Innovative foundations for Zuari and Mandovi bridges

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Construction of foundation is a time-consuming process and hence a critical activity of bridge construction. The article highlights broad features of foundations of three major bridges, namely Mandovi-I, Mandovi-II and Zuari bridges located on the Konkan Railway passing through the state of Goa. It presents a detailed account of sinking pneumatic caissons for the Zuari and Mandovi-I bridges. Use of "Toyo" pumps and cutter assembly for excavation and dredging helped in speeding the construction process.

The Konkan Railway alignment crosses two major rivers - Mandovi and Zuari - in the state of Goa. While the alignment crosses the river Mandovi at two locations, it intercepts the river Zuari only at one location. It is therefore essential to construct three major bridges at these locations.

Based on the hydraulic data and other investigations, the linear waterway requirement for the Zuari bridge is fixed at 987m and that for Mandovi-I and Mandovi- II bridges at 559m and 235m, respectively, Figure 1 .

Both these rivers are important from navigational point of view and sufficient navigational clearances have been provided at each bridge. While two navigational spans of 124m each have been provided for the Zuari bridge, Mandovi-I and Mandovi-II bridges carries one navigational span of 124m and 53.5m, respectively.

Table1 presents salient features of the three bridges.

Choice of foundation

All three bridges are located in the reaches of rivers affected by tidal variations (esturian conditions). In these reaches, the rivers are not prone to floods and therefore deep scours are not expected. However, the river strata at the bridge sites comprised of soft marine clay, dense sand, sandy clay, etc. and weathered rock was encountered at a depth ranging from 10m to 35m below the bed level. Boulderly strata is generally not encountered at these bridge sites. The maximum depth of standing water at bridge locations ranged from 4.5 m to 8.7 m. Considering all these aspects it was decided to adopt a combination of open, pile and well foundations for these bridges, Table 1.

Construction of well foundation is a time-consuming process and hence efforts were made to provide a minimum number of these foundations, which however became obligatory as the depth of standing water is more than 5 to 6 m and the foundations are to support 124-m long steel girders.

Table 1. Salient features of Zuari and Mandovi bridges

Sr. No.	Description	Zuari bridge	Mandovi-I bridge	Mandovi-II bridge
1.	Bridge length, m	987	559	235
2	Span arrangement			
	1. 124 m long steel girder	2	1	-
	2. 53.5 m long PSC box girder	7	6	1
	3. 22.8 m long 'T" girder (3-girder)	16	5	8
3.	Navigation clearance, m			
	1. horizontal	124	124	53.5
	2. vertical (above H.T.L.)	13.7	11.08	8.0
4.	Maximum depth of water, m	8.7	4.5	7.7
5.	Type of foundations			
	1. Piles of 1.2m diameter	14	4	10
	2. Piles of 1.5 m diameter	5	3	-
	3. Caissons W1 type	3	2	-
	4. Caissons W2 type	2	3	-
	5. Open type	2	1	-

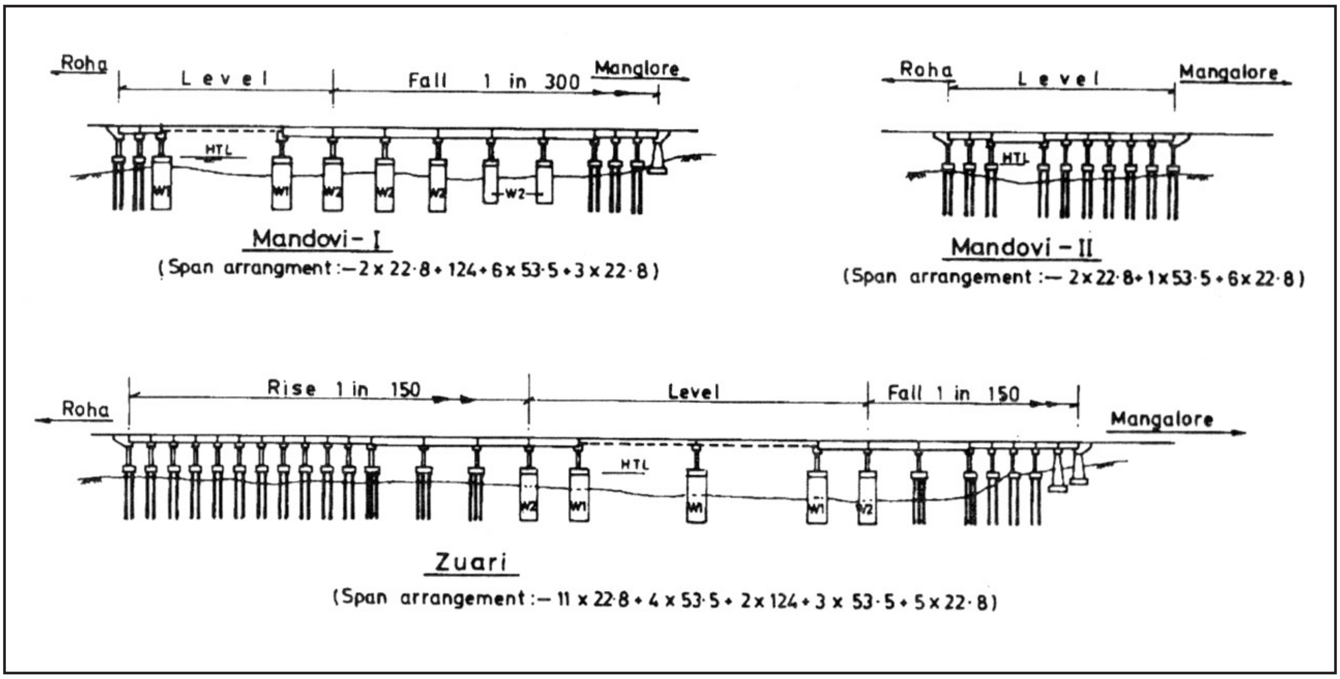

Figure 1. Longitudinal sections of Mandovi-I, Mandovi-II and Zuari bridges in Goa

Figure 1 shows the longitudinal sections of these bridges and it could be seen that wells foundations were provided only in the central gorge portion of Mandovi-I and Zuari bridges (5 Nos each). For a majority of other foundations, piles of 1.2m diameter and 1.5 diameter were adopted. Open foundations were provided for the Mangalore-side abutments of Mandovi-I and Zuari bridges. It may be noted that for the Mandovi-II bridge, only pile foundations were adopted.

Pneumatic caissons

Sinking of wells was envisaged as the critical activity and hence reinforced concrete pneumatic caissons are proposed which are having following distinct advantages over the conventional well sinking method.

1. Self weight of the caisson is less

2. Positional accuracy can be maintained easily during grounding and sinking operations. During the initial stages even the entire caisson can be refloated by providing additional buoyancy collars or increasing air pressure inside of pressure chamber or by reducing the sand ballast.

3. In case of caissons, tilt and shift corrections can be done in a shorter period due to which a relatively higher rate of sinking can be achieved.

4. Steining thickness of caisson being less (600 mm), the volume of concreting is reduced drastically which results in reduction in construction time and saving in cement and steel requirements.

5. Caissons require less sinking efforts since the outer diameter of steining is much less than the pressure chamber diameter and this reduces skin friction. Excavation is possible right upto the cutting edge and speed of excavation and dredging is higher due to use of 'Toyo" pumps and cutter assembly. The provision of the latter arrangement is a special feature of the construction activity at these bridge sites. This results in higher rate of progress.

6. The founding level strata can be thoroughly inspected before bottom plugging as the working chamber can be made dry by air pressure.

7. Bottom plugging of the well is done always under dry conditions by using pumped concrete and hence quality of concrete can be ensured.

8. Positive air pressure is maintained inside the pressure chamber. Therefore, chances of sand blowing are minimised and working inside pressure chamber is always safe.

Sequence of construction

Precasting, launching and grounding of caisson

There are two types of RC pneumatic caissons, namely W1 type and W2 type. While in W1 type, the pressure chamber of outer diameter is 11m and steining diameter is 9.5m in respect of W2 type, the corresponding figures are 9.5 m and 8.0 m, respectively.

The RC working (pressure) chamber of caisson is cast on a submersible dock barge in one continuous pour using M30 grade concrete. Thereafter 3-m high RC steining is cast. Once the bulkhead slab shuttering is removed, the dredge pump unit consisting of 'Toyo" pump with cutters along with the rotation frame is installed with all accessories in the working chamber. The pressure chamber is then sealed and tested for leakage. Simultaneously, buoyancy tanks are fixed around

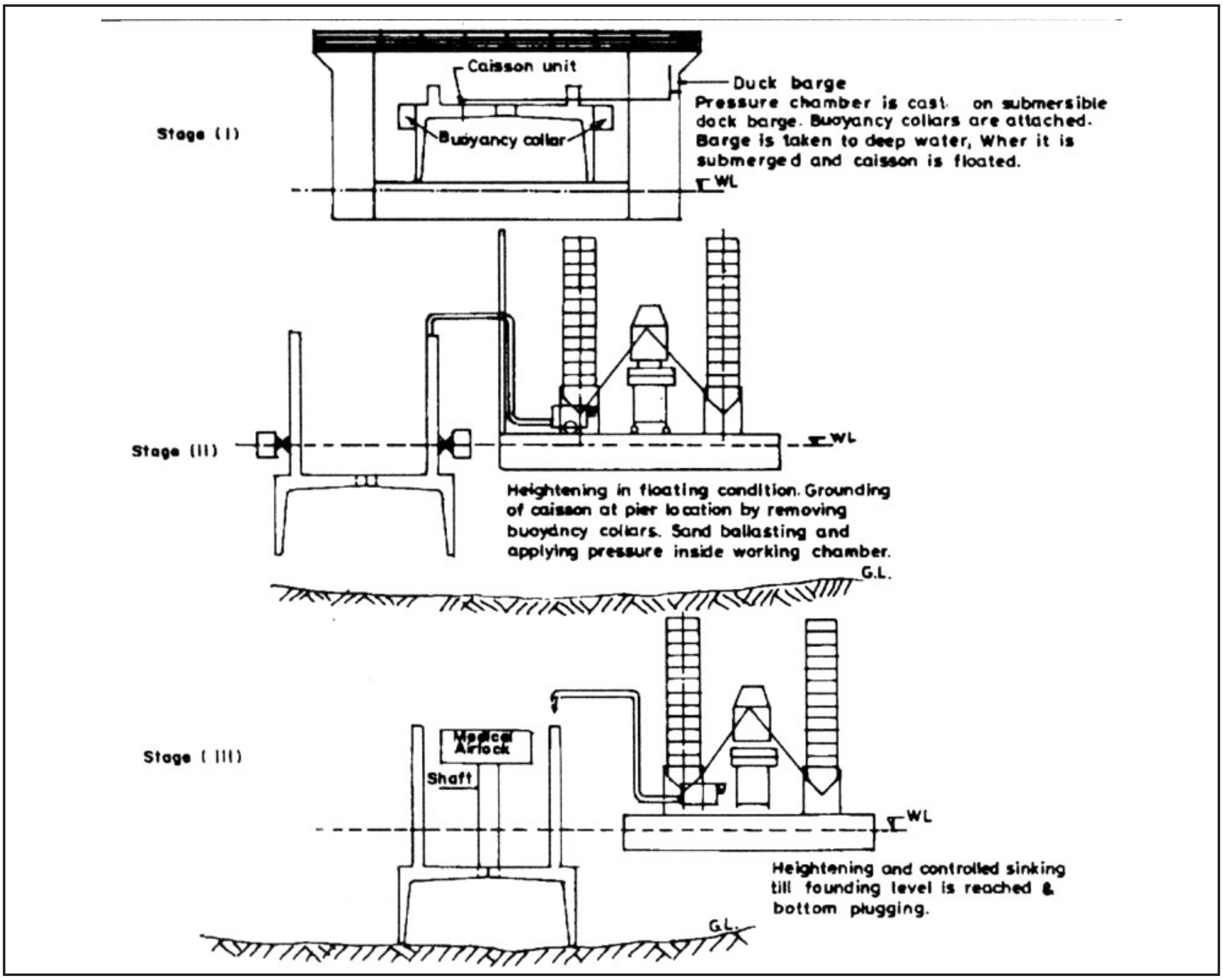

Figure 2. Sequence of pneumatic sinking operation

pressure chamber to provide additional buoyancy for stability. The caisson is now ready for floating.

The submersible dock barge is towed close to the location of pier where sufficient draft is available. Dock barge which contains a number of independent water tight compartments and in which water can be taken in by opening sluice valves in a chronological order, is submerged uniformly. The caisson starts floating when it attains the full draft and at this stage submersible dock barge is released. The total cycle time is 33 days from cleaning of submersible dock barge upto launching of caisson.

Floating caisson is towed to desired pier location and is anchored with four marine anchors. Further raising of the steining height is done in stages depending upon the bed level and water depth at pier location. At each stage of concreting the lift of floating caisson is checked to avoid overtopping. When requisite height of steining is achieved accurate survey is done to position the caisson correctly at pier location by using "One second" theodolite and EDM.

Sinking

Figure 2 shows the sequence of pneumatic sinking operations. Shaft pipes are fixed and an air lock assembly is installed. The workers enter the working chamber through the air lock and shaft pipes to commence sinking operation. The operator sits in a cabin and controls position and direction of excavation by moving the 'Toyo" unit inside the pressure chamber. In case of W1 type of wells 'Toyo" pump will be operated by remote control mechanism by an operator working inside a separate cabin provided in the working chamber at normal pressure. In W2 type of wells the "Toyo" pump will be operated by the operator by sitting in the main chamber itself at high working pressure.

The operator moves the "Toyo" pump inside the pressure chamber and cutters disturb the soil around it and soil water slurry is pumped out by the pump into hopper barge which is then taken to suitable location for dumping the dredged material. There is constant communication between the operator working inside the pressure chamber and the outside supervisors. Continuous monitoring of the position of caisson for lift and shift is done using theodolite and EDMs. For

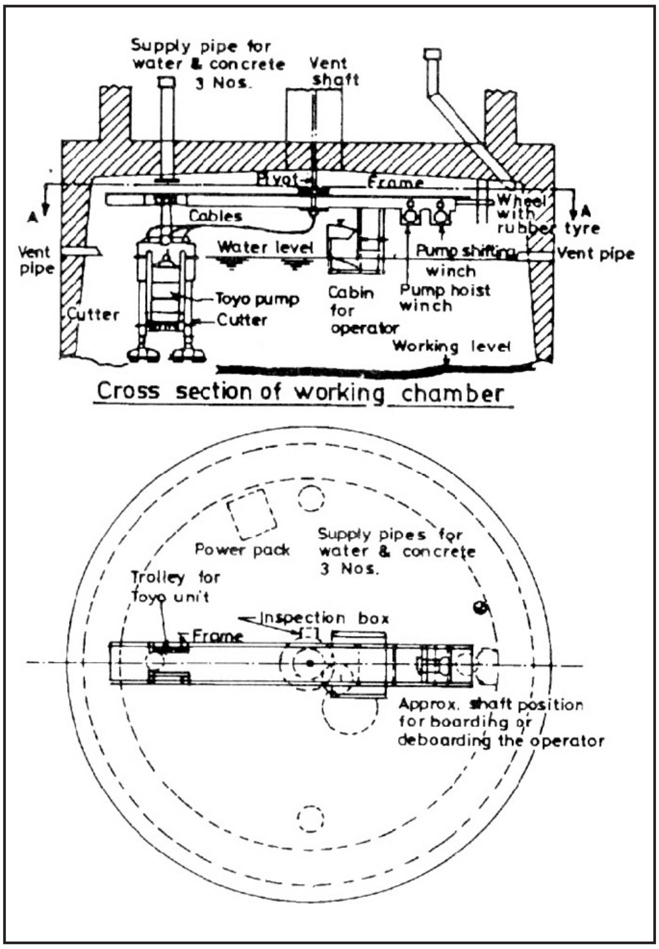

Figure 3. General arrangement of "Teroyo" pump and accessories inside working chamber

rectification of tilt, the excavation is done below the cutting edge higher side and the outer side is supported on props which are erected firmly between bulkhead slab and wooden planks below. The number of props to be provided depend upon the weight of caissons. Once decompression is done props hold the caisson and outer side sinks and the caisson tilts upto desired limits. Figure 3 shows a general arrangement of "Toyo" pump and accessories inside the working chamber.

Whenever hard strata obstructions are met with jack hammers are used and excavated materials are either broken into pieces and taken out by "Toyo" pump or dredged material is taken out through shaft. High pressure water jetting through nozzles is also restored to dislodge hard strata including stiff clay. After excavation the caisson is sunk, 40 to 50 cm at a the time. This is done in a controlled manner by reducing the air pressure in the working chamber. Due to decompression the downward weight increases and caisson sinks upto the excavated depth. Sand ballast is added to increase the downward weight of caisson to facilitate the sinking operation.

Simultaneously, the steining height is increased in stages of 2.0 m and air lock is shifted upward by adding more pipes. An average sinking of 2m per week is achieved by this method.

Once the founding level is reached the strata is thoroughly inspected by engineers by going inside the pressure chamber in dry condition. Figure 4 shows a view of the caisson sinking for pier No. P-14 for the Zuari bridge.

Bottom plug

After reaching the founding level the dredge pump is dismantled and taken out through shaft pipes and air lock. Bottom plug concreting is done with floating batching plant using concrete pumps through openings provided in the bulkhead slab. Since the chamber is pressurised concreting is done in dry condition. Thus, good quality concrete is ensured in the bottom plug.

The air pressure is maintained for a day or so till concrete has stiffened. Now air locks and shaft pipes are removed and inside of steining is filled with ballast and further work of top plug and well cap is completed.

Plant and machinery

Following important plants and machinery are required during sinking.

1. A personnel-cum-material air lock connected with the shaft pipe to the pressure chamber to facilitate passage of men and materials from atmospheric pressure to working pressure inside the working chamber and vice-versa.

2. Floating machine station having oil-free air compressor with stand-by compressor and air receiving tank in case of failure of compressor to supply purified, dry and regulated compressed air to personnel working in air lock and pressure chamber. Also generators are provided on this machine station for running compressors. "Toyo" pumps and accessories are procured for generally lighting.

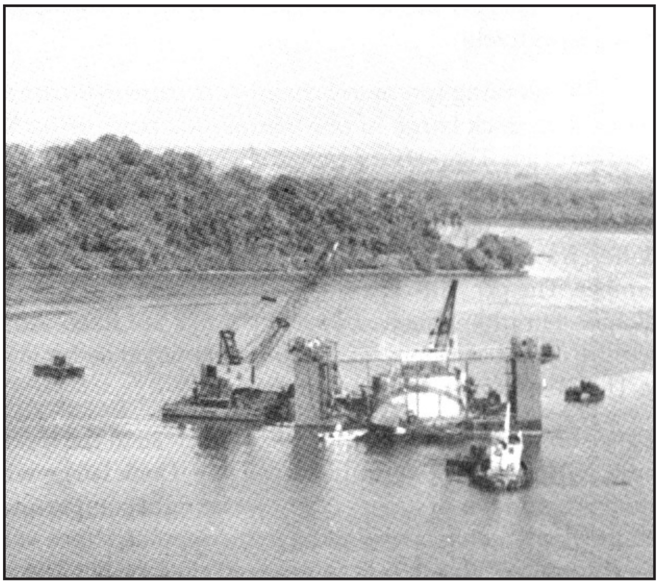

Figure 4. A view showing sinking of caisson in progress for the Zuari bridge

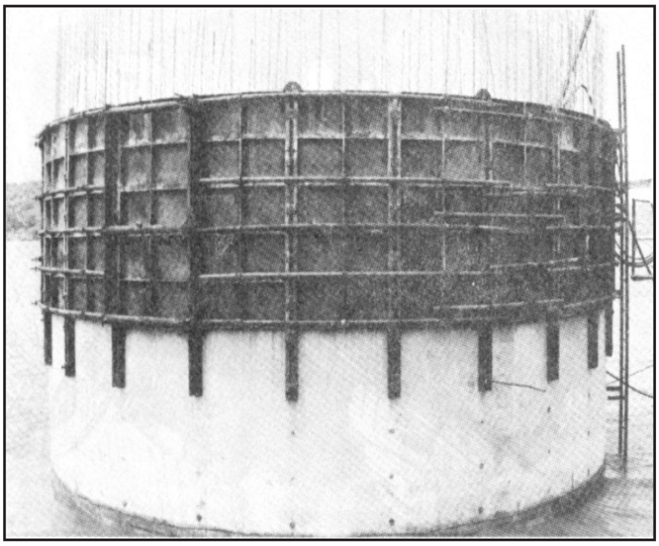

Figure 5. Extending the steining height of caisson at Zuari bridge

3. Floating automatic batching plant equipped with concrete pump and derrick for handling hose for pump concrete.

4. Floating cranes for installing and shifting of formwork, air lock shaft pipes and fixing and removing of sand ballasting and for removal of dredged material from bucket.

Quality control

A field laboratory is set up at site for routine material testing of various materials including cube testing and permeability testing for concrete. Other specialised tests for quality control are conducted by a reputed material testing laboratory. Apart from this a separate quality surveillance team engaged by KRCL ensures the quality assurance system at every stage of execution.

Project monitoring

All planning and project monitoring is done using PRISM software program. Progress monitoring, documentation of various activity, preparation of drawings are also done using various available computer software programs.

Safety measures

1. Medical aid is available at short notice to provide help for men suffering from compressed air disease. Physical fitness of staff working in the air lock is checked before they enter into working chamber. A well equipped medical centre with full-time medical attendant is available.

2. A gas detector is used to ascertain the presence of inflammable gases.

3. Well-maintained communication system between working chamber and outside supervisors is provided for monitoring sinking operations.

4. Direct current, low voltage lighting system is provided inside the airlock shaft pipe and working chamber to avoid electrical hazards.

5. Earth leakage circuit breakers are connected to the 'Toyo" pumps and cutter circuits.

6. All air-locks and air receiving tanks are provided with suitable air safety, air-release valves and pressure monitoring gauges.

7. Fire extinguishers are installed in caissons and floating machine stations.

Cost

The cost of Zuari bridge is estimated to be Rs 26.77 crores and that of Mandovi I and II to be Rs 21.0 crores.

Conclusion

RC pneumatic caisson with controlled sinking arrangements ensure faster execution, better quality control and safe working conditions for workers inside the pressure chamber. Use of 'Toyo" pumps for removal of muck reduces the manual intervention to the minimum, thus improving safety. The entire procedure also speeds up the sinking process.

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