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# Fenders for the Zuari Bridge in Goa

## Défenses pour le pont de la Zuari à Goa

## Stoßfänger für die Zuari-Brücke in Goa


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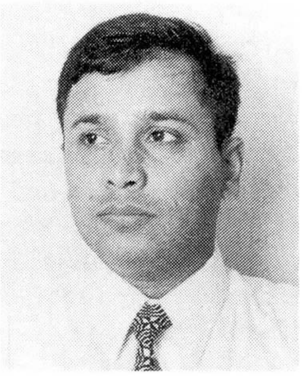
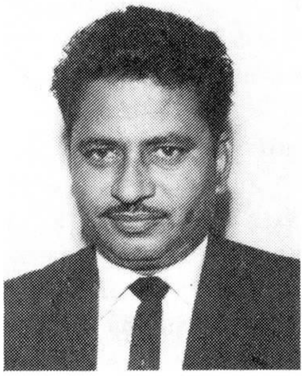


Haridas, born 1940, got his Civil Engineering degree at the University of Bombay. He has been actively associated with the design of civil engineering structures such as bridges, hydraulic structures and industrial structures. He has been responsible for the design of prestressed concrete fertilizer silos, long-span cantilever bridges including Zuari Bridge.



Hiranandani, born 1927, got his Diploma in Mechanical Engineering from Karachi. For the first 14 years he worked with a Partnership firm of Hochtief, Germany and was working at Kandla Project, dealing mainly with foundation work. Joined Gammons in 1963 and has been working on various prestigeous projects and is at present posted in Goa.


**SUMMARY**

This papers describes the design and construction of the bridge across the river Zuari in Goa, a Union Territory of India. This prestressed concrete long-span bridge was an urgent need of the area as there was no through road communication to Panjim - the capital and Margao - the commercial city of the territory. The only available mode of communication, viz. ferry crossing of the heavy road traffic with loaded trucks was dangerous as it had to negotiate the river plying with heavily loaded ore - barges. The paper highlights the fendering system provided for the bridge, and which is a novelty of its kind and has been adopted for the first time in India.

**RÉSUMÉ**

L'article décrit la conception et la construction du pont sur la rivière Zuari dans le territoire de Goa, en Inde. Ce pont, en béton précontraint et d'une grande portée, était vital car il n'existait aucun axe routier de pénétration allant jusqu'à Panjim, la capitale, et jusqu'à Margao, le centre commercial du territoire. Le seul moyen de communication possible, c'est-à-dire le passage en bac de l'importante circulation routière constituée de poids lourds, présentait des dangers car il empruntait la rivière encombrée de péniches. L'étude met en lumière le système de défenses conçu pour le pont, système d'un type original adopté pour la première fois en Inde.

**ZUSAMMENFASSUNG**

Der Artikel beschreibt den Entwurf und die Konstruktion der Straßenhochbrücke über den Zuari-Fluß in Goa, einer Provinz in Indien. Diese vorgespannte Betonbrücke mit langer Spannweite wurde dringend benötigt, da es keine durchgehende Straßenverbindung nach Panjim, der Haupstadt, und nach Margao, dem Handelszentrum der Provinz, gab. Die einzige Verbindung, eine Fähre für den schweren Straßenverkehr mit beladenen LKWs, mußte den Fluß mit schwer beladenen Erzkähnen teilen. Der Artikel stellt das Stoßfängersystem für die Brücke dar, das eine Neuheit auf diesem Gebiet darstellt und erstmals in Indien eingesetzt wird.

## 1. THE TERMS OF REFERENCE

### 1.1 Location

Goa, a Union Territory on the West Coastal of India is a picturesque land strewn with silvery beaches, palmfringed coastal line, green paddy fields and a virdant land of natural resources, famous churches and ancient temples and populated by simple joe de vivre people with harmoneous blend of Hindu and Western cultural. The area has become a great tourist attraction with people coming from all over the world to enjoy sunbathing and eating savory, hot Goan sea foods. This land is cut across by two rivers viz. Mandovi and Zuari whose hinderland is famous for iron ore. The river Zuari separates Panjim its capital with Margao the commercial city of Goa, leaving no through road communication thereby forcing ferry services for moving the traffic across the river. Exporting iron ore demands barge traffic for transportation upto Maramgao Port as easiest and economically more viable proposition. The river has, therefore, a very heavy navigational traffic both along and across the river plying with heavily ore - laiden barges upto 1000 tonne displacement as also the ferry traffic carrying loaded trucks and transport vehicles. With the industrial boom in the area and rising tourist traffic for the users of the road, ferry crossing has become increasingly hazardous in a river where loaded barges are plying day in and day out all throughout the year. A high level road bridge which could allow the navigational traffic of ore - carrying barges to pass underneath was therefore the pressing need of the day.

### 1.2 Planning

The bridge presently under construction caters for two numbers of navigational traffic lanes each of 55.0 M with 13.70 M clear head room above the highest tide level of R.L + 2.80 M, one for upstream and one for downstream traffic. The bed level of the river in the navigational channel is around R.L. - 6.70 M at the deepest portion. Though the river flow is affected by tidal variations because of sandy strata met at the location, a scour upto R.L. - 20.00 M has been estimated based on the velocity of current during the monsoon floods, once the bridge foundations are executed.

The navigational traffic lanes demanded a long span prestressed concrete bridge, with caisson foundations to sustain the effect of impact due to accidental collision of barges during the adverse monsoon conditions and night traffic under poor visibility. To protect the foundations and thus the bridge, a positive system of fendering arrangement was a necessity.

## 2. GENERAL ARRANGEMENT

### 2.1 Layout

The final proposal accepted for the bridge has an overall length of 807 M consisting of 627 M length of main bridge over the river portion and a viaduct of 180 M on the land portion of the Agacium bank. The main bridge has been provided with four intermediate spans of 122 M each and two end spans of 69.5 M, and the viaduct portion has five spans of 36.00 M each. The bridge caters for a 7.5 M clear roadway and 1.5 M wide footpath on either side with arrange ments to carry 150 mm dia. water pipe lines, telephone lines and electrical cables for lighting the bridge.

The central two spans ensure main traffic while adjacent spans light river traffic. Though the span arrangement and the deck structure (see figure 1) provides sufficient clearances for such navigational traffic, the central 488 M portion of the main bridge deck has a vertical curvature with end spans provided with a 2.5 percent gradient which continues over the viaduct portion as well.

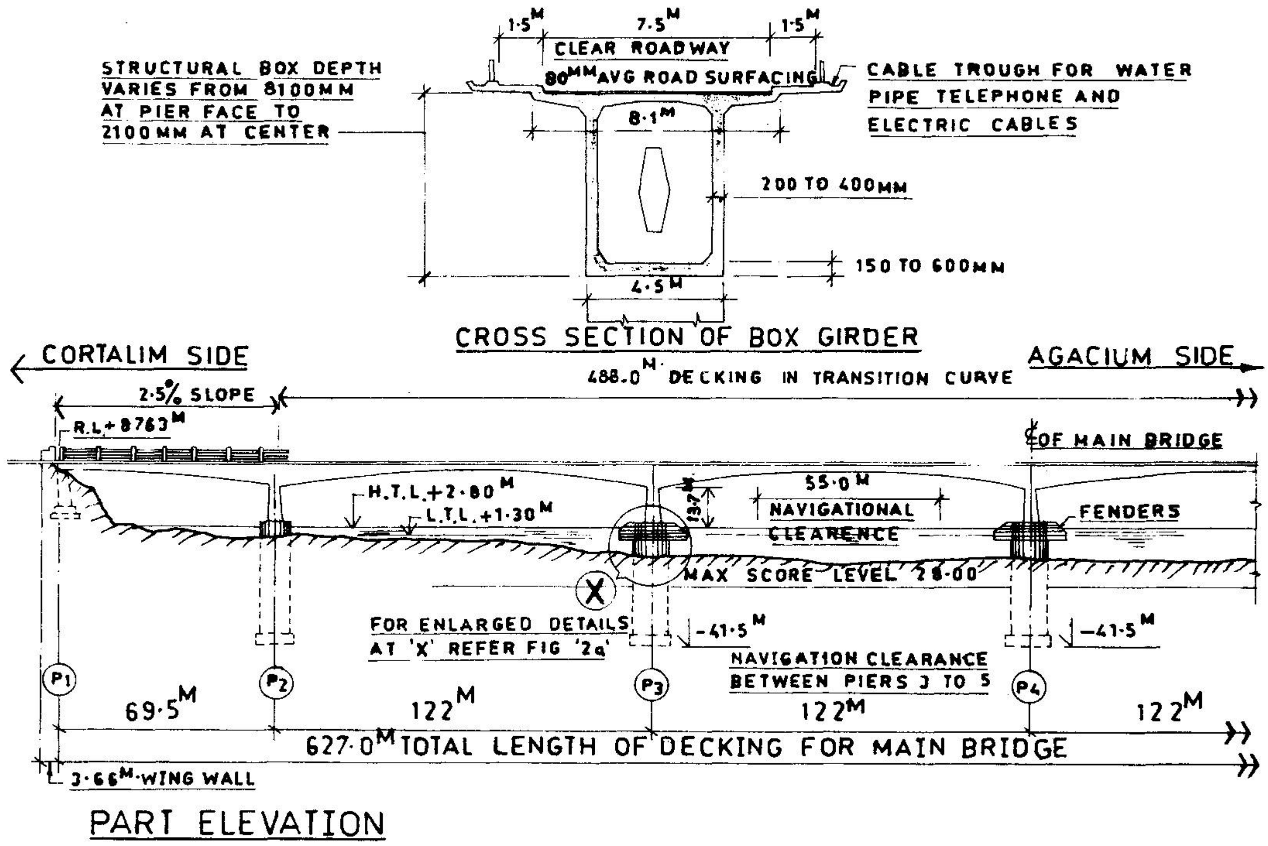



Fig. 1 Zuari Bridge in Goa. General Arrangement

## 2.2 Superstructure

The superstructure of the main bridge consists of a single cellular prestressed concrete box of overall width of 4.5 M over the webs and 8.1 M at the deck level and has a variable depth ranging from 8.1 M at the pier face to 2.15 M at the mid span, where the mating cantilever arms have been connected through cast steel pendulum bearings. The end cantilever arms support reinforced concrete twin girder decking of 19.5 M each. The box deck is cast-in-situ in segments by cantilever construction system using travelling gantries. The viaduct portion has a box deck with an uniform depth of 2.15 M. The prestressing force is generated by Freyssinet 2 -12 ∅ 7 mm H.T. cables stressed simultaneously from either side.

The foundations of the main bridge having fenders, consist of single cellular reinforced concrete caissons of about 39 M depth, with a minimum grip length of 21.5 M below the worst anticipated scour level of R.L. - 20.0 M. The caissons have an external diameterof 9.45 M and a thickness of 1.2 M at the top which is increased to 1.425 M below the scour level. The cellular reinforced concrete piers are monolithic with the superstructure and have rectangular shape at top widening to octagonal at the base so as to sit squarely on the caisson shell below.

## 2.3 Fenders

The ore laiden barges are likely to collide head on with the pier in adverse weather. This called for a system which besides withstanding the impact would protect the bridge foundations and still be available for rectification for subsequent use. In the scourable river, sheet pile fendering was found to be unsuitable; besides, if provided would demand heavy maintainance expenditure due to aggressive corrosive atmosphere prevailing. Reinforced concrete fenders were therefore accepted as a better proposition.

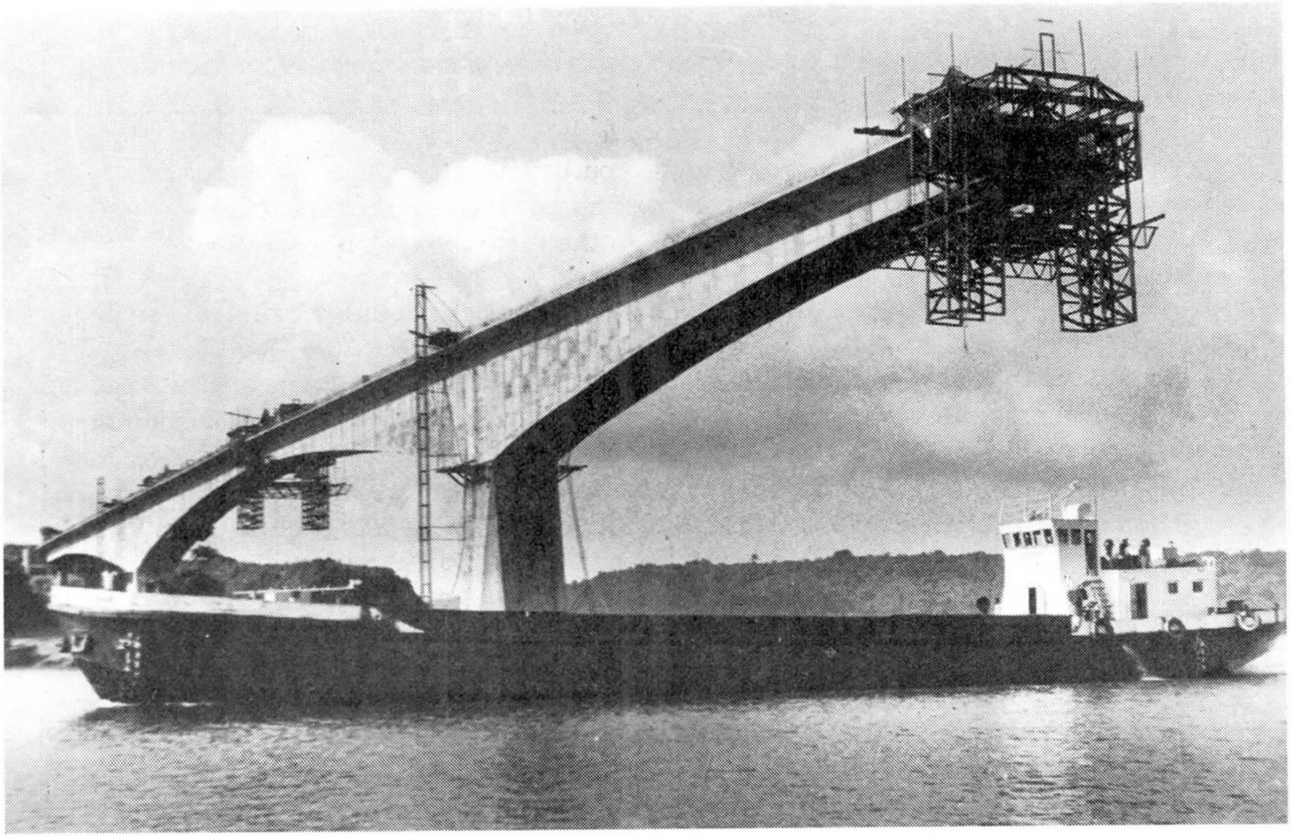
# 3. DESIGN CONSIDERATION

## 3.1 Design Data

The barges upto 1000 tonnes displacement (see photograph 1) are expected to ply downstream at 6 knots (3.2 M/sec. absolute) in the river flowing at a velocity of 1.8 M/sec. The fenders are, therefore, required to sustain a static force due to impact of these barges when they collide head on at H.T.L.

The particulars of barges plying are as under :

| | | |
|---|---|---|
| Displacement weight | : | 1000 tonne |
| Length of the barge | : | 44.2 M |
| Breadth of the barge | : | 10.0 M |
| Depth of the barge | : | 2.5 M |
| Draft | : | 2.1 M |
| Thickness of plates of the barge | : | 12 MM |



Photograph 1: Showing empty barge plying upstream of the river with superstructure behind under construction.

### 3.2 General Scheme

It was felt desirable to plan the fendering system on the basis of two considerations :

(a) Psychologically - by devicing a system which would deter the captain of the barge from head on collision for the fear of destroying of the barge itself.

(b) Technically - by designing the fender in such a way that it would transfer least amount of force to the foundations and be capable of rectification if disturbed.

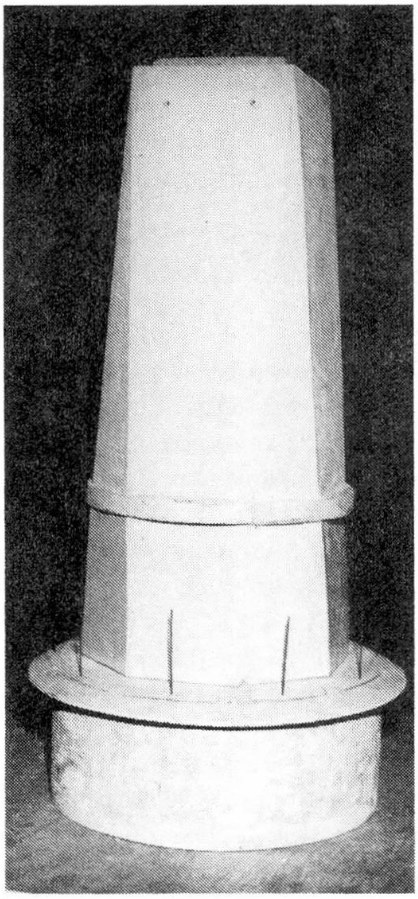
The scheme envisaged provision of ten vertical fins stiffened by four horizontal diaphragms projecting from cellular cofferdam type protective fender wall (see figure 2). The outline of the fins is so shaped and the diaphragms so placed that hull of a normal barge would collide on a larger area of fins or on two or more diaphragms simultaneous. It is envisaged that these concrete fins covered with steel armour plate at the tips would penetrate a colliding barge and tear its plate thus bring the barge to rest by dissipation of energy. To ensure only a reduced impact force is transferred to the foundations, the fender was also made discontinuous from the caisson foundation, so that, in the event of the barge collision the fender as well as the barge would move a certain distance, before the projecting portion of the fin(s) below R.L. - 1.30 M would abut against the caisson (or well) cap and stop further movement. The friction force generated between the sliding surfaces is expected to absorb most of the energy. The fender walls have been provided with 8 - 100 mm dia. holes for lifting the entire fender work from the pier head above for repairs in case of major damage. The pins provided along the inner periphery are expected to help guide down the fender during lowering once the rectification is over (see photographs 2 to 4) to ensure even seating over the match-cast surface of the cap. These pins project only 150 mm above the collar just enough for handling (the pins seen in the photograph Nos. 2 and 3 are only for identification) and would also the sharing some quantum of horizontal force incidentally.

### 3.3 Final Proposal

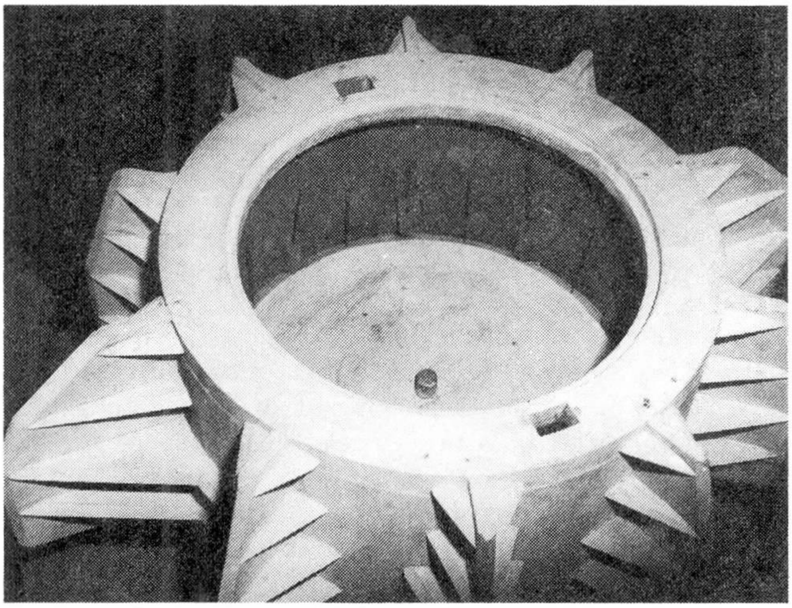
Original scheme envisaged supporting the fenders on the sloping portion of the well cap (see photograph 2) which projects beyond the outer face of caisson. This was subsequently made horizontal as the construction scheme involved casting of the fender wall before final sinking of the caisson. Besides, the construction of sloping cap to line and level would have posed difficulty. The fender wall (see figure 2) was cast-in-situ on two layers of tarfelt to ensure water tightness for permitting casting of pier in dry condition later on, once the caisson is sunk to final depth and plugged. The reinforced concrete diaphragms are adequately stiffened by embedding structural steel channels, and 12 mm thick mild steel armour plates outside along the bevelled edges.

### 3.4 Model Studies

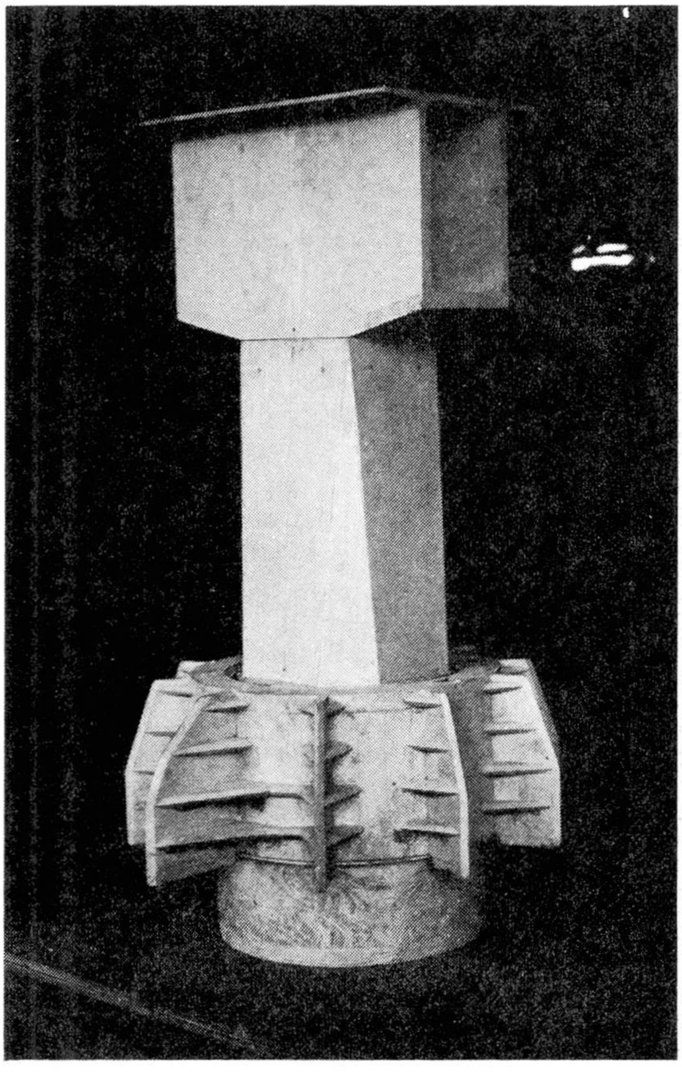
As the fendering system of this kind was being adopted for the first time, the accepting authorities viz. The Public Works Department of Government Goa and Ministry of Shipping & Transport, New Delhi, referred the case to the Central Water & Power Research Station, Khadakwasala, for a model study. The findings of the Research Station corroborated theoretical calculations. The 500 tonne static force allowed in our design was found to be adequate, though head on collision anticipated was realised to be a unlikely possibility. It was suggested a reduced speed limit be imposed on the barge traffic since barges of 1500 tonne displacement are expected to ply shortly.



Photograph 2: Model showing caisson, well cap and pier with guide pins in the well cap.



Photograph 3: Model showing fender resting on well cap without pier, guide pins shown inside periphery of model are not to scale and would be of very much smaller length (refer text)



Photograph 4: Model showing section of the bridge deck, pier, fender and caisson.

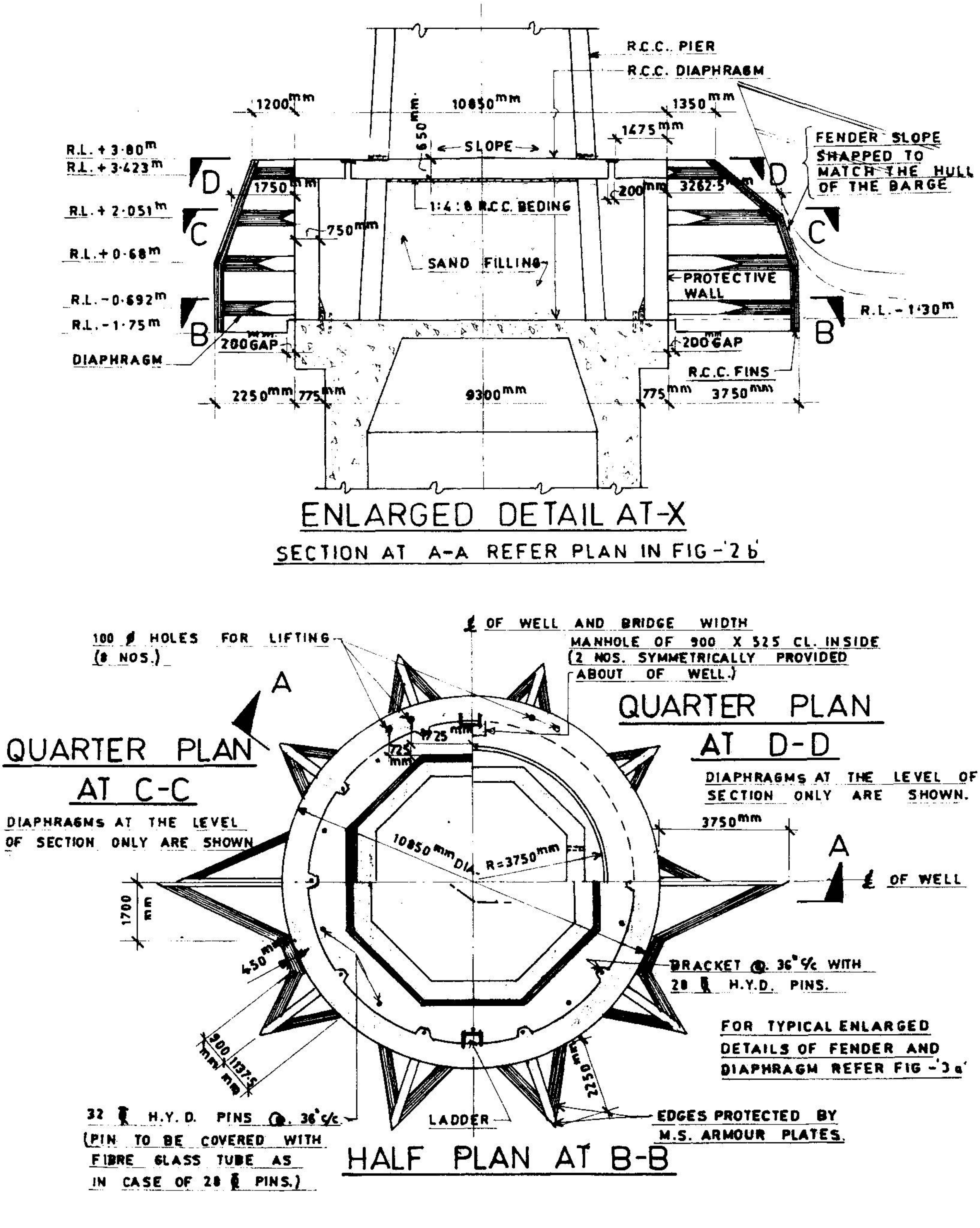



Fig. 2. Fenders for Zuari Bridge

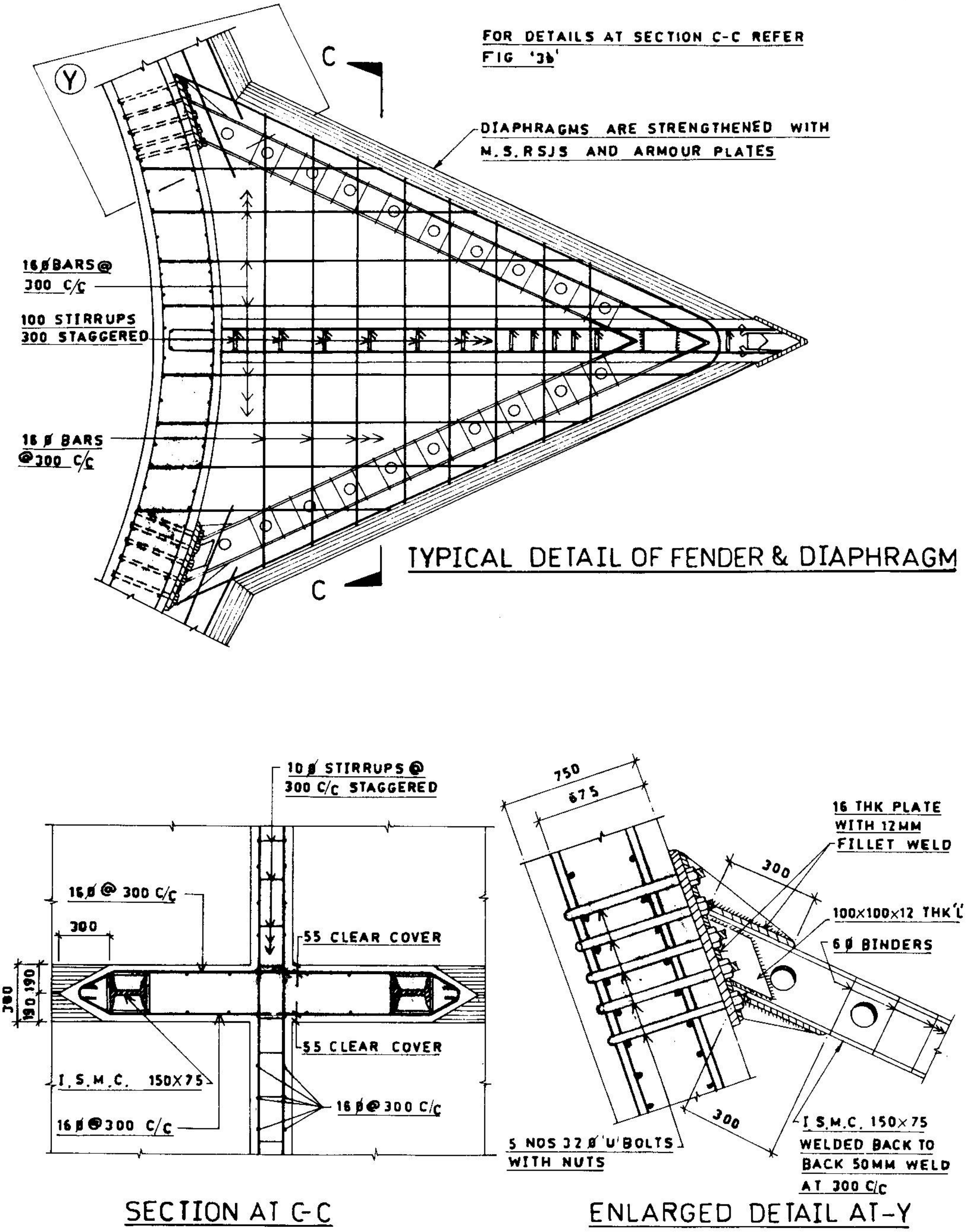



Fig. 3 Details of fenders for Zuari Bridge

# 4. CONSTRUCTION

## 4.1 Construction Sequence

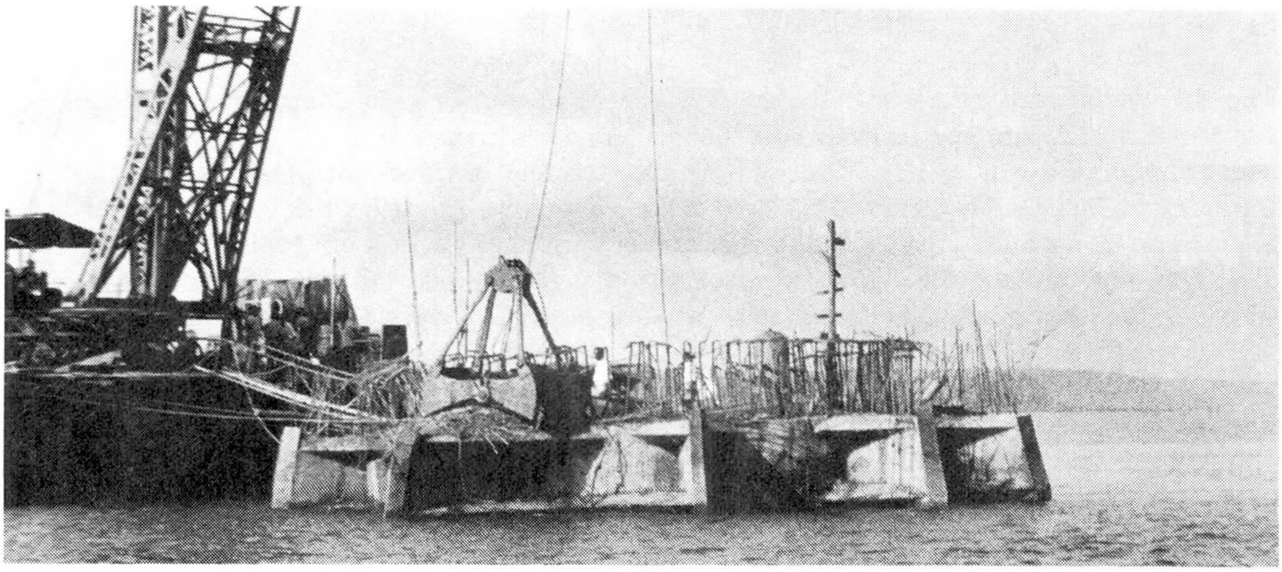
The construction sequence adopted was as follows :

First ten brackets fabricated out of mild steel twin angles and twin channels were fixed on the outer periphery of the caisson exactly below the location of the fins. The channel brackets were under the upstream and downstream fins and at the other fin locations angle iron brackets were used. Over these brackets working platform was provid: The concreting was carried out in stages. The first lift of protective fender wall and fins were cast from the bottom most level upto the bottom of the first diaphragm. The second lift consisted of the diaphragm and the protective wall for the height of the diaphragm. The next life consisted of the fins and protective wall from the top of the first diaphragm to the bottom of the second diaphragm. Similar sequence was continued till top diaphragm was reached. Thus one complete fendering system involved eight stages of concreting and each stage of concreting involved four to five days of working.

## 4.2 Problems faced during execution

The major problem encountered was casting of the fender wall itself. The base of the fender wall having been fixed at 1.30 M below L.T.L., it was necessary to cast the same before final sinking of the well. Since the depth of water as also the marine slush found at location demanded floating of structural steel caissons, towing them to the position and sinking, precision sinking of such floating caissons plumb at the exact location was found to be not practicable. Further the alternate hard and soft layers of bed strata dipping fairly steeply, resulted in tilting of the caissons. This necessitated casting of the fender wall carefully so that after final sinking the wall remained plumb.

The casting of fins together with the fender wall restricted sinking operation by cranes, as the projecting horizontal diaphragms and vertical fins would keep the floating crane away from the normal position (see photograph 5). The project being the first of its kind in India, precasting the fins and diaphragms was considered to be a technically advanced and risky proposition. However, with the experience gained, it should be possible to precast the system in future.

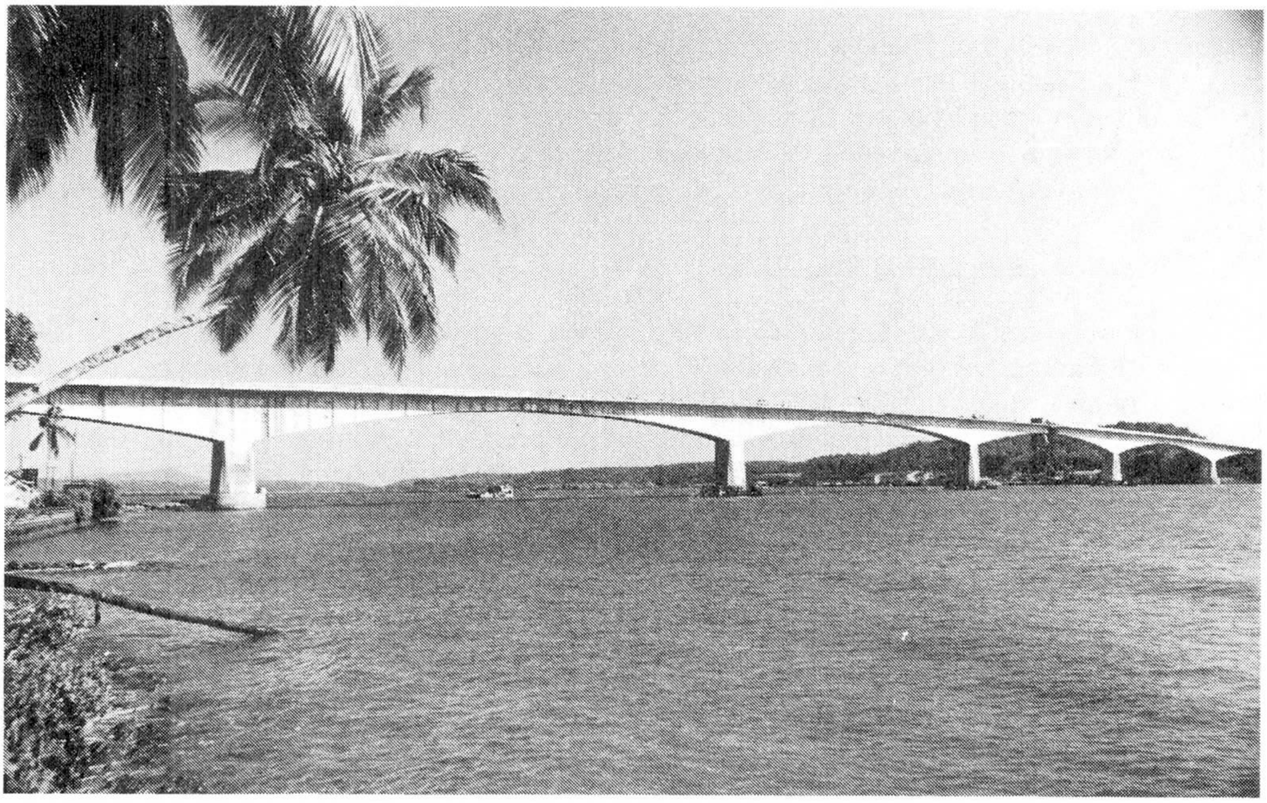


Photograph 5: Showing fender under construction.

## 5. MATERIAL CONSUMPTION

The quantity used in each fender :

| | | |
|---|---|---|
| Concrete of grade 35 N/sq. mm | : | 240 Cu. m. |
| M. S. reinforcement of grade 240 N/sq. mm | : | 80 KN |
| H. Y. S. D. reinforcement of grade 415 N/sq. mm | : | 300 KN |
| M. S. structurals embedded of grade 240 N/sq. mm | : | 150 KN |



Photograph 6: Panoramic view of nearly completed bridge.

## ACKNOWLEDGEMENT

The successful construction of the bridge with the novel type fendering system provided for the first time in our country has been largely due to the alround co-operation and encouragement given by the Public Works Department of Government of Goa as also the Ministry of Shipping & Transport, New Delhi, under whose aegis the bridge was designed and constructed. The authors also acknowledge the encouragement given by Mr. T. N. Subba Rao, Managing Director of their firm, under whose constant analytical guidance the design and implementation of this novel feature was carried out.