# A marine cargo berth design at Mumbai port trust

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***Abstract*— *In the present dissertation a berthing structure was analyzed and designed using different load conditions and the best possible way to construct a new berthing structure was described. All the suitable and useful data was adopted from the proposed site location at Mumbai Port and studied carefully before designing the structure. The proposed berthing structure was modeled with suitable geometry using STAADPRO, after which all considerable loads on the structure were induced and analyzed carefully. Different sectional dimensions were trialed during the analysis and the most acceptable structure was designed with providing all structural members with suitable reinforcement and satisfying all marine safety conditions.***

***Index Terms*—*port construction, berth design, berth structure,***

## I. Introduction

The berthing structures are constructed for the berthing and mooring of vessels to enable loading and unloading of cargo and for embarking and disembarking of passengers, conveyances etc. The design of berthing structures depends on sundry factors. In the present study of the project, we described a felicitous way to design an incipient berthing structure with example of one of the proposed berthing structure in Mumbai port. So, after analyzing and designing, the influence factors which effected on the structure were taken into consideration such as soil characteristics of the proposed location, environmental conditions and range of traffic.

All the rudimental Data was adopted from Mumbai port which were supposed to be utilized in the project such as geotechnical data, environmental data, and traffic forecasting data. The entire Berth length of 100m was divided into 3 units of each 33.33 in length with an expansion joint of 40mm between successive units and proposed in the inner harbor, designated for handling liquid cargo like Sulphur acid, Phosphoric acid, phosphoric acid, edible oils etc. The details of the structural element are discussed under the conceptual design. The design dredge level is taken as -16.10m.

## II. Vadodara

Mumbai Port has three enclosed wet docks. Prince's Dock was commissioned in 1880. As of 2008, it has 8 berths with a minimum draft of 6.4 meters (21 ft). Victoria Dock, commissioned in 1891, had 14 berths as of 2008 with a minimum draft of 6.7 metres (22 ft). Indira Dock, commissioned in 1914, had 21 berths, with a minimum draft of 7.0 metres (23.0 ft). Prince's Dock and Victoria Dock are semi-tidal docks, with vessels docking and departing at high tide. Indira Dock has a lock, enabling vessels to enter or depart at any time. The port has four jetties on Jawahar Dweep, an island in the harbour, for handling Crude and petroleum products. These jetties have a draft of 12.2 metres (40 ft). Liquid chemicals are handled from a jetty on Pir pau. Ballard Pier Extension has a passenger terminal, including immigration clearance facilities for crews and passengers of cruise liners. The port has a total of 63 anchorage points. A pilot is mandatory for all vessels of over 100 tonnes net weightage. Mumbai port coordinate $18^{0}$56.3’N and $72^{0}$45.9’E. Mumbai port operated by government of India.

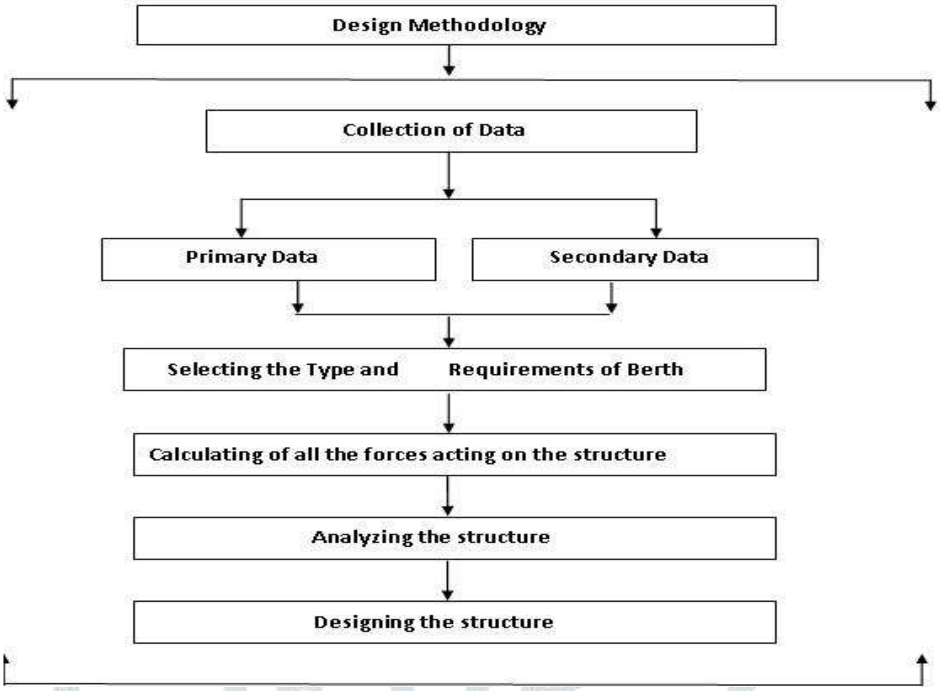
## III. Problem Definition

The Indira dock works on a lock-gate system with a lock length of 228.6 m and a width of 30.5 m, through which vessels can enter and leave the docks at any state of tide. There are 21 berths inside the basin and 5 berths along the harbour wall (**Table 3.2**). The design depth available inside dock and at outside berths is 8.8 m and 7.5 m, respectively. The depth of berths inside the basin can be further increased by 1.2 m by impounding water by electric pumps. As can be seen from the figures, berths 1 to 17 are inside the dock basin and berths 18 to 23 are outside along the dock wall. Inside berths 6 to 9 are used for berthing port crafts and are not used for handling cargo. Berth no. 17 is also not operated since it is close to the lock gate. So new berth construction at Indira dock, Mumbai port trust.

## IV. Waterway as a Major Mode of Transportation

Waterways are also an important means of transportation. Centuries ago our ships have been sailing to the Eastern and Western countries for trade. India has a long coastline of about 5700 kilometers. It is the second largest shipping country of the world. It has a large shipping fleet. The ships sail from India to other countries in the world. The ships sail from the places along the coast called seaports. India has about 10 major seaports and about 160 small seaports along its coastline. Mumbai is the largest seaport in India. Ships carry large quantities of cotton, cement, iron-ore, jute, manganese and other forms of produce to other countries of the world. They transport fertilizers, petroleum, machinery and some other goods from other countries to India. The articles we send to other countries in the world is known as export and the articles we bring from other countries to our country is called import.

## V. METHODOLOGY




The design methodology adopted for the project are focused into reinforced concrete design and general design approach of the structure based on the Code Provisions of IS 4651-1 (1974) Code of Practice for planning and design of ports and harbours.

## VI. DESIGN OBJECTIVE

To Analyze and design the passenger berthing structure as per the guidelines provided by the bureau of Indian Standards and followed by the bye laws of International Maritime Organization.

- The Objective of this project is to analyze a Passenger berth structure of size 200m x 20m.
- To design all the components in the berthing structure as per the code provisions.
- To analyze the structure using the STAAD. Pro.

***Berthing Structure***

The berthing structures are constructed for the berthing and mooring of vessels to enable loading and unloading of cargo and for embarking and disembarking of passengers, vehicles etc. The planning and design of berthing structures depend on various factors. A berthing structure is a capital-intensive project, thereby; optimum use of both space and capital becomes imperative. This means that proper planning of the various units of the structure, for the present and an optimistic future demand, is necessary. Berthing structures world over suffer from congestion or inflexibility due to short comings in planning or due to wrong estimate of the traffic and or land requirement.

***Components of Berthing Structure***

- Beam
- Slab
- Pile
- Fenders
- Bollards

***Selection and Requirements of Berth***

After having decided about the location of the berthing structure, the type of the structure to be constructed needs to be examine.

- The factors controlling the selection of the type of structure are the flow conditions and based on the soil properties. Berthing structures can be classified as wharfs and piers.
- The number of berth required in the terminal largely depends on the traffic to be handled in terms of number of ships to be serviced and their arriving pattern.
- The length of berth to be provided depends upon the function of the terminal and the size and the types of ships that are likely to call at the port.
- Berthing area should be based on the length and breadth of the largest size of the ships using the berths.

***Calculating of all the forces acting on the structure***

All the possible loads on the berthing structure were calculated as per IS 4651 (1974) - 3 Code of Practice for planning and design of ports and harbours Loading Conditions.

## VII. DESIGNING THE STRUCTURE

The design of the slabs, beams and piles are design as per IS 456:2000, SP: 16 and IS 2911 (1). Suitable forms have been developed to design and draw the required reinforcement in the structural members.

***Working Stress Design***

There are uncertainties in load, material and theoretical models. Two different methods are available to take into account the uncertainties, namely the working stress design method and the limit state design method. The working stress method can be expressed as:

S* < S/SF

Where,

S = Nominal stress capacity

SF =Safety Factor

S* = Design stress

Stress: Nominal or Shear

The disadvantages of working stress method are not consistency reliable.

***Limit State Method***

Limit state design is a design method in which the performance of a structure is checked against various limiting conditions at appropriate load levels. The limiting conditions to be checked in structural steel design are ultimate limit state and serviceability limit state. Ultimate limit states are those states concerning safety, for example load carrying capacity, overturning, sliding, and fracture due to fatigue or other cause. Serviceability limit state are those state in which the behavior of the structure under normal operating conditions is unsatisfactory, and these include excessive deflection, excessive vibration, and excessive permanent deformation.

***ANALYSIS OF THE STRUCTURE***

***Load Calculations,***

***Dead Load [IS 875-1987 Part I]***

All dead loads of and on structures relating to docks and harbor should be assessed and included in the design. Dead loads consist of the weight of all components of the structure as well as the weight of all permanent attachments. The DL of a port related marine structure constitutes a relative small percentage of the total load acting on the structure.

Slab Weight = 0.2×25 =5KN/m2

Transverse beam = 1.10×1.80×25 = 50KN/m

Longitudinal beam = 1.10×0.6×25= 16.5KN/m

Pile = ((pi×22)/4) ×25 = 78.5KN/m

***Live Load [IS 4651(Part III)-1974]***

Surcharges due to stored and stacked material, such as general cargo, bulk cargo, containers and loads from vehicular traffic of all kinds, including trucks, trailers, railway, cranes, containers handling equipment and construction plant constitute vertical1ive loads. Vertical LL consists of the weight of all movable equipment on the structure. The function of berth related to Truck Loading B (Passenger Berth) so we are adopted 10KN/m2.

Table 1. The function of berth related to Truck loading

| Serial number | Functioning | | Truck loading | | vertical LL(T/m) |
|---|---|---|---|---|---|
| | berth | | | | |
| 1 | Passenger berth | | B | | 1.0 |
| 2 | Bulk | Loading | A | | 1.0 to 1.5 |
| | Berth | Loading | | | |
| 3 | Container berth | | A or 70R | AA | 3 to 5 |
| 4 | Cargo berth | | A or 70R | AA | 2.5 to 3.5 |
| 5 | Heavy | Cargo | A or 70R | AA | 5 to 6 |
| | berth | | | | |
| 6 | Small boat berth | | B | | 0.5 |
| 7 | Fishing berth | | B | | 1.0 |

***Berthing Load [IS 4651(Part III) – 1974]***

Berthing Energy, when an approaching vessel strikes a berth a horizontal force acts on the berth. The magnitude of this force Depends on the kinetic energy that can be absorbed by the rendering system. The reaction force for which the berth is to be designed can be obtained and Deflection-reaction diagrams of the fendering system chosen. These diagrams are obtainable from fender manufacturers the kinetic energy, E, imparted to a fendering system, by a vessel moving with velocity V m/s is given by:

$$E = \frac{W_D V^2}{2g} \text{x(Cm) x (Cs) x(Ce)}$$

*WD* = displacement tonnage (DT) of the vessel

*V* = velocity of vessel in m/s, normal to the berth

*g* = acceleration due to gravity in m/s2

*Cm* = mass coefficient

*Ce* = eccentricity coefficient

*Cs* = soft coefficient

$$E = \frac{200000X0.10^2X\ 0.51X1.60X0.95}{2X9.81}$$

= 80kN.m

27 Nm/33m for 1unit of berth (33 meters).

***Mooring Load [IS 4651 (Part III) -1974]***

The mooring loads are the lateral loads caused by the mooring lines when they pull the ship into or along the dock or hold it against the forces of wind or current. The maximum mooring loads are due to the wind forces on exposed area on the broad side of the ship in light condition.

$F = Cw\, Aw\, P$
$F$ = force due to wind in Kg
$Cw$ = shape factor = 1.3 to 1.6
$Aw$ = wind age area in m2
$P$ = wind age pressure in m2 to be taken in accordance with IS: 875-1964
The wind age area (Aw) can be predictable as follows:
Aw= 1.175Lp (DM-DL)
Where
Lp= length between perpendicular in meter
DM= mould depth in m, and
DL=average light draft in m.

Actual this is the definite procedure but port engineers suggested that bollard pull =900kN is adopted (Design load) Generally mooring load act in various angle of forces so we have to resolve on the mooring point while designing the berth. And spacing taken as bollard to bollard is 15m c/c, if suppose we fixed 7 bollards then the load on each bollard is 900/7 =F =128kN
Resolving of forces on mooring points are
Horizontal component = FcosΘ = 90kN
Vertical component = FSinΘ = 90kN
Generally angle is taken as $45^0$ here if necessary need to calculate at different angles as per maximum ship moment observations.

***Current load [IS 4651(Part III)-1974]***

Loads because of Current - Pressure because of flow will be connected to the zone of the vessel beneath the water line when completely stacked. It is roughly equivalent to *w* v2/2 *g* per square meter of range, where *v* is the velocity in m/s and *ID* is the unit weight of water in tones/ml. The boat is for the most part berthed parallel to the current with powerful currents and where berth arrangement really goes astray from the bearing of the current, the' likely force should be considered by any familiar method and taken into account.

$$F= \frac{WV^2}{2G}$$

Unit weight of water(w) =1.025tonnes/m3
Velocity of current (v) = 0.26m/s
Acceleration due to gravity =9.81m/s2
F=0.035Kn/m2
For 1 unit of berth F= 0.035X 33X21.65= 25kN
25kN for 12 pile for each pile F= 2.02 kN
Load distribution is converted as uniform on pile F=2.02/21.65=0.096KN/m.

***Wind Load [IS 875-Part (III) - 1987]***

Wind contributes primarily to the lateral loading on a pier. It blows from many directions and can vary without detect. The wind impinging upon a surface increases the pressure on that surface and results in a force loading. However, given the construction characteristics of an open pier, the loading on the structure itself is minor compared with the wind effects of the ship moored alongside. The exposed, directional, surface region of the ship is susceptible to wind loading which is then transferred to the pier. When designing a pier, historical wind data, along with the design ship size, is analyzed to size the structural members according to the predominant wind direction.
Design wind speed(Vz)= Vb k1k2k3
Vb= basic wind speed
k 1= probability factor (risk coefficient)
k 2= terrain, height and structure size factor
k 3= topography factor
location Mumbai
wind speed =50 m/s
Appendix A (IS:875-PART 3)
Vz= 50 x 0.92x 1.05x 1 = 48.3 m/sec
Design wind pressure = 0.6 x(Vz)2 xp = 1400N/m2 =1.4 Kn/m2
Now the design wind pressure is resolved as nodal loads on structure
=1.4X 33X1 =46.2/12 =3.85 kN

***Seismic load [IS 1893 - Part (1)]***

Design seismic base shear VB= AhW
Ah = horizontal seismic coefficient
W = seismic weight of structure

$$Ah= \frac{Z}{2} \text{ x } \frac{Sa}{g} \text{ x} \frac{I}{R}$$

Z= zone factor = 0.16
I= importance factor = 1.5
R= response reduction factor =5
Sa/g = 2.50(hard rock)

Ah= $\frac{0.16}{2}$ x 2.50 x $\frac{1.5}{5}$ = 0.06
W= seismic weight of the structure=55318.5kN
VB= 4500.5kN
The approximate fundamental natural frequency period of vibration (Tsin sec)
=0.009h/$\sqrt{d}$
H= height of the structure in meter
D= Base dimension of structure at plinth level in m
Ts =0.09$X$ 23.25/ $\sqrt{33}$ = 0.35 sec

***Earth Pressure [IS 4651(Part III)-1974]***
Pa= $K\gamma h$
K = coefficient of earth pressure
$\gamma$ = unit weight of soil=kN/m3
H= height of the structure =m
K=$\frac{1-sin\theta}{1+sin\theta}$
$\Theta$ = angle of internal friction of the soil
Pa = $\frac{1-sin33°}{1+sin33°}$ x 20 x 3 =0.29x 20x 3 = 17.4 Kn/m2
= 17.4 X 3X33(for 1 unit of berth)
= 1722.6/12(0n each pile)
= 143.55/3(level)
Converted as uniform load =47.85kN/m

**Hydrostatic Pressure [IS 4651(Part III)-1974]**

On account of waterfront structures with inlay, the weight created by distinction in water level at the fill side and waterside must be considered in design configuration. The magnitude of hydrostatic pressure is affected by the tidal extent, free water variances, the ground water deluge, the porousness of the establishment of foundation soil and the structure and also the proficiency of accessible refill drainage in the case of waterfront structures with backfill, the pressure caused by difference in water level at the fill side and waterside has to be taken into account in design.
P= γh
$\gamma$=unit weight of water=10kN/m3
H= water head on structure; m
P=10 X 18 =180kN/m2
= 180X1.57
=270kN/m on each pile

***Basic Load Combinations***

- D.L+1.5L.L + 1(Earth Pressure) + 1 (Hydrostatic Pressure) + 1.5 (Berthing Load) + 1.5 (Mooring Load)
- 1.2D.L+1.2L.L+1E.P+1.2H.P
- 1.2D.L+1.2L.L+1E.P+1H.P+1.5 (Wind Load)
- 1.2D.L+1.2L.L+E.P+1H.P+1.5 (Seismic Load)

***DESIGN OF THE STRUCTURE***
***Design***
1. Data
Lx =2.62m, Ly=2.62m
Fck= 40N/mm2, Fy=415 N/mm2
2. Depth of the slab
Overall depth is taken as D=300mm
Effective depth d=217mm
Effective coverd1 = 83mm
Clear cover = 75mm
3. Loads
Self-weight of slab = 0.30 X 25 =7.5 kN/ m2
Apron cover = 0.20 X 25 =5 kN/ m2
Service load = 50 kN/ m2
Design ultimate load = wu= 1.5 X 63 =94 kN/ m2
4. Ultimate design moments and shear forces
Mu= $\frac{\text{wl2}}{8}$ = 80.65 kN.m
Vu=$\frac{\text{wl}}{2}$ = 123Kn
**5.**$\frac{Mu}{bd2}$=1.68
Percentage of steel required pt =50 x = 0.62 %
Ast=$\frac{0.62}{100}$ x1000 x 217 = 1345.4 mm2
Provide 1460 mm2 Area of steel.

Diameter of the bar is 16mm is taken
Area of the bar= $\frac{\pi}{4}$ x d2 =200mm2
Required spacing between bars =$\frac{200 \times 1000}{1460}$ = 136.98 mm
Number of bars required per meter = $\frac{\text{Ast}}{\text{Area of the bar}}$ = $\frac{1460}{200}$ =7

***Check for shear stress***
Consider the unit width of slab
$\tau v = \frac{Vu}{bd}$ x $\frac{123}{1000 \times 217}$ =0.56 N/mm2
Pt= $\frac{100Ast}{bd}$ x $\frac{100 \times 1460}{1000 \times 217}$ = 0.67 N/mm2
Refer Table 19 of IS:456 and read out:
K$\tau c$= 0.58 N/mm2 > τv
Hence the Shear stresses are within the safe permissible limits

***Check for deflection control***
(l/d) max =32
(l/d) max =12.78
(l/d) max > (l/d) actual
Hence deflection control is satisfied.

***Reinforcement in edge strips***
Ast = 0.12 percent of effective depth=0.0012 X 1000 X 217 =261mm2
Provide 12mm diameter bars at 78 mm

***Torsion reinforcement at corners***
Area of torsion steel at each of the corner in 4 layers = (0.75% of area of steel)
Length over which torsion steel is provided = (1/5) short span= 420mm
Provide 10 mm diameter bars at 84mm centers for 420 mm at all four corners in 4 layers.

***Longitudinal beam design***
Grade of concrete: M30
Grade of steel: Fe415
Cover: 50mm
Spacing between bars: 125mm
Longitudinal reinforcement: 20 mm
Shear reinforcement in x direction: 12 mm diameter @ 150 mm c/c
Shear reinforcement in y direction: 12 mm diameter @ 250 mm c/c
Size of beam: 600mmX 1100mm
Area of top reinforcement: 1280.60mm2
Area of bottom reinforcement: 2304 mm2
Skin reinforcement is provided: 4 bars with 20
mm diameter with spacing 250 mm
Number of bars used in top and bottom: 4

***Transverse beam design***
Grade of concrete: M40
Grade of steel: Fe415
Cover: 50mm
Spacing between bars: 238mm
Longitudinal reinforcement: 32 mm
diameter bars used Shear reinforcement in x direction: 12 mm diameter @ 110 mm c/c
Shear reinforcement in y direction: 12 mm diameter @ 200 mm c/c
Size of beam: 1100mm X 1800
Area of top reinforcement: 6065.81mm2
Area of bottom reinforcement: 11923.18 mm2
Skin reinforcement is provided: 6 bars with 32 mm diameter with spacing 242 mm
Number of bars used in top: 8
Number of bars used in bottom: 8

***Pile Design***
The design result is adopted from STAAD PRO V8.I
Grade of concrete: M40
Grade of steel: Fe415
Diameter of the pile:1700mm
Size of bar: 40mm
Spacing between bars: 76 mm

Number of bars provided: 66
Cover: 50mm
Tie reinforcement: 16mm diameter of the bar @300mm c/c
20mm thick stiffeners at every 2 meters span is used.
Reqd. Steel area: 81712.84 sq.mm
Reqd. Concrete area: 2188088.25 sq.mm.
Main reinforcement: provide 66 - 40 dia. (3.61%, 81995.57 sq.mm.) (Equally distributed)
Lateral reinforcement near pile head: 3(Diameter of the pile)
Volume of spiral: 0.6% of gross volume.
Lateral reinforcement near pile head:
Spiral reinforcement is provided in the core of the pile for a length of 3D = 5100mm
Volume of spiral = 0.6% of gross volume
Using 16 mm diameter helical ties (As=200mm2)
Volume of the spiral per mm length = 0.006 X πr2 X1 =13618.80mm3
Pitch of the spiral = $\frac{\text{Circumferenceofspiral X As}}{\text{vol.of spiral}} = \frac{\pi \text{ x } 1600 \text{ x } 200}{13618.80}$ = 74 mm

Provide 16mm diameter spiral at pitch of 74 mm for a length of 5100mm near pile head. the spiral is enclosed inside of the main reinforcements.

Lateral reinforcements near pile ends Volume of ties = 06% of gross volume of concrete for a length of 3D=5100mm
Using 16mm diameter ties, As=200mm2
Volume of each tie = Asx2X3.14x850 = 1068141.5mm3
Pitch of the ties p = 1068141.5 = 0.006X $\pi r2$ X P
P = 80mm

Provide 16mm diameter ties at 80mm centers for a distance of 5100mm from the ends of the pile both at top and bottom.

Size of bar: 40mm
Spacing between bars: 76 mm
Number of bars provided: 66
Diameter of pile: 1700mm
Lateral reinforcement near pile head:
Helical tie reinforcement: 16mm
Pitch of the spiral: 74mm
Lateral reinforcement near pile ends:
Tie reinforcement: 16mm
Pitch of the spiral: 80mm

***STAAD. Pro Analysis***

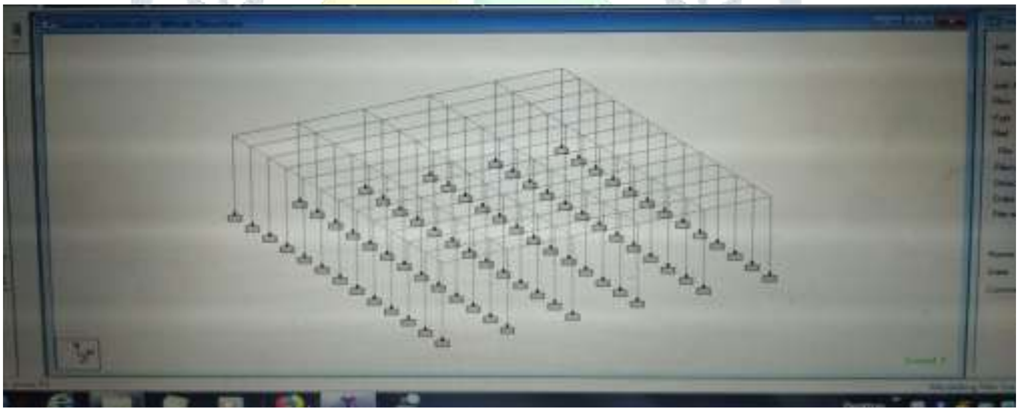


Fig 1. Simple geometry of berth structure

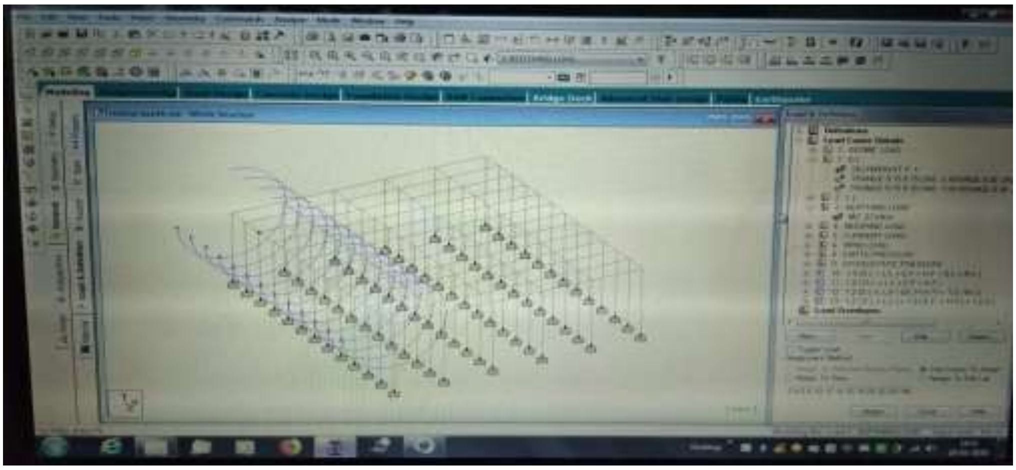


Fig 2. Load calculation

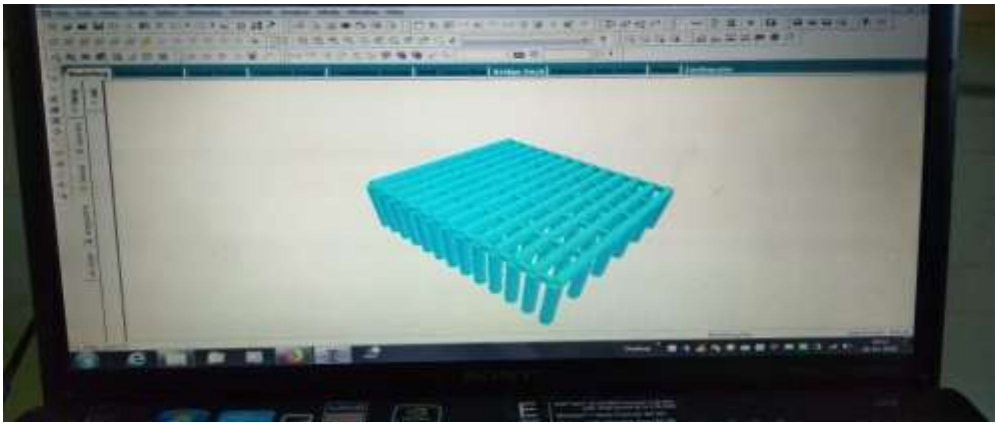


Fig 3. Final design

## VIII. RESULT DISCUSSION

The structure was analyzed and designed satisfying various loading conditions and dimension analysis for economical aspect was also taken care of without exceeding the structural safety. Before going for designing or planning a berthing structure, all the present and future optimistic conditions regarding traffic data, hinterland expansion and industrialization of that particular hinterland are to be studied, which also play a major role in determining the project inception at the first place.

## IX. CONCLUSION

The Analysis and Design of Marine Berthing Structure has been Completed Successfully. The Structural elements are designed manually by using limit state design and the whole Berthing structure has been analyzed by using STAAD Pro Software. The Design of Slab, Beam has been done as per limit state design. The beam having the maximum positive and maximum negative bending moment is taken from the manual analysis report and it is designed using limit state method of design. The compression and tension reinforcement is calculated and the shear reinforcement is provided. Thus the structural elements in the berthing structure are designed and reinforcement details are calculated successfully.

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