

# Cost benefit analysis on different configurations of berthing structure

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**Abstract.** Port and harbors are essential for handling of the imports/exports of good transported through shipping. This paper discusses the different configuration of berthing structure, their design with respect to the site conditions and suitability. The analysis includes detailed load calculations conforming to the various codal provisions and design of the structure. The configuration of berthing structure considered are analyzed and designed using STAAD Pro for different combination of loads as per IS 4651. Bill of Quantities are prepared and final cost of construction is calculated. Factors affecting the construction and maintenance such as land availability, soil conditions, hydrodynamics of the site, dredging requirements, design ship size etc. are considered to finalize the configuration of the berthing structure. Result of the study shows that Diaphragm wall type of berthing structure is economic for Ennore port.

## 1. Introduction

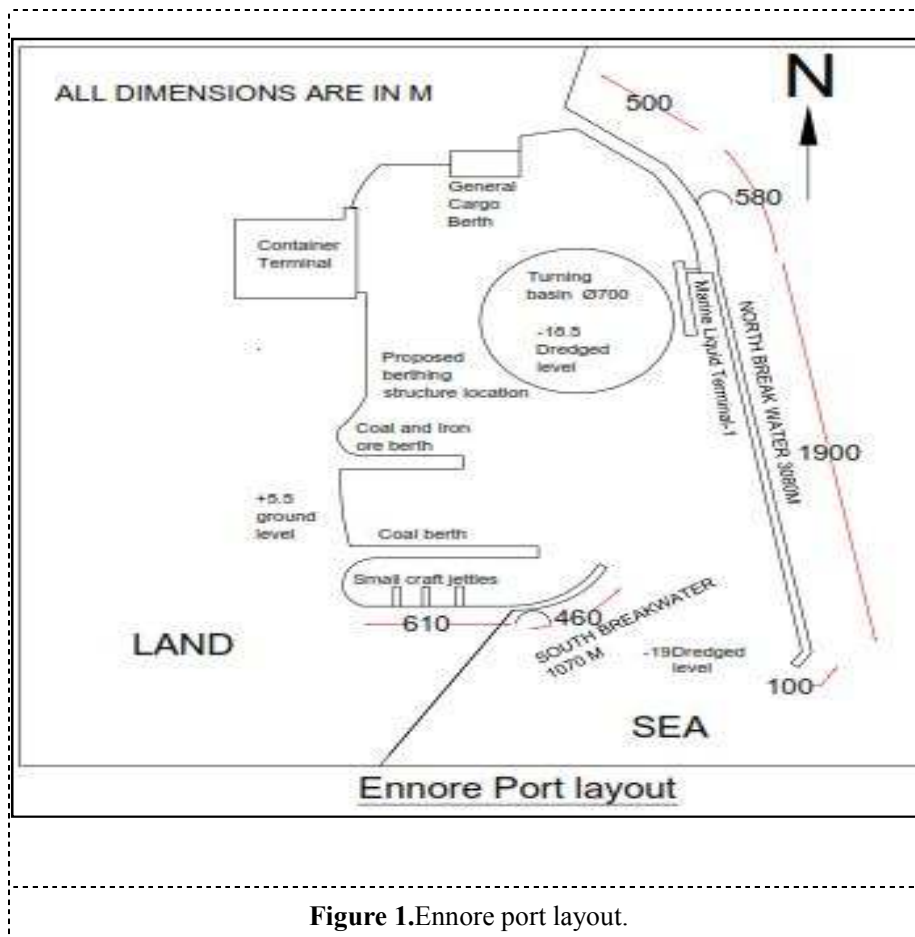
Ennore port is the twelfth major port in India. Ennore port is protected by two breakwaters, such as 3,080 m long northern breakwater and 1,070 m long Southern breakwater. It consists of six berths for handling coal, export of automobiles, Marine Liquid terminal (MLT), Iron ore etc. Due to increase in the traffic of vessels, import/export of cargo and coal, the numbers of berth are to be increased. Figure 1 shows the layout of Ennore port.

A berthing structure is constructed to help with berthing and mooring of ships. It enables easy transfer/handling of cargo and easy movement of people from land to ships and vice-versa. Quays are defined as one or more berth, continuously bordering on and in contact with land or dock area. A structure that projects from the land out into water is called jetty.

Economic design of any structure requires a good preliminary analysis of the environs. Selection of configuration at planning stage plays an important role in reducing the cost and time consumed. However it is a challenge to provide the suitable configuration of structure in the early stages. [1] Discusses about the Analysis of forces acting on jetty using STAAD pro. [2] Created an expert system to structurally design the various component of berthing structure. [3] Discusses about the various loads acting on the berthing structure and manual design of RCC members. [4] Illustrates the various



parameters affecting the planning of a berthing structure. [5] Discuss about the configuration of berthing structure with diaphragm wall. [6] Gives details about Young's modulus of dense sand.



**Figure 1.**Ennore port layout.

Literature review shows that comparison between the different types of berthing structure and its economic impact based on site specific features of the port were not studied. This paper discusses about the suitable configuration of a berthing structure for a particular location and Dead Weight Tonnage (DWT) of ship 1.2 lakh tonnes. Three types of configurations of berths are considered namely Piled jetty, Piled jetty with approach, Diaphragm wall berthing structure and the most economical configuration is finalized as the best design for particular location, depending on the various factors affecting the design of structure. Analysis and design of all the structures is done using STAAD Pro and analytical calculations.

## 2. Methodology

Various data and information such as location of Ennore port with its various components, bathymetry report, soil report, Tide, wave and wind data, are collected. The maximum size of ship and their characteristic such as draft and keel clearance are found out.

[7] is a report given by environment clearance for the construction of coal berths and gives information regarding the site specific condition of Ennore port. The dredging level is found out to be -17m and top level of deck is found out as +7 m above Chart datum.

The different configurations considered are given below.

- Piled jetty of size 39m x 350m at a distance 98 m from the shore where there is a dredge level of -17 m and reclamation of land between shore and jetty could be used as container terminal.

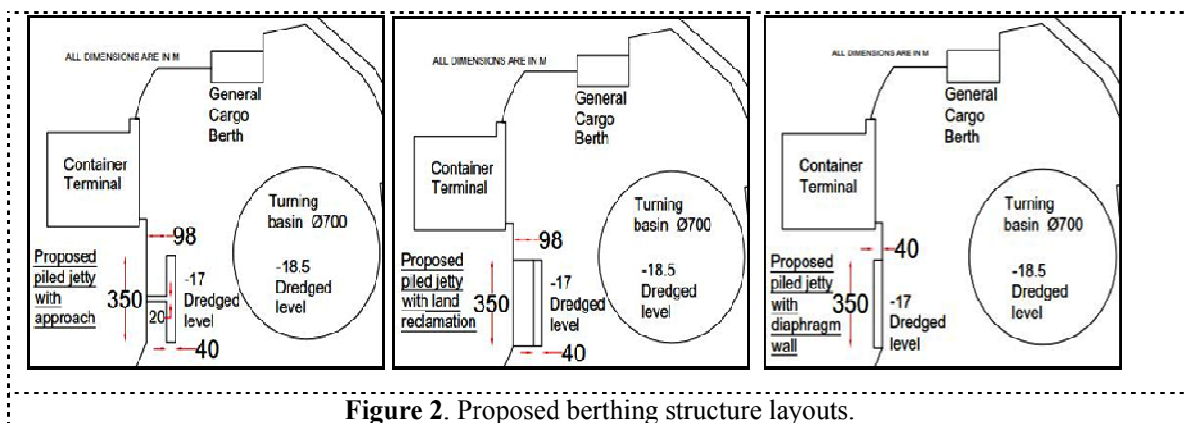
- Piled jetty of size 39m x 350m with approach of width 21m and length 98m.
- A 350 m long Diaphragm wall jetty with piles for the crane beam including tie rod and dead man wall is considered for the design.

Analysis and design of all three types of berthing structures are carried out using STAAD Pro. The soil for the diaphragm wall is modeled as springs with appropriate spring stiffness value according to Vesic formula.

Bill of quantities is prepared with the rates for each part of construction, based on the current market rates. The approximate cost for all the type of berthing structure is found. Technical and cost comparison between the berthing structures is discussed and final results are obtained. Figure 2 shows the location of the proposed berthing structure.

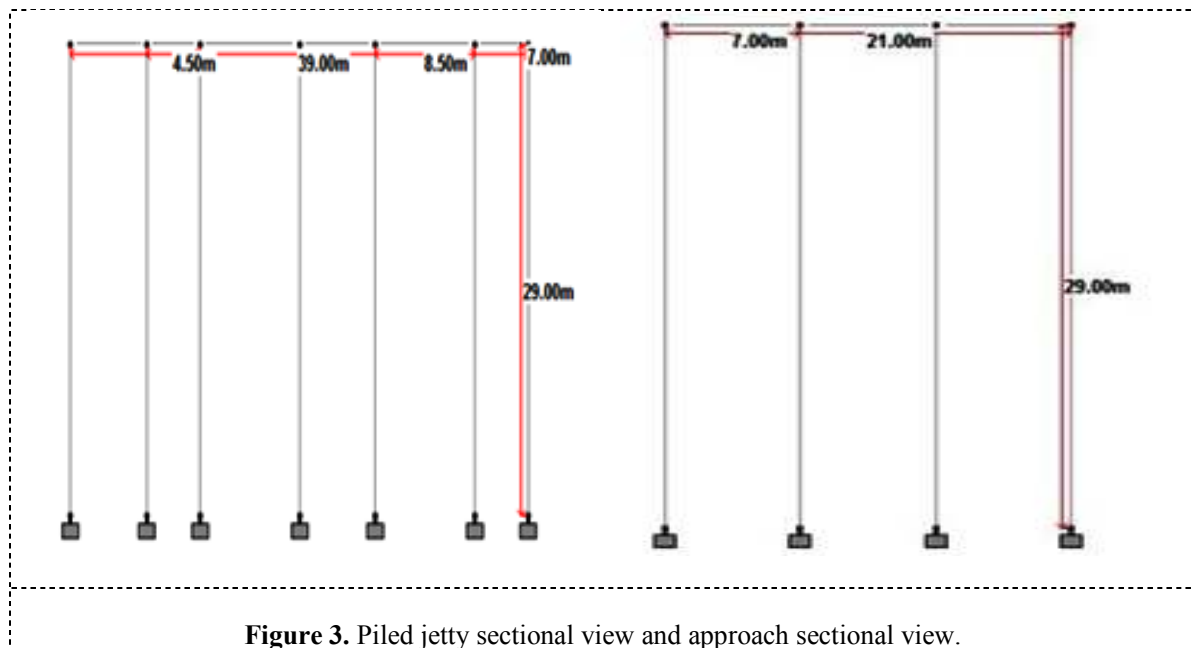
### 3. Structural Analysis

The magnitudes of different loads acting on the structure are worked out. Concrete grade of M30 and Fe500 steel are considered. Table 1 gives the various loads acting on the structure and its values. Figure 3 shows the side view of the piled jetty. Seven rows of piles were used at different spacings that were decided after a number of trials. The total length of pile up to the depth of fixity is 29 m. Figure 3 also shows the sectional view of the approach, 4 rows of piles at a spacing of 7 m c/c are used. Figure 4 shows the side view of diaphragm wall. Depth of diaphragm wall is 34 m. The soil is modelled as springs with dead man wall at a distance of 40 m connected by a post tensioned tie rod.



**Figure 2.** Proposed berthing structure layouts.

Mooring forces were found using [8] which gives the information about the calculation of current and wind forces acting on the ship. [9] informs about the various forces acting the berthing structure and the formulas for calculating the forces.



**Figure 3.** Piled jetty sectional view and approach sectional view.

### 3.1. Loads combination

General design considerations of berthing structure are given in [10]. The load combination according to IS 4651(part4):1989 are given below.

#### Limit state of collapse

$1.5DL+1.5LL+1EP+1HY+1.5BL, 1.5DL+1.5LL+1EP+1HY+1.5ML, 1.2DL+1.2LL+1EP+1.2HY, 1.2DL+1.2LL+1EP+1HY+1.5WL, 1.2DL+1.2LL+1EP+1HY+1.5EL.$

#### Limit state of serviceability

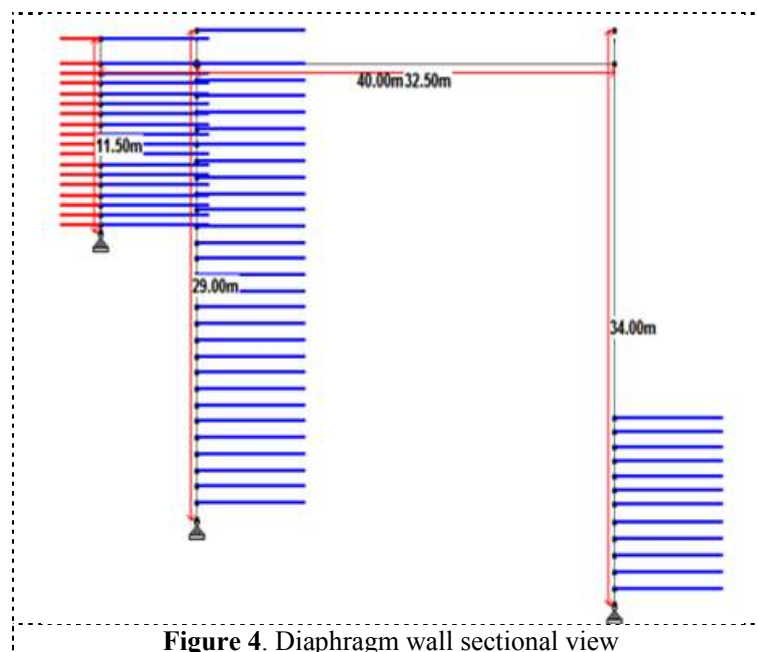
$1DL+1LL+1EP+1HY+1SF, 1DL+1LL+1EP+1HY+1BM$

DL- Dead load, LL-Vertical Live load, EP- Earth pressure, HY- Hydrostatic and hydrodynamic forces, BL- Berthing force, ML- Mooring forces, SF-Secondary stresses, WL-Wind load, EL- Seismic forces. Other load combination included the extreme and normal wind loads, wave loads and crane loads. Due to different direction of wind, earthquake, wave forces and various possibilities of berthing, mooring and crane loads about 138 combinations of loads were considered for analysis using STAAD Pro.

**Table 1.** Loads acting on structure

S. No.	Load Type	Pattern of Load / Formula	Load	Remarks
Berthing structure type I and II- Piled jetty				
1	Dead load	Self-weight	25 kN/m <sup>3</sup>	
2	Live load	Uniformly distributed load	50 kN/m <sup>2</sup>	IS 4651 part 3
3	Crane load	Post Panama crane	12000 kN	Maximum extreme load per corner on sea side
		Post Panama crane	11200 kN	Maximum operating load per corner on sea side

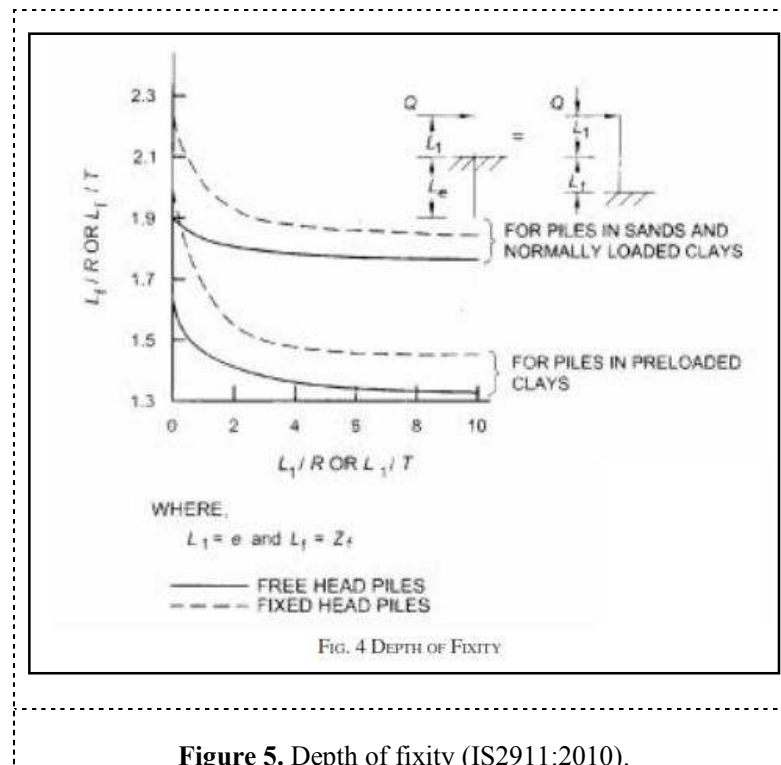
4	Berthing load	$E = (W_D V^2 / 2g) \times C_m \times C_e \times C_g$ Using DCN1600H fender	2494 kN	As per IS 4651 and shore protection manual
5	Mooring load	Force on bollard	1500 kN	As per BS6349 wind and current forces on ship
6	Wave forces on piles	$F_{DM} = 0.5 \times C_D \times \rho \times D \times H^2 \times K_{DM}$ $F_{IM} = 0.5 \times C_M \times \rho \times D^2 \times H \times K_{IM}$	2.67 kN	Extreme wave load
		$F_{DM} = 0.5 \times C_D \times \rho \times D \times H^2 \times K_{DM}$ $F_{IM} = 0.5 \times C_M \times \rho \times D^2 \times H \times K_{IM}$	2.024 kN	Operating wave load
7	Wave force on 7m wall	$P_m = 101 \times H_b \times w \times d \times (D+d)/(L_D D)$ and $P_s = wH_b/2$	2616.12 kN/m	Operating wave load
		$P_m = 101 \times H_b \times w \times d \times (D+d)/(L_D D)$ and $P_s = wH_b/2$	3270 kN/m	Extreme wave load
8	Wind load	$V_Z = V_b \times K_1 \times K_2 \times K$	0.4822 kN/m <sup>2</sup>	As per IS 875 Extreme load
		$V_Z = V_b \times K_1 \times K_2 \times K_3$	0.3086 kN/m <sup>2</sup>	As per IS 875 Operating load
Berthing structure type III- Diaphragm wall				
9	Earth pressure	$E_p = K_a \gamma h$	67.74kN/m <sup>2</sup>	According to layers of dense sand
10	Differential water pressure	Good drainage condition	5.5kN/m <sup>2</sup>	According to change in tide levels



**Figure 4.** Diaphragm wall sectional view

### 3.2. Depth of fixity

The depth to the point of fixity is given in Figure 5. “e” is the effective eccentricity of the point of load application obtained either by converting the moment to an equivalent horizontal load or by actual position of the horizontal load application. The Indian standard for construction of piles [11] is used to calculate the depth of fixity. [12] Gives information about the forces acting on the jetty and also about depth of fixity. Depth of fixity is found to be 5.89 m in dense sand as per the soil condition given in [7].



**Figure 5.** Depth of fixity (IS2911:2010).

### 4. Design of RCC Sections

The design of pile, crane beams, beams are designed for the piled jetty structures. The diaphragm wall with its tie rod and dead man wall were analysed and percentage of reinforcement is calculated.

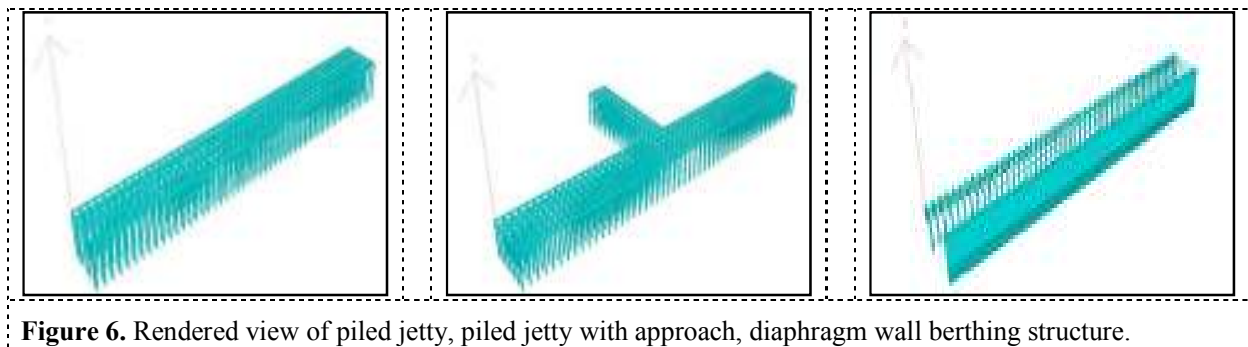
The finalized geometry of the structure is given the Table 2. The general rectangular and circular shape of sections was used. The geometry of diaphragm wall is considered from [5]. The geometry was finalized after a series of trials. The maximum percentage of reinforcement for each section is given in Table 2.

**Table 2.** Geometry of members

S. No.	Member	Size of member	Reinforcement %
<b>Berthing structure type I and II- Piled jetty</b>			
1	Pile(crane beam)	1.3m diameter. Depth of foundation 34m	3%
2	Pile	1.2m diameter. Depth of foundation 34m	2.25%

3	Crane beam	1.3m x 1.4m	0.659%
4	Beam	0.9m x 1m	0.888%
5	Slab	Depth of 0.5m	0.5%
<b>Berthing structure type III- Diaphragm wall</b>			
6	Diaphragm wall	1.1m thick wall with 4 m panel. Expansion gap every 60 m	Vertical =0.7% Horizontal=0.15%
7	Tie rod	Post tensioned 75 mm diameter rod	
8	Dead man wall	0.6m thick wall 1m in length for every 7 m	0.15%

The rendered view of the piled jetty and piled jetty with approach is shown in Figure 6.



**Figure 6.** Rendered view of piled jetty, piled jetty with approach, diaphragm wall berthing structure.

## 5. Comparison between the Berthing Structures

Bill of quantities for the three type of berthing structure is prepared and the total cost of construction is estimated according to present market rate. Some of the main Technical difference are land reclamation, dredging. Cost is calculated for each type of berthing structure and approximate overall cost is given in Table 3.

**Table 3.** Cost of berthing structures.

S. No.	Type of structure	Cost in Rs. (Crores)
1	Piled jetty with reclamation	83.12
2	Piled jetty with approach	86.74
3	Diaphragm wall berthing structure	71.71

## 6. Conclusion

Detailed analysis and design of the three types of configuration of berthing structure are done using STAAD Pro. Approximate cost of structures is calculated. It is seen that the cost of Diaphragm wall berthing structure lower than that of piled structures but the amount of land available on the land side and the soil condition will be major criteria in deciding the use of diaphragm wall type of berthing structure. Soil stabilization must be done in case of loose sand and more number of piles must be designed if it is clayey soil which will increase the construction cost.

Environmental impact assessment must be carried out using numerical modeling to decide feasibility of each type of structure. Reclaimed region in piled jetty with reclamation can be used as

container terminal. Piled jetty with approach is very useful for future development as additional jetty can be constructed parallel to approach and more number of ships can be accommodated.

The factors discussed can be used to create an expert system to decide the configuration of berthing system in the planning stage of the project.

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