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Wave Energy Caisson for A Power Plant

Caisson pour une centrale d'énergie houlomotrice

Caisson für ein Wellenenergie-Kraftwerk

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SUMMARY
A wave energy power plant is being erected off the south-west coast of India near Trivandrum. The system has a caisson in reinforced concrete, resting on a prepared sea bed. The caissons can simultaneously be used as a breakwater for a harbour. The caisson was built and placed in position in December 1990. The paper explains the concept of the caisson type facility and describes its analysis, design, construction and installation aspects.

RÉSUMÉ
Une centrale électrique est en cours de construction sur la côte sud-ouest de l'Inde, à proximité de Trivandrum. L'ouvrage comporte un caisson en béton armé, reposant sur une assise préparée sur le fond marin. Ce type de caisson peut même servir comme brise-lames dans un port. Il a été construit et mis en place en décembre 1990. L'article expose la conception, le calcul statique, le dimensionnement, la construction et différents aspects d'installation de ce modéle de caisson.

ZUSAMMENFASSUNG
Vor der Südwestküste Indiens (nahe Trivandrum) wird zur Zeit eine Anlage zur Stromerzeugung aus Wellenenergie erbaut. Zum System gehört ein Stahlbeton-Caisson, der auf dem vorbereiteten Meeresboden gegründet ist und in dieser Art auch als Wellenbrecher vor Häfen dienen könnte. Der Caisson wurde im Dezember 1990 gebaut und eingeschommen. Der Beitrag erläutert die Funktionsweise sowie Aspekte der Berechnung und Konstruktion, des Baus und der Installation.

1. PROJECT OVERVIEW

1.1 Introduction

Wave energy is one of the promising forms of renewable energy which has received considerable attention. Sponsored by the Department of Ocean Development, Government of India, a pilot Project to generate electricity from ocean waves is under implementation off Trivandrum coast by the Ocean Engineering Centre, IIT, Madras. The system consists of (a) Concrete Caisson (b) Power module mounted on the top which comprises of a butterfly valve, an air tubine and an induction generator. Fig.1(a) shows the cross section of the system ,1(b) the plan of caisson, 1(c)the location plan and 1(d) the cross section showing the system, breakwater and the approach bridge.

1.2 Principle of operation

The Oscillating Water Column (OWC) concept is chosen. The OWC consists of a chamber exposed to wave action through an entrance in the front.Due to wave action the air inside the chamber gets compressed and rarified. The air movement is used to drive an air turbine (Fig.1a).

1.3 Functional requirements

The OWC chamber dimensions were selected to make it resonate with the incoming wave. Since the wave parameters vary from time to time and from place to place, it is very important to see that the device absorbs wave energy equally well in the range of wave climate predominant at the site. This means that the device should have a very broad frequency bandwidth of absorption. The device is tuned for an optimum wave period of 10 seconds.

1.4 Site for sea trial

The choice of site was arrived at based on the following criteria:

-Power availability: From the analysis of wave data collected at several places along the country's coastline it was found that wave power along Trivandrum coast is promising (Fig.2) with an annual average wave power of 13 kW/m length of coast .

-Extreme Wave Conditions: The OWC caisson must be designed to withstand the extreme wave likely to occur at the particular site The maximum wave recorded for Trivandrum coast was only 6m between 1983 and 1987. On the other hand waves upto 9m have been measured on the east coast. The design wave near Trivandrum is smaller. It is also known that during the last 100 years no cyclone crossed the west coast near Trivandrum.

-Construction facilities: The fishing harbour at Vizhinjam near Trivandrum offered the required infrastructural facilities for the construction and installation of the caisson.

-Sea Bed: The sea bed at chosen location consists of medium to coarse sand, densely packed, offering a good base for supporting the gravity structure.

2. WAVE ENERGY CAISSON

The wave energy caisson comprises of a bottom box 23.2m x 17m x 3m high, supporting a 12m high chamber with a curtain wall in front and guide walls on either sides to facilitate wave entry (Fig. 1a & b). Over the chamber is a double cubic curve concrete dome 10m x 7.75m at bottom reducing to 2.0m diameter circle at top and 3m high to support the power module. The caisson top is at +5.00m with respect to still water level.

3. DESIGN PARAMETERS

3.1 Operating Condition :

The system is expected to deliver a peak power of 150 KW at significant wave height of 1.52m and design wave period of 10 seconds.

3.2 Design extreme condition :

Based on the wave data collected off Trivandrum coast the design non-breaking and breaking wave heights were estimated to be of 7.0 mts. with a period of 10 secs.

3.3. Estimation of wave forces :

The estimation of wave forces on large rectangular or square caisson itself is complex. Unlike for circular cylinders, the incident wave direction has a significant influence on the forces. As the OWC caisson, has an opening on one side, the estimation of wave forces becomes uncertain because of the complex fluid flow and wave oscillations inside it.

For the estimation of non-breaking wave force, all the known procedures have been tried and finally, the method proposed by Isaacson [3] was used. The maximum wave force works out to 14000 kN. Finally the structure was designed for 15000 kN.

The front lip wall is a critical part of the caisson. The total average dynamic pressure at SWL due to breaking wave height of 7m calculated according to Minikin [4] is 1.18 MPa and the lip was designed for this. The total magnitude of breaking wave force is about 30000 kN. For future designs, elaborate measurements from a prototype structure and scale model studies in the laboratory are essential for an assessment of the breaking wave forces.

3.4 Scour Protection :

Scour Protection model studies conducted at the Ocean Engineering Centre show that scour is a linear function of current velocity and the maximum scour occurs at points 45^{o} to the flow direction. Superposition of waves on current results in an increase of scour depth by 20% to 62%. The currents were found to be very less at the location of the caisson.

4. STRUCTURAL ANALYSIS AND DESIGN

After considerations of several possible alternatives, cellular construction was chosen for the walls, lip and bottom raft. The caisson structure was analysed using finite element method for global and local forces. The material is RCC with M30 grade concrete. The components of the structure to be designed are walls, lip, bottom raft and dome.

4.1 Walls and lip

The caisson walls are analysed using thin quadrilateral (flat) shell elements with 30 degrees of freedom. They are assumed to be fixed on the raft and consequently all the degrees of freedom at the bottom are arrested. As the wall is assumed to be a thin plate, it is rigid in its own plane and hence all the degrees of freedom (rotational) perpendicular to its own plane are arrested. The lip was analysed using thin shell elements. It was considered free at top and bottom and connected to the side walls. The maximum bending moments and dimensions of the back wall, side wall and lip are as follows:

Component	Maximum Bending Moment kNm/m		Wall width (mm)	Thickness of vertical panel (mm)	Thickness of horizontal diaphragm (mm)
	Horizontal direction	Vertical direction			
Back wall	+ 318	+297	2500	200	250
Side Wall	-1440	-616	2000	200	250
Lip	+4000	+363	2000	250	400

4.2 Raft

The raft is also analysed using thin plate elements and is assumed to be resting on equivalent soil springs. The reaction from the bottom most elements of the wall (due to wave forces) are also taken as part of the load on the raft.

The maximum bending moments along the length and width of the bottom raft and its dimensions are as follows :

Max. Bending moment (kNm/m)		Height of the box (mm)	Thickness of horizontal slab(mm)	Thickness of vertical walls (mm)
along the length	along the width			
-553	-208	3000	(top) 200 (bottom) 250	200

The raft was checked for the stresses during the various stages of construction of the caisson in floating mode.

4.3 Dome

The dome consists of two cubic parabolas meeting at mid height, the height of the dome being 3.0m. The sectional profile of the dome varies from place to place and it has a quadrantal symmetry. Finite element analysis was carried out using thin plate and shell elements of the SAP finite element library. The dome has been designed for the following load cases.

- Internal pressure of 1 bar + self weight of dome + weight of power module.

- Internal pressure of -0.5 bar + self weight of dome + weight of power module.

The maximum membrane force and moment considered for the design are 500 kN/m and 58 kNm/m respectively. The thickness of the dome is 25 cms and the percentage of steel is about 1.5% of the cross sectional area of dome in the meridienal direction.

4.4 Stability of Caisson

The caisson should be stable against overturning and sliding at its final location. Stability is to be ensured during various stages of construction and towing.

4.4.1 During construction and towing :

As the caisson is not symmetric about its transverse axis, it tilts when it is floating. To correct this tilt, predetermined quantities of sand were added in the chambers of the bottom box. The metacentric height was always ensured to be not less than 5% of the draught. The draught of the caisson during towing was 9.75m.

4.4.2 On the prepared sea bed :

The structure has adequate factor of safety (F.S. > 1.5) both against horizontal sliding and overturning for non breaking wave forces. The author is of the opinion that the breaking wave force need not be considered for overall stability. However, even for this condition the F.S. is greater than 1.

4.5 Material Quantities

Some of the approximate quantities of the materials used for the construction are

Concrete	-	1020 cubic mts.
Reinforcing steel	-	1450 kN
Structural steel	-	1100 kN
Stones for Sea bed foundation	-	6200 kN

Stones for scour protection around caisson	8000 kN

5. CONSTRUCTION ASPECTS

5.1 Caisson

The caisson construction and installation are of major importance, particularly in view of the fact that no slip ways or heavy-lift facilities are available at the site. Keeping in view, the bathymetry, site conditions and availability of the harbour(Fig.1c) the following methodology was adopted. Figs.3a-d show the major sequences of construction.

-The bottom concrete box 3mt. height,was constructed in a pit 5m deep, on the beach area inside the harbour. The water table was held down below the construction level by well point dewatering system.

-The bottom box was made to float by allowing the water table to rise. Subsequently, the sand bund between the pit and the harbour basin was breached.

-The box was then towed to deep water area near a jetty where further construction of walls and other portions was continued in floating mode. Climbing forms were used for the construction of walls to achieve accurate alignment and speed of construction. As the construction proceeds the draught of this asymmetric structure increases and hence to ensure floatation, a temporary steel gate was erected in stages to close the front opening. Gate has over all dimensions of 10m x 10m x 1m and was held in position by lock channel arrangement. The level of the structure was kept by ballasting the different chambers of the bottom box with sand/water.

5.2 Dome

Because of the special shape of the dome, the shuttering work was expensive and labour intensive. Wooden joists were cut to lines and levels to form the basic shape of the dome on which plywood shuttering were fixed. The form work for the dome started from the bottom box slab which is 15 meters below.

5.3 Sea Bed Preparation

Along with the construction of caisson, a sea bed was prepared at the final location for the proper seating of the caisson. An area of about 30m x 23m was marked on the sea bed and stones of 20mm to 40mm size were neatly packed to lines and levels to form an even horizontal bed. Stones were conveyed using pontoons and dumped from it. The bed preparation was done by divers. The top level of the foundation was checked by conducting soundings and taking fly levels. Underwater photographs provided a fairly good indication of the eveness of the bed.

6. TOWING AND SEATING

The towing and seating operation of caisson was a very critical one with regard to the Project which needs meticulous planning. The caisson was towed out of the harbour to the final location using powerful tugs at the aft, stern and abreast. Powerful fishing trawlers also assisted in the operation. The caisson was installed on the prepared sea bed on 31st Dec. 1990. The exact positioning was done by controlling winches on board the caisson connected to bollards on the shore and anchors on the seabed.

Subsequently, a steel bridge (45m long) was erected to span the caisson and breakwater for the transport of power module and access to caisson top (Fig.3d).

7. POWER MODULE

The power module mounted on top of the dome consists of an air turbine of 2m diameter coupled to an induction generator of 150 KW rating. The induction generator system has been selected because, it is cheaper and does not require rectification and inversion normally associated with a variable speed alternator. The induction generator also has the advantage that it can be used as a start up motor for the air turbine when the wave heights are low. Thus the induction generator will always be connected to grid, drawing power from mains when the turbine speed is below synchronous speed and pumping power to the grid when the speed of turbine increases above the synchronous speed. When the grid fails, the turbine will race and attain a very high speed. To prevent this, a butterfly valve has been provided between the turbine and the caisson.

ACKNOWLEDGEMENT

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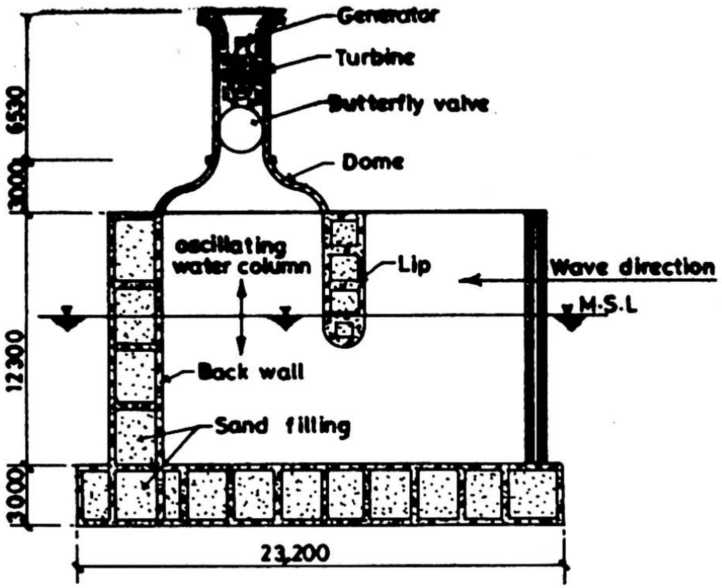

Fig.1.a Cross section of wave power plant

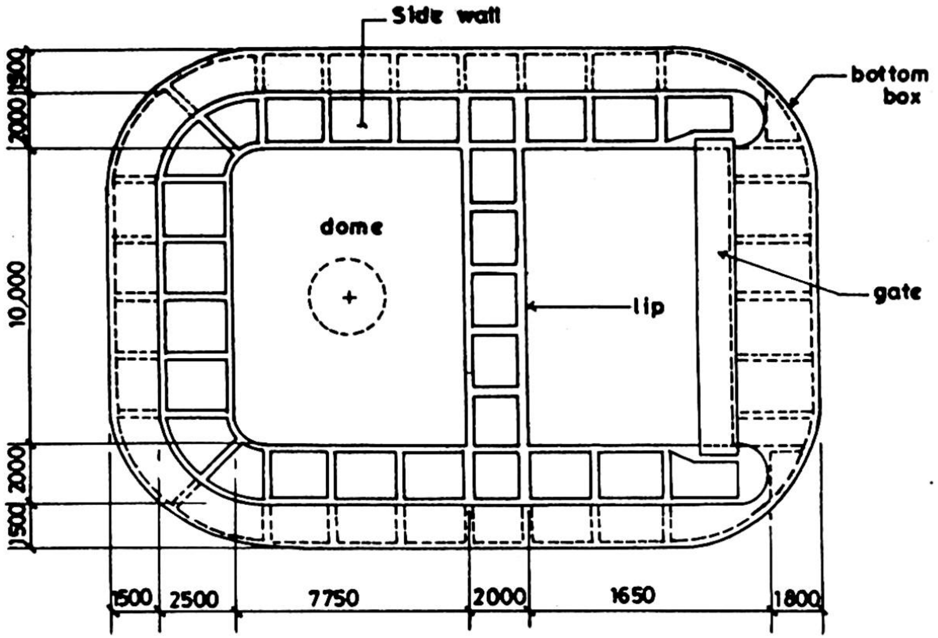

Fig.1.b Cross sectional plan of Caisson

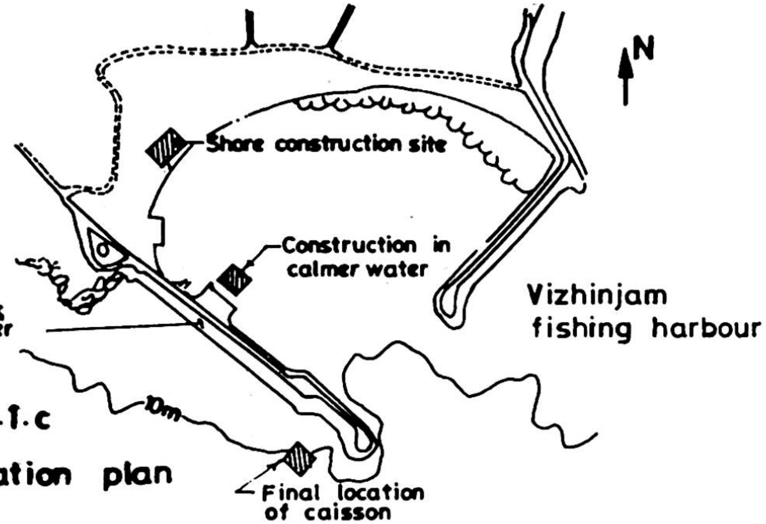

Fig.1.c
Location plan

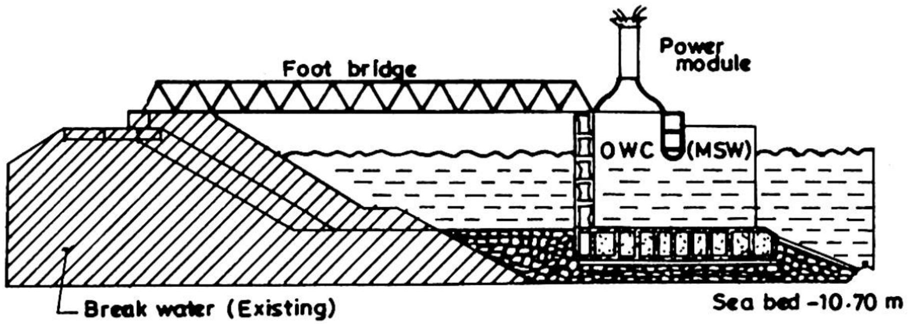

Fig.1.d Cross section of wave energy device and break water

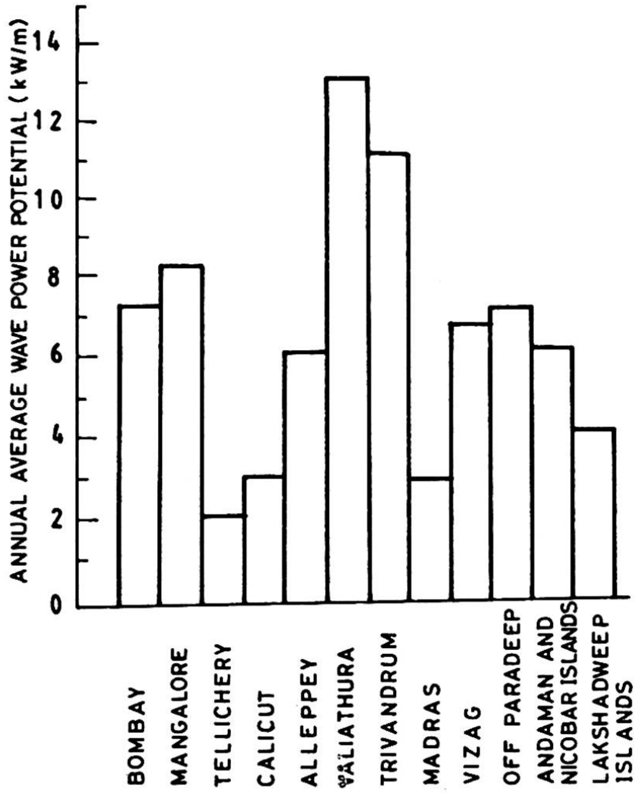

FIG. 2. WAVE POWER POTENTIAL ALONG INDIAN COAST

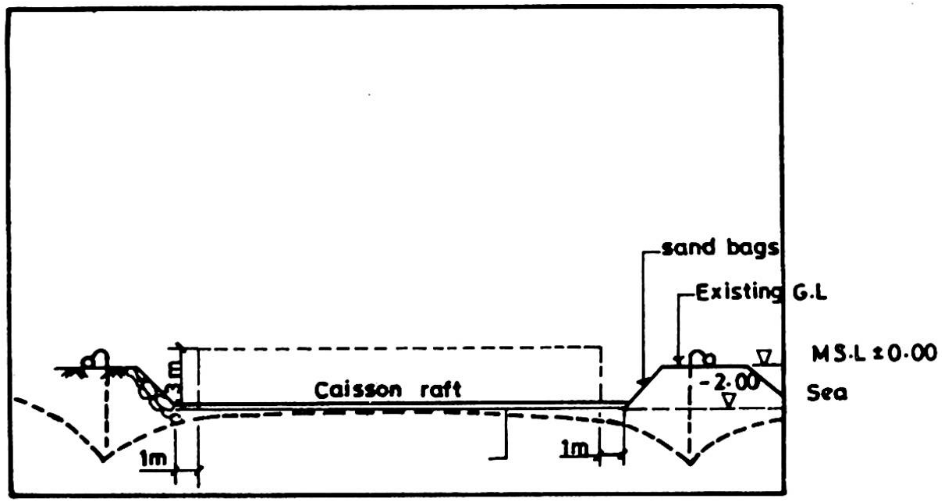

Fig.3.a Construction of bottom box and bund

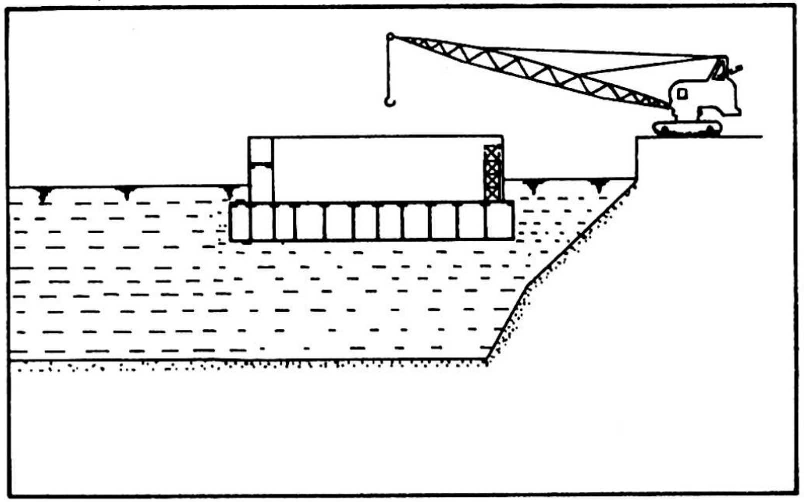

Fig.3.b Construction in floating mode

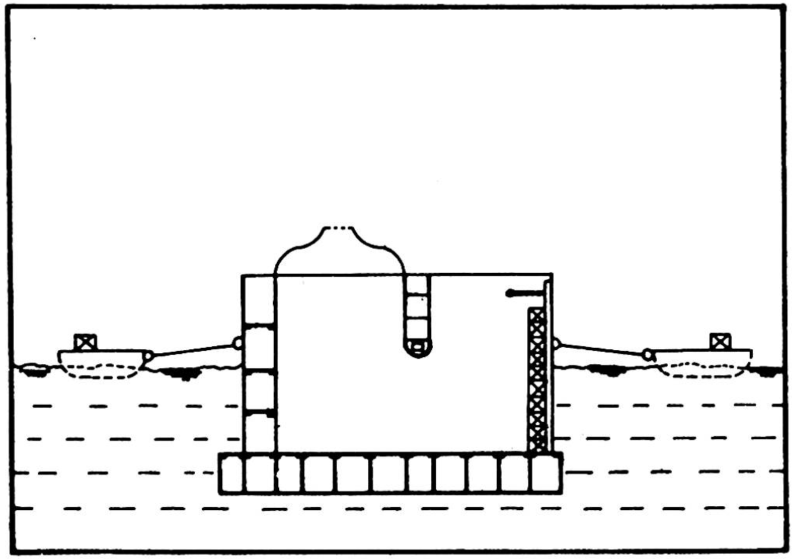

Fig.3.c Towing

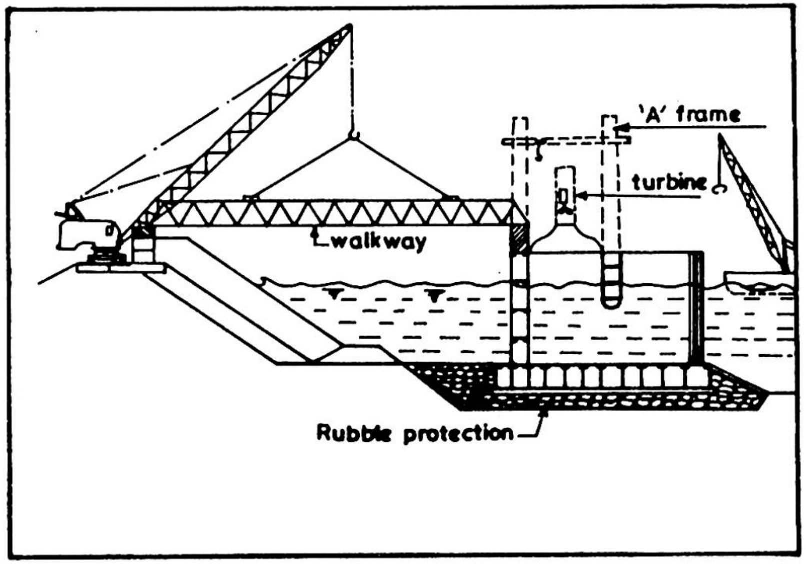

Fig.3.d Erection of bridge