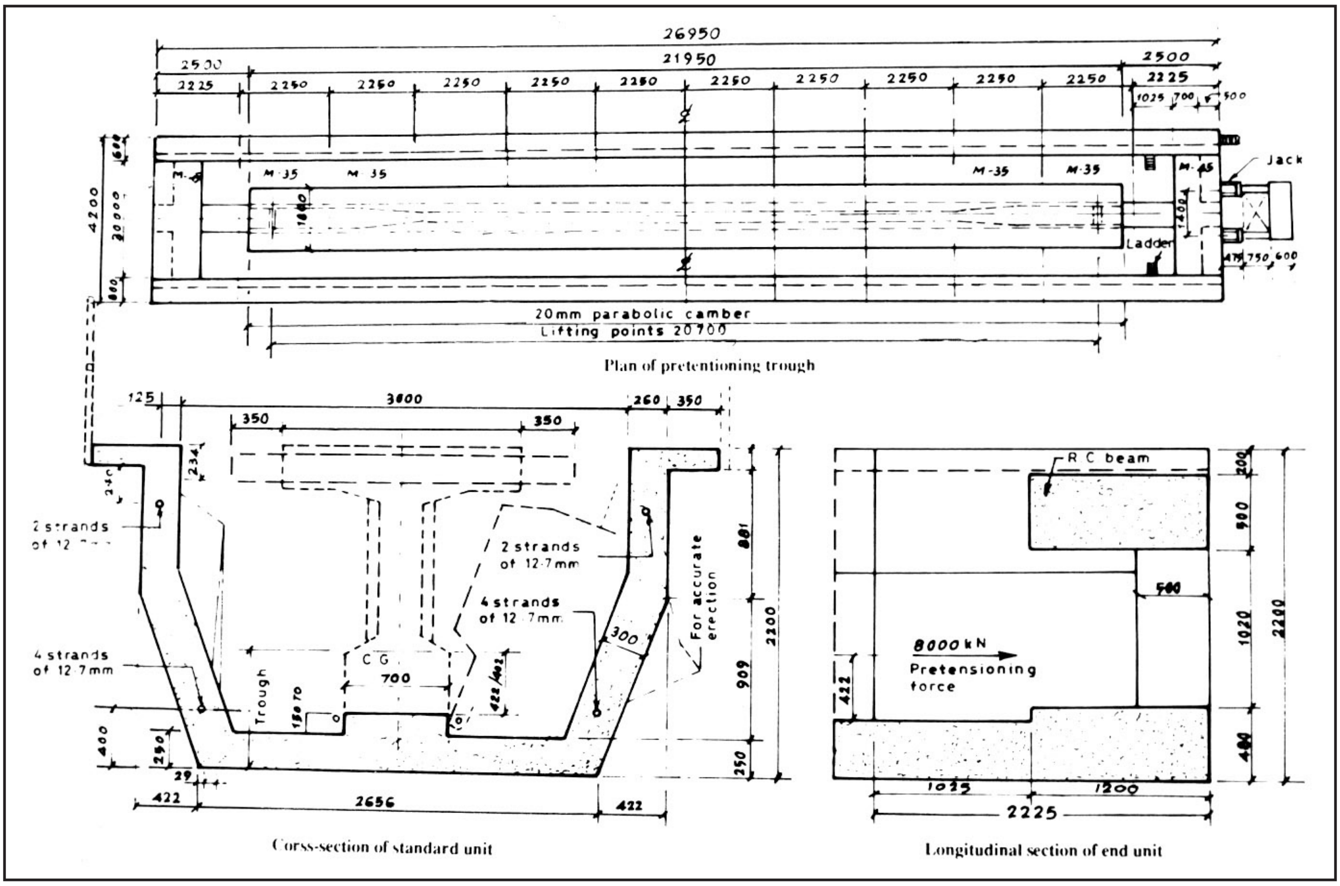


Figure 5. Trough unit for pre-tensioned girder

Innovative design of bridges

The cross-sections of some of the superstructures are indicated in Figures 1 to 4. Standardization of deck system helped Konkan Railway to decide upon the bridge spanning arrangements expeditiously. The design of decking system was optimized by trying out several configurations by using computer analysis wherever necessary. With this it has been possible to achieve considerable economy in construction cost.

To ensure quality workmanship all prestressed concrete girders were required to be precast in a casting yard set up at each site and launched with suitable launching systems. In these cases the provision of cast-in-situ concrete was reduced to a minimum, limiting the same to casting of cantilever extensions to box girders for items 1 and 2 (Table 1), casting of diaphragms for items 3, 5 and 9 and casting of a strip of slab and diaphragms for item 4, Table 1. In case of 12.2-m I'SC girders the deck slab and diaphragms are cast in-situ, basically to avoid expensive launching systems for smaller category of the major bridges. Choice of reinforced concrete T-beam and slab and reinforced concrete slab for 15m and 10m spans is limited to bridges with few spans (for example, road crossings) wherein prestressed concrete work involves much higher costs due to higher overheads. Pretensioned PSC girders of 10m span could not be adopted due to limitations of transportation facility by road.

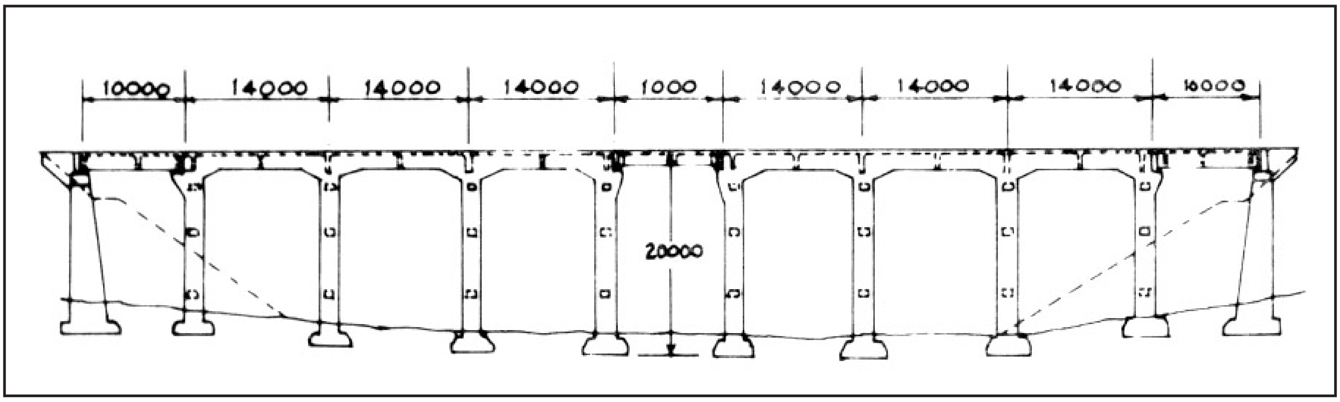


Figure 6. Longitudinal section of framed viaduct

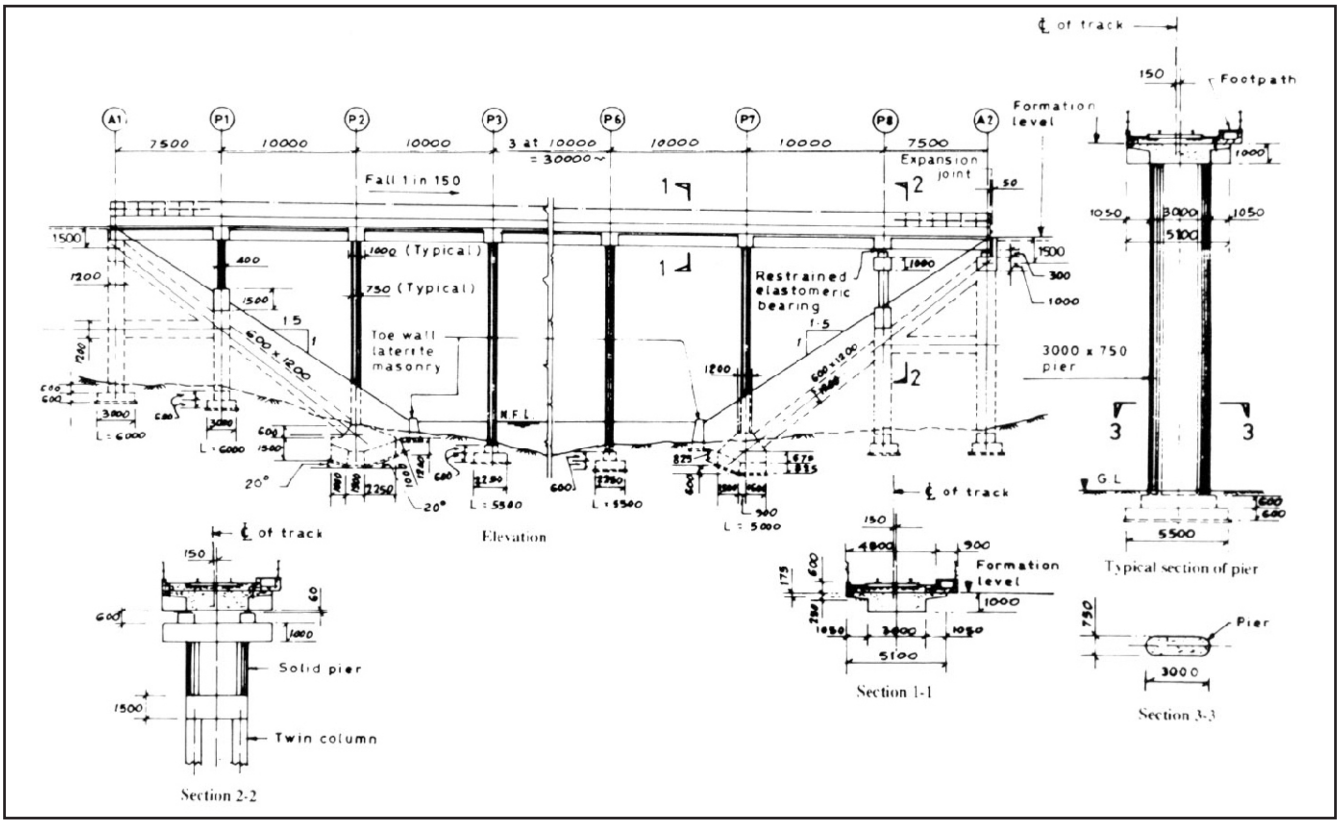


Figure 7. Framed viaduct bridge

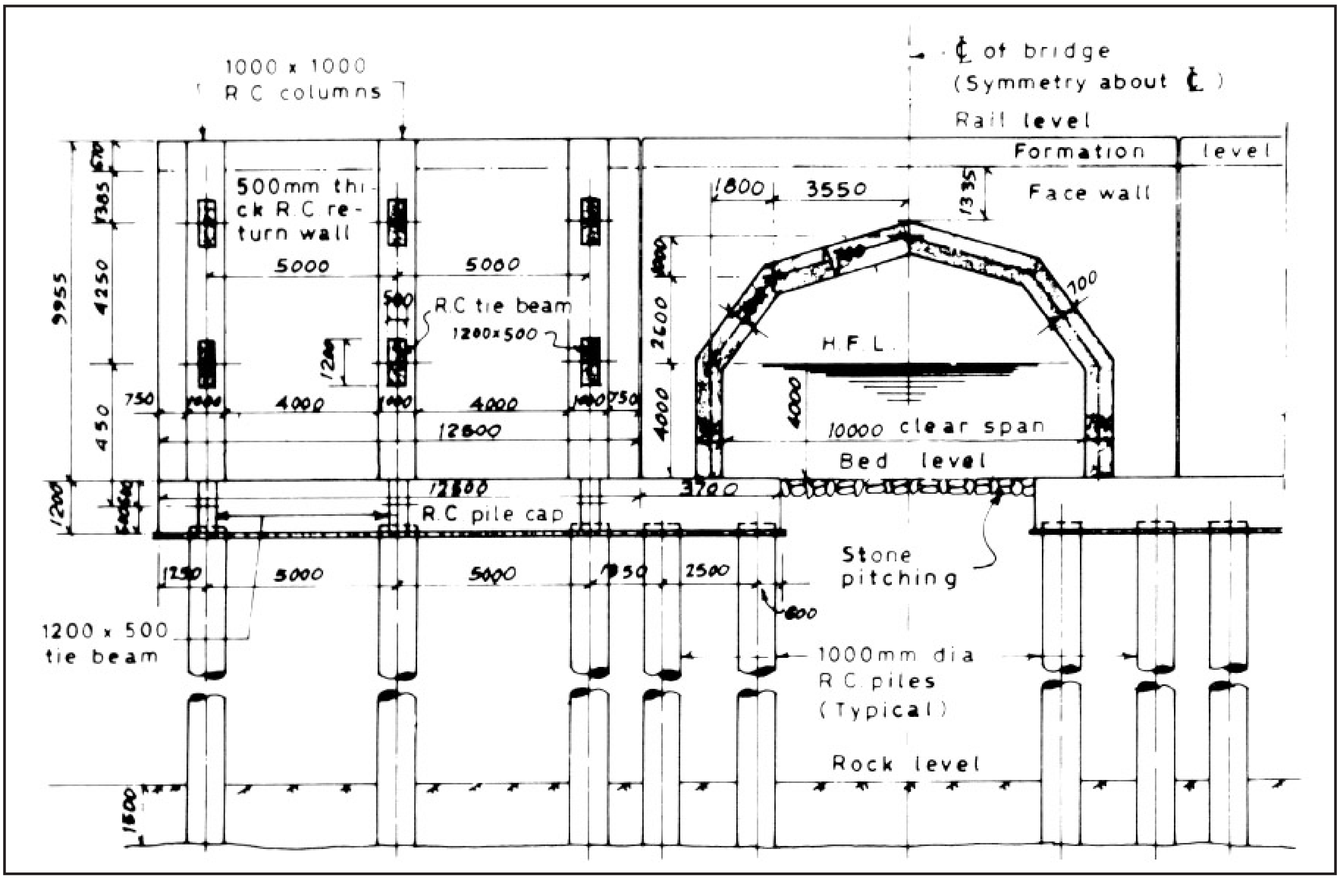


Figure 8. Longitudinal section of a funicular culvert on pile foundations

Table 2. Various type of pier configuration

Sr.No.	Type	Remarks
1.	Twin circular RC columns 1.2m, 1.4m, 1.5m diameter	Upto 16m height
2.	Single circular 1.8m and 2m diameter RC columns with uniform section or flared at top and bottom	Upto 12m height wherever bridges cut the river obliquely and for road crossings
3.	Hollow rectangular RC piers with uniform section 4m x 2.5m x 0.4m wall thickness	For tall viaducts upto 25m height
4.	Hollow circular RC piers 2.8m dimmer x 0.4 m wall thickness	For tall viaducts crossing river streams upto 25m height
5.	I lollow rectangular RC piers uniform section but stepped	For tall viaducts upto 40m height
6.	Hollow rectangular tapered RC piers 4m x 2.5m at top, wall thickness 0.4m and taper along the track direction 1:40	For tall viaducts upto 45m height
7.	Hollow circular tapered RC piers 2.8m diameter at top, wall thickness 0.4m and a tapper of 1 in 40	For tall viaducts crossing river streams upto 45m height

Note : The reinforced concrete piers comprises of M25/M30 grade concrete

Table 3. Criteria for selection of the type of foundation

Type	Strata conditions	Remarks
Open foundations	Wherever hard strata with safe bearing capacity >40 0/m^2 and hard rock is met with at shallower depths (upto 10m in some cases of viaducts where dewatering problem did not exist)	Mostly adopted for bridges and viaducts in Maharashtra area
Pile foundations		
1.0m diameter bored piles	In rivers with perennial flow. Rock depths from 10m to 35m below bed level. Estuarine rivers. (Normally 4 piles/pier)	For river streams with scourable beds
1.2m diameter bored piles	-do-	For river streams with higher scours and longer spans
1.5m diameter bored piles	-do-	Rivers subjected to very high flood levels
Well foundations (RC wells 9m and 11m diameter with wall thickness 0.6m)	Wherever in the river stream hard rock is not available at reasonable depths	Only for 10 locations on Zuari and Mandovi bridges under 53.5m PSC girder and 124m steel girder spans

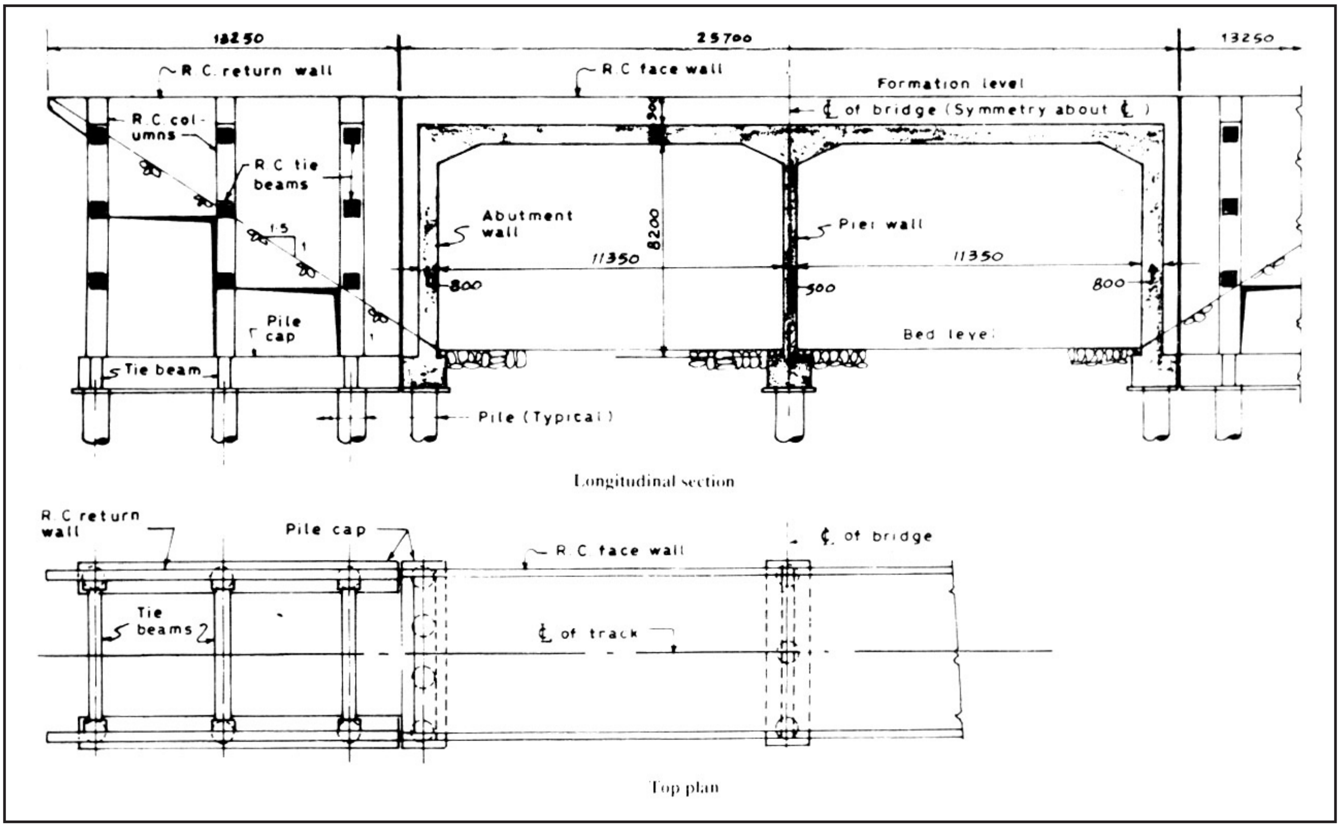


Figure 9. Framed bridge on pile foundations

Pretensioned PSC girders have been adopted for the first time on Indian Railways (item 4, Table 1). Pretensioned girders enhance durability as grouting is completely eliminated. A novel technique is being adopted to produce these girders at site. Casting bed comprises of precast U-shaped RC units each weighing about 1.5 tonnes. Twelve such units are connected by prestress to form a trough and the girder is cast inside this trough. Prestressing cables of the girder which are straight obtain their reaction from this trough itself. After casting of the girder the trough is covered with steel cover plates and entire girder is steam cured; thus the trough acts as a steam curing chamber. A cycle time of 72 hours has been achieved with this arrangement. The trough system is shifted from one site to another on completion of work at the earlier site. Thus the whole system is portable and efficient. Figure 5 shows the details of the same.

Table 4. Salient features of concrete arches

Span, m	Rise, m	Overburden, m	Thuckness of arch rug, mm
3	1.00	2.5 to 15	350
4	1.30	2.5 to 15	400
5	170	2.5 to 15	500
6	2.00	2.5 to 7.5	550
6	2.00	7.5 to 15	600

For launching of precast prestressed concrete box girders, floating cranes (for Zuari, Mandovi and Sharavathi bridges) as well as launching girder (for Kali Nadi, Gad and Shastri bridges) are being used. For other PSC girders use is made of Sicet trolleys, launching girders or lifting frames.

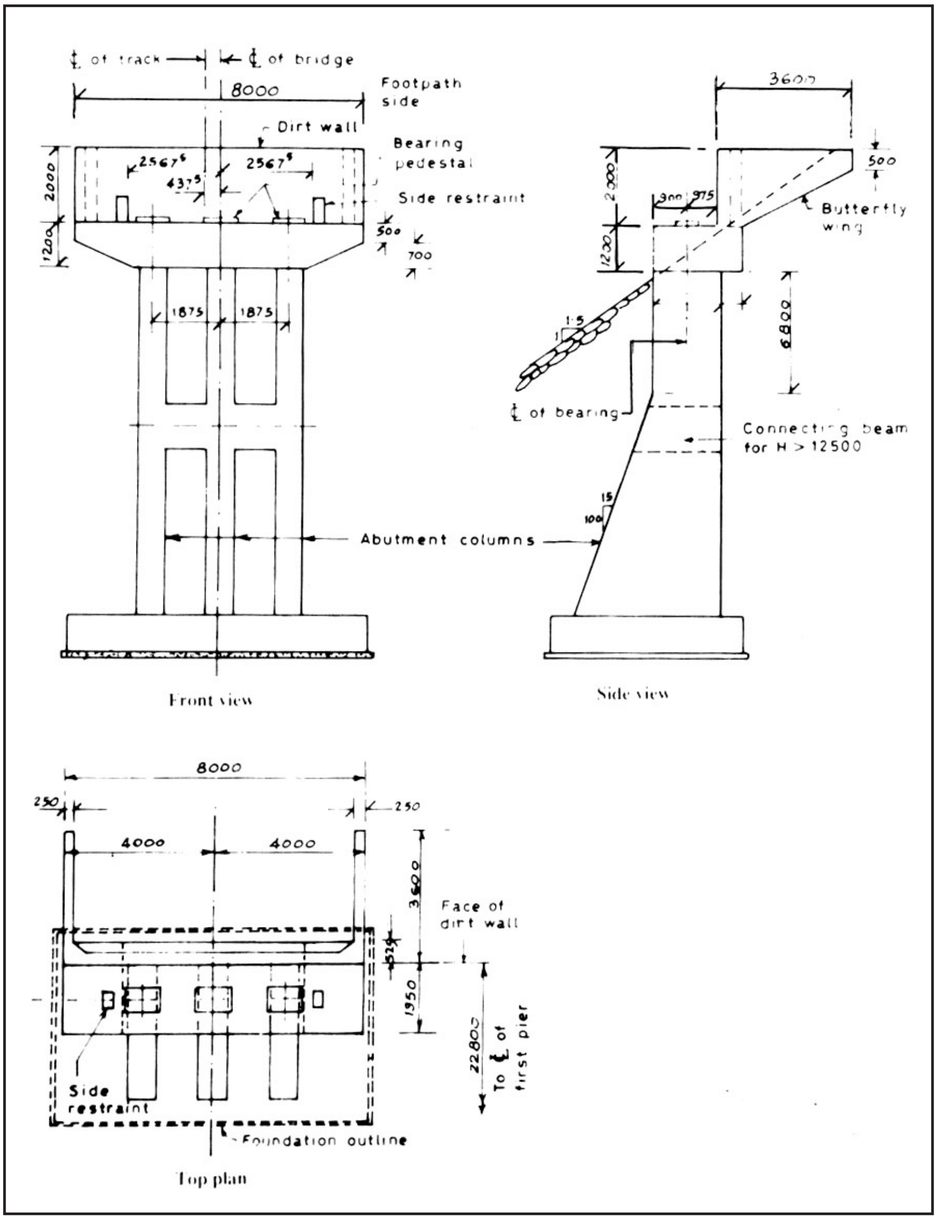


Figure 10. Spill-through type abutment

Precasting the girders has made it possible to speed up the bridge works as works on bridge superstructure and substructure could progress simultaneously.

Framed superstructure

For some tall viaduct bridges founded on hard rock, framed configurations have been tried. Figure 6 and Figure 7 are typical cases of these configurations. These are entirely in reinforced concrete.

These configurations lead to substantial economy in the consumption of materials as the bending moments in the tall piers reduce substantially due to framing of deck with piers. The framing also helps in making the structures more resilient to seismic forces. In areas falling in seismic zone configuration with 1 x 10 m + 3 x 14 m (frame) + 1 x 10 m is adopted to isolate individual frames from each other to take care of out-of-phase earthquake ground motions.

Framing in of abutment with the frame as in Figure 7 helps in reducing the abutment sections and the resultant economy.

These configurations have a great scope for adoption where bridge foundations are laid on hard rock. Overall cost of these schemes work out to 65 percent of the cost of viaducts with simply supported prestressed concrete/reinforced spans.

Framed superstructure on pile foundations - typical solutions

A typical site condition was encountered on Mangalore Udupi section at Br.No 77 which was proposed as 1 x 10 m RC slab with mass concrete abutments and wing walls on open foundations. On detailed soil exploration it became evident that the soil for the first 8 to 10 m depth comprises marine clay with 'N' values varying from 1 to 8. Water table was at ground level. Conventional slab bridge with mass concrete abutments and wing walls would have required 40 piles of 1-m diameter. An innovative solution was adopted with funicular shaped culvert founded on pile foundations and returns which were tied to each other. Figure 8 indicates the scheme.

One more location in Goa sector also presented similar foundation problems as above where 2 x 11.35 m span framed system on pile foundation is being adopted. This configuration required only 23 piles including 12 nos. under the returns which are also tied to each other. Figure 9 indicates the scheme.

Substructure and foundations

Piers

Various types of pier configurations have been adopted based on efficiency and waterway requirements, Table 2.

Above choice of foundations have helped in achieving speedy and economic construction.

For the RC wells at Zuari and Mandovi bridges a new

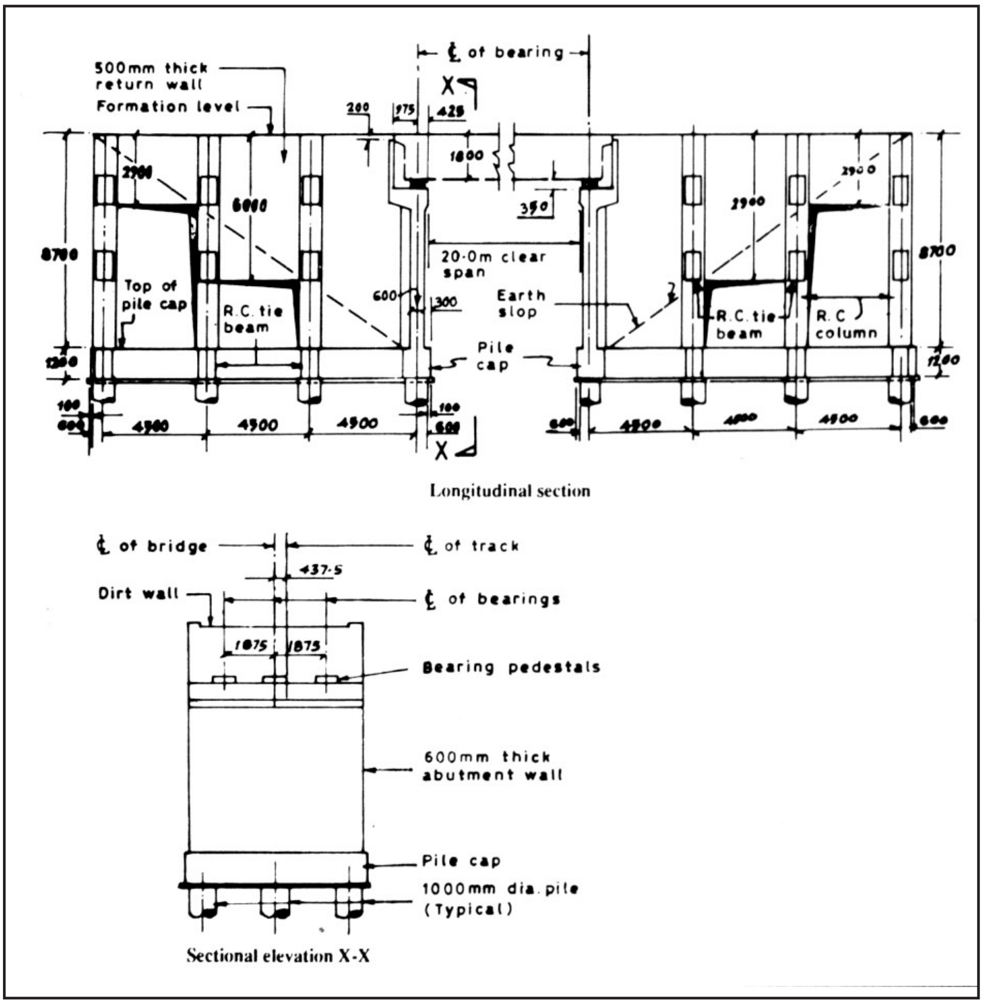


Figure 11. Integrated abutment with box return on piles

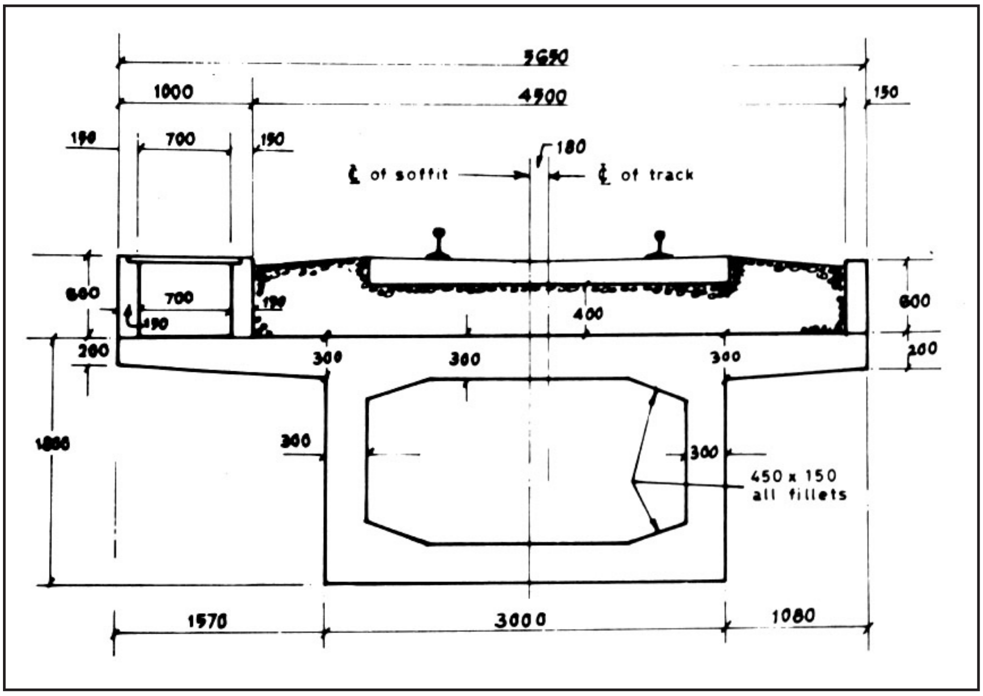


Figure 12. (a) Cross-section for road-under bridge for 26-m span PSC box girder

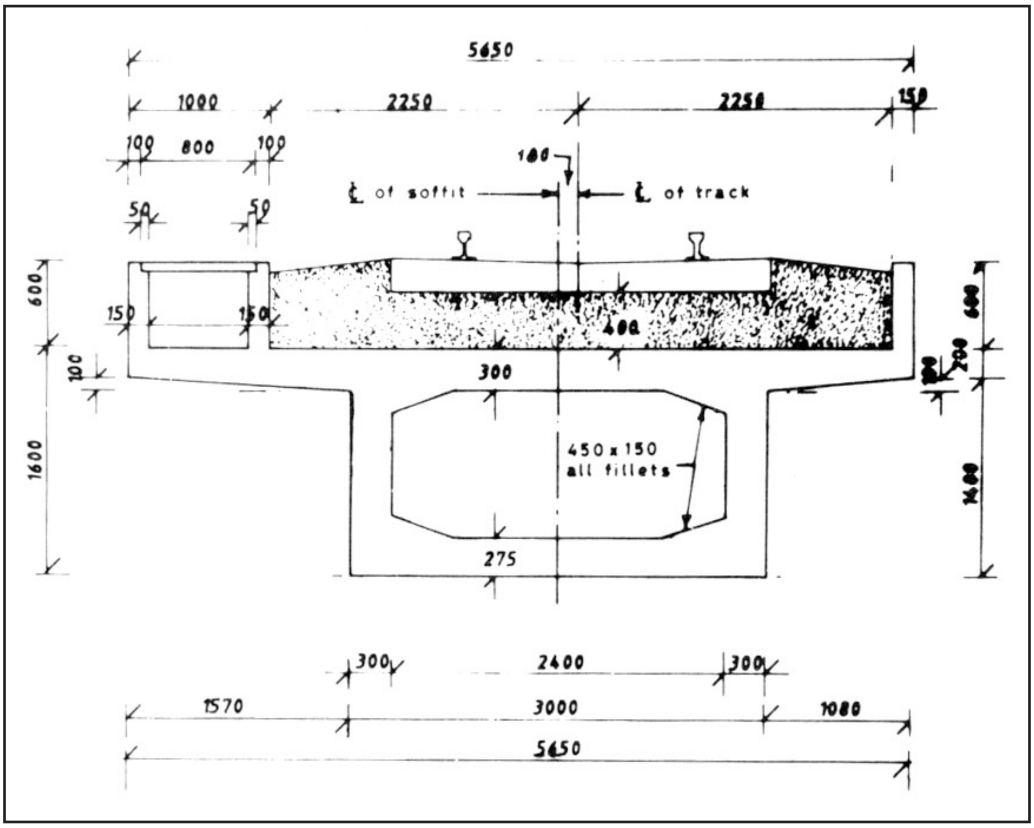


Figure 12. (b) Cross-section for road-under bridge for 26-m span PSC box girder

a few cases this system was adopted for abut ments and returns supported on open foundations as well.

technique is being adopted in which dredging and muck removal is carried out by dredger (Toyo) pumps. Initial experience shows that with this technique well sinking operation becomes simpler and speedy.

Abutments

1. Site conditions at many bridge locations require very tall abutments, with the maximum height being 26m. To achieve economy spill-through abutments with two/three rectangular RC columns were designed (Figure 10). These are founded on open or pile foundations depending on site conditions.
2. Wherever abutments with box type returns were to be supported on pile foundations, a new philosophy of 3-D integrated RC abutment walls and returns with the opposite side returns tied with each other by RC ties was adopted. (Figure 11). This solution has resulted in effecting large saving in pile foundations (reduction in number of piles and even distribution of lateral forces on piles) as well as concrete in walls. In a few cases this system was adopted for abutments and returns supported on open foundations as well.
3. In case of framed RC bridges, spill-through abutments were provided with inclined RC struts connecting the top of abutment columns to the foundation of adjacent piers. This has resulted in the transfer of lateral earth pressure, surcharge pressure and longitudinal forces through the compression in the inclined struts and brought about substantial economy in abutment sections. (Figure 7).

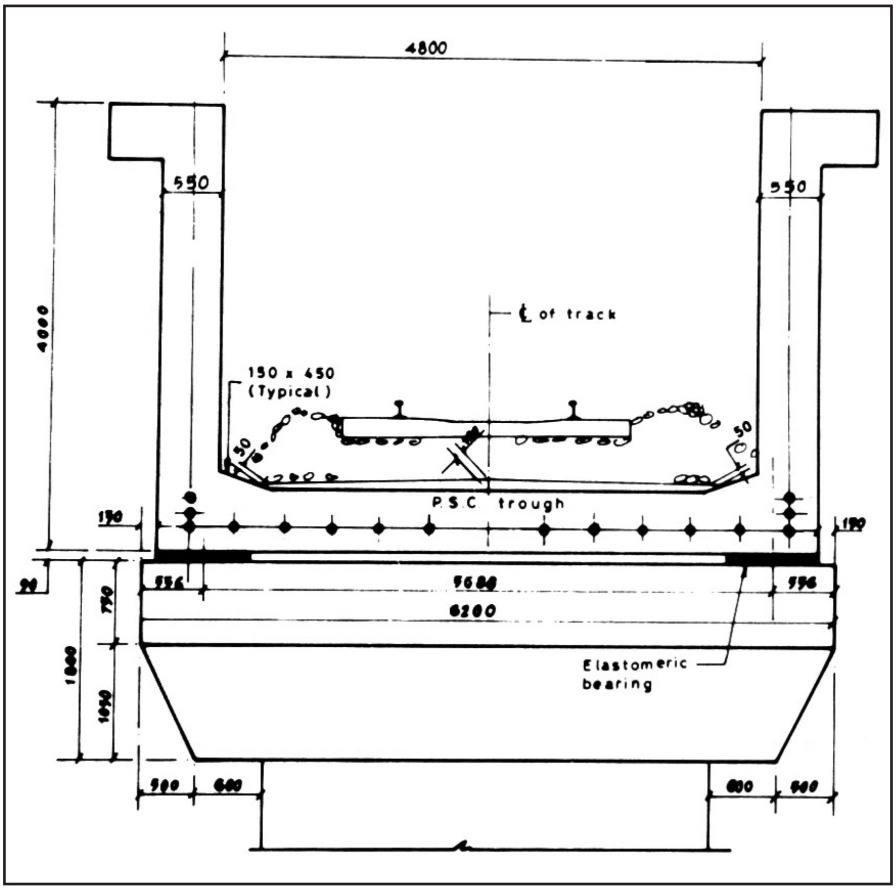


Figure 13. Cross-section of trough girder having 37.46 m overall length

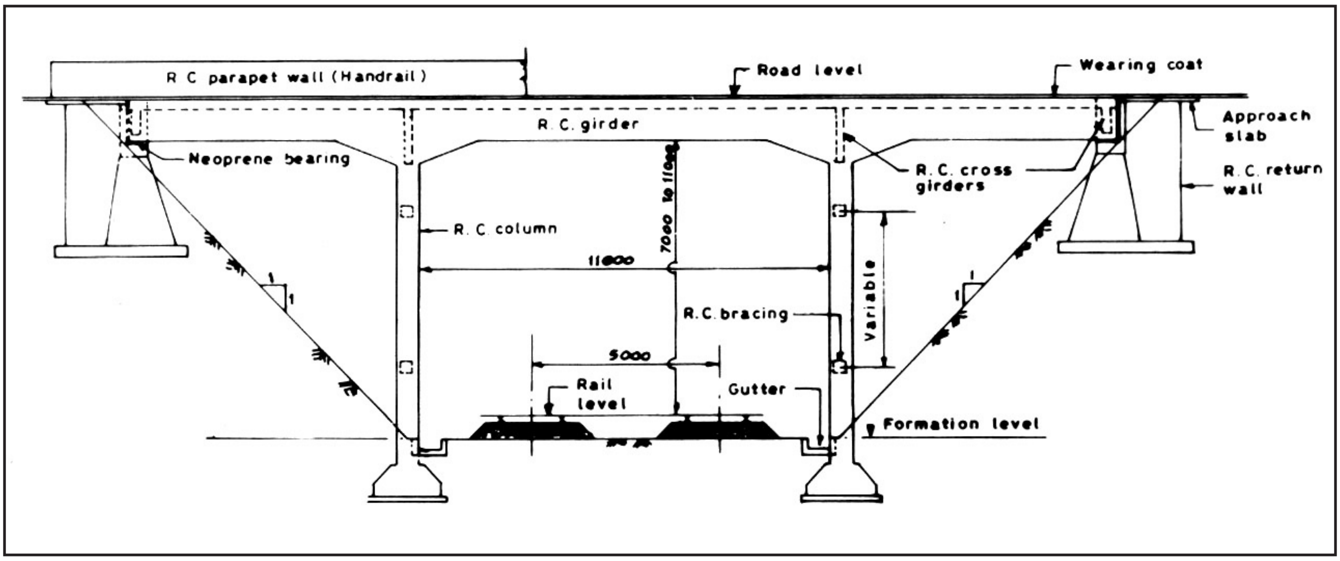


Figure 14. Framed road-over-bridge

Minor bridges

There is a large number of minor bridges with high overburden (small openings in high embankment areas). Here, the first choice is RC pipes of 1.2m and 1.8m diameter. Wherever bigger openings are necessary RC slabs with mass concrete abutments and wing walls as well as RC boxes were adopted, the latter in case of weak foundation strata.

Wherever rock is met with at shallow depths, an optimized design of concrete parabolic arch was evolved, which has proved to be beneficial in terms of savings in quantities of concrete and elimination of reinforcement. Salient features of these arches are given in Table 4.

Road bridges

Road under bridges

At two National Highway crossings PSC post tensioned cast-in-situ girders were laid without diversion of traffic. Cross sections of these box girders are shown in Figure 12a and b. The works on these crossings were completed in a record period of 6 months including monsoons.

At some locations, where high overburden is available, funicular RC frames founded on open foundations are adopted.

PSC trough type superstructure is being adopted for a few NH crossings, where the available construction depths for clearance requirements are limited. (Figure 13)

Road over bridges

Apart from simply supported RC slabs, Tbeam slabs, new designs were evolved for framed road over bridges (ROBs) suitable for locations where track is in cutting and foundations are in hard strata (settlement free). Thelatter results in substantial economy in construction costs. Figure 14 indicates the scheme adopted for these framed ROBs.

Panvel Nadi viaduct

At Panvel Nadi near Ratnagiri the alignment crosses a deep valley. To cross this valley a novel method of incremental launching of PSC box girder is being adopted for the first time in India. The maximum height of piers at this location is 65 m. Bridge configuration is lx30m + 9x40m x30m. Continuous span bridge deck is supported at piers on pot bearings. The 423-m long deck will be fixed to one abutment after launching, thus substantially reducing the longitudinal forces on the piers and bringing commensurate economy in pier design. Piers are hollow octagonal in reinforced concrete with the grade of the concrete being M35 /M30. The wall thickness is 325 mm and the pier is tapered along the height.

Two separate articles on this viaduct are included elsewhere in this issue.

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