Analysis and Design of Dock Berth Structure

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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 Visakhapatnam 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.*

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, vehicles etc. The planning and design of berthing structures depend on various factors.

In the present study of the project, we described a suitable way to design a new berthing structure with example of one of the proposed berthing structure in Visakhapatnam port. So before analysing 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 basic Data was adopted from Visakhapatnam port which were supposed to be used 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 harbour, meant for handling liquid cargo like Sulphuric 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.

A berthing structure is a capital demanding project, thereby; optimum use of both space and capital becomes essential. This means that proper planning of the various units of the structure, for the present and an optimistic future demands, is compulsory. Berthing structures world over undergo from congestion or inflexibility due to short comings in planning or due to wrong estimate of the traffic and or land requirement. Berthing structures vary generally from port to port. The number of berths will depend upon the number of ships to use the port and the time it will take to ejection and take on cargo or passengers. Berthing structures should be located in the most protected part of the harbor or along the lee side of the breakwaters. Where possible the berth should be so oriented as to have the ship alongside headed as nearly into the wind and waves as possible.

Berthing facilities contain mooring bollards, bitts, and rings for protect mooring cables. Fenders, which are customarily composed of resilient materials in sundry shapes and are hanging in front of the berthing facilities, are provided to diminish the impact when the ship is brought alongside or is driven in opposition to the dock by the wind. Dolphins are often utilized as fenders.

II. BASICS IN DESIGN OF BERTHING STRUCTURE

2.1 GENERAL STRUCTURAL CONFIGURATIONS

2.1.1 Location

The location for berthing structures was decided based on a number of factors such as easy accessibility for the ships, availability of sufficient draft throughout the year, favorable Meteorological and wave Hydrodynamic conditions. The last factor plays a major role in determining the magnitude of forces acting on the structures.

2.1.2 Classification

After having decided about the location of the berthing structure, the type of the structure to be constructed needs to be examined. The factors controlling the selection of the type of structure are the flow conditions and the soil properties.

Berthing structures can be classified as wharfs and piers.

1) Wharf - A wharf is a berthing structure parallel to the shore. It is generally contiguous with the shore, but may not necessarily be so.
2) Pier - A pier is a berthing structure which projects out into water. A pier does not necessarily need to run

perpendicular to the shoreline but may project under any angle. It may also be connected with the shore by a trestle and may thus be T or L shaped.

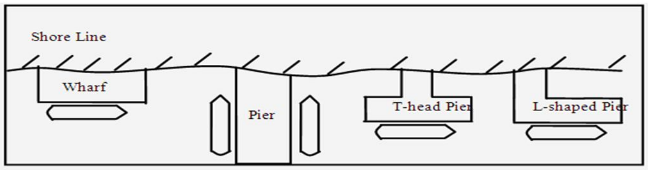


Fig 2.1.2 representation of type of berth

2.1.3 Selection on type of berthing structure

The selection of the type of berth and the material used for its construction will depend upon a number of factors, such as

Local customs and practice: for example the massive quays are generally used in Europe, whereas, open and light structures are usually constructed in America.

- ➢ Availability of materials.
- ➢ Economy of construction.
- ➢ Size and weight of ships using in the port.
- ➢ Method of construction.

2.1.4 Number of berths

The number of berths required in the terminal largely depends upon the traffic to be handled in terms of number of ships to be serviced and their arriving pattern. However, initial investment also plays a major role while planning a new terminal.

The approximate relation used for the determination of the number of berths is:

N1= W/ R* H * D
Where,
N1= required number of berths for a certain cargo.
W = annual amount of this cargo imported and exported. (T/year)
R = handling rate of this cargo on the berth. (T/ hour)
H = number of working hours per day. (Hour/ day)
D = number of working days per year. (Day/ year)

N1 is calculated for each type of cargo, and the total number of berths in the port N for all types of cargo is:
N = N1 + N2 + N3 +……..

2.1.5 Length of berth

The berth length 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.

Berth length required for main line vessels is
275 + 25 = 300m
Berth length required for feeder vessels is
150 +50 = 200m

2.1.6 Area of berth

Berthing area should be based on the length and breadth of the largest size of ship using the berths. Berthing area is the area in front of the berthing structure required for berthing vessels and also accommodates the service vessels. Length required for berthing a vessel and its surging movements due to wave and currents are generally specified as 10% of ships length, subject to a minimum of 15m. d1 should not be less than (L1+L2)/20 and d2 >= (L2+L3)/20 where there are solid obstructions, the safe distance of d0 = 25 – 30 m is allowed. The width of the berthing area should be 1.15 B + b where B is the beam width of the design vessel and b is the width of the attending craft.

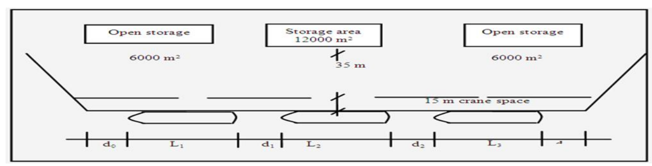


Fig: 2.1.6 Determining area of berth

2.1.7 Draft alongside berth

The third generation container vessels have a draft of 12.5 m. Hence a depth of 13.5 m has to be maintained alongside the quay during all conditions allowing sufficient depth for various allowances. Depth at the berth should be 10% in excess of maximum loaded draft of design vessel to allow for silting and vertical motion.

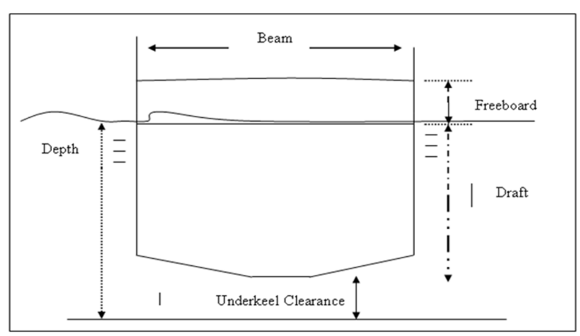


Fig: 2.1.7 draft representation along the berth

2.1.8 Apron width

Apron width a pier is dependent on the type of equipment used for loading and unloading operations. The apron width is decided based on the facilities provided.

2.1.9 Deck elevation

Deck elevation is fixed at or above the highest high spring water level plus half the wave height near the berth plus a free board of 1m. The maximum distance of quay edge inclusive of fixed fenders from the outer track of the crane is about 2.65m.

2.1.10 turning circle

Dimensions of turning circle are dependent on the prevailing intensity of wind, current and the power of tugs available for assistance. The following criteria may be followed in either case for calculating the radius of the circle:

i) Without tug assistance - 1.7 l
ii) With tug assistance - 0.85 L

The third generation ships will have a draft of 12.2 m. Hence a navigational channel which can accommodate these ships is necessary with a minimum depth of 13.5 m.

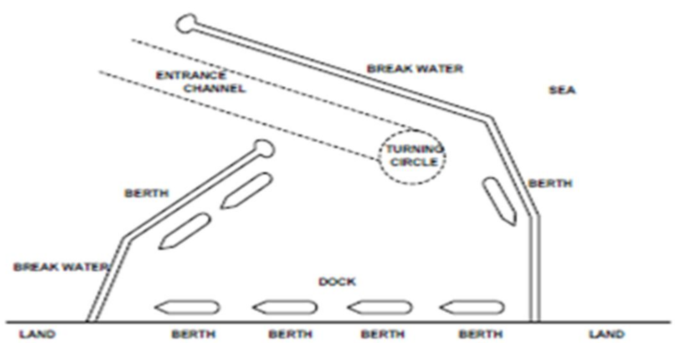
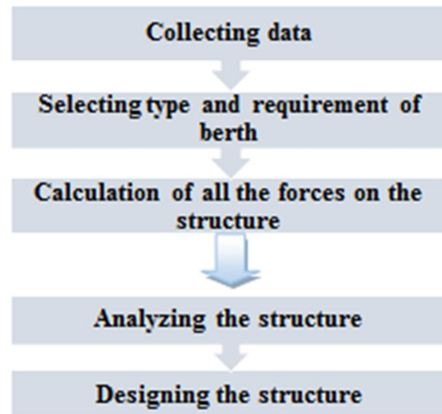


Fig: 2.1.10 turning circle

2.1.11 Stacking area requirements

The area required for storage of container within the terminal depends on the following factors:

1) Throughput expected to pass through the terminal per annum.
2) Dwell time of containers within the terminal. This is the average time a container would spend in the yard after import and before re-export in a transit terminal.
3) The type of container handling equipment used for stacking.
4) Average stacking height: Containers are not stacked to the maximum height in all the slots within the stacking area. This is required to enable the handling equipment to pick up the lower containers in the stack for discharge. Furthermore, containers need to be segregated by destination, weight class, and direction of travel sometimes by types and often shipping line or service. Hence there is always a ratio between the average stacking height and maximum stacking height.
5) Peaking factor: This is the ratio of the peak traffic to the average traffic, usually taken in between 1.3 to 1.4.
6) Ratio of working slots: All the slots provided on the ground cannot be available for stacking due to various reasons. The ratio of working slots to overall slots is usually taken as 0.8.



III. PLANNING OF THE STRUCTURE

3.1 INTRODUCTION

A proper planning of the various units of the structure for the present and an optimistic future demands is necessary. Berthing structures suffer from congestion or inflexibility due to short comings in planning or due to wrong estimate of the traffic and or land requirement over the world. Planning a berthing structure should satisfy certain basic objectives.

1) The berthing structure should be planned to incur minimum capital expenditure to handle the expected traffic.
2) Planning of various systems should keep the operating costs to a minimum.
3) Planning should include a fair degree of flexibility to incorporate future expansion programmes.
4) Planning should ensure free, smooth traffic with adequate road/rail access facilities.

IV. ANALYSIS RESULTS OF THE STRUCTURE

4.1 LOAD CALCULATIONS

4.1.1 Dead load

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.

Wearing coat (Apron) = 0.20 X 25 = 5 kN/m^2(density of the concrete is taken 25 kN/m^3)
Slab weight = 0.30 X 25 = 7.55 kN/m^2

Beams
Transverse beams = 1.10 X 1.80 X25 = 50kN/m
Longitudinal beam = 1.10 X 0.60 X 25=16.5 kN/m
Pile =1.70X21.65X25 = 920.12 kN/m

4.1.2 Live load

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 consist of the weight of all movable equipments on the structure

TABLE 4.1.2
Truck loading and a uniform vertical live load

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

The function of berth related to Truck loading A or AA or 70R (Heavy cargo berth) so we are adopted 50 kN/m^2.

4.1.3 Berthing load

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:

$$E = \frac{W_D V^2}{2g}(C_m)(C_e)(C_s)$$

W_D = displacement tonnage (DT) of the vessel

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

g = acceleration due to gravity in m/s^2

C_m = mass coefficient

C_e = eccentricity coefficient

C_s = soft coefficient

$$E = \frac{200000\,X\,0.10^2\,X\,0.51X1.60\,X\,0.95}{2\,X\,9.81} = 80\text{kN.m}$$

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

4.1.4 Mooring load

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

$$F = C_w A_w P$$

F = force due to wind in Kg

C_w = shape factor = 1.3 to 1.6

A_w = wind age area in m^2

P = wind age pressure in m^2 to be taken in accordance with IS: 875-1964

The wind age area (A_w) can be estimated as follows:
A_w= 1.175L_p (D_M-D_L)
Where
L_p= length between perpendicular in meter
D_M= mould depth in m, and
D_L=average light draft in m.

Actual this is the actual 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 = F$\cos\theta$ = 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.

4.1.5 Current load

Forces due to Current - Pressure due to current will be applied to the area of the vessel below the water line when fully loaded.

F= w v^2/2 g

Unit weight of water (w) =1.025 tonnes/m^3

Velocity of current (v) =0.26m/s

Acceleration due to gravity = 9.81m/s^2

F = 0.035kN/m^2

For 1 unit of berth F = 0.035X33X21.65 =25kN

25kN for 12 piles for each pile F = 2.02 kN

Load distribution is converted as uniform on pile F= 2.02/21.65 =0.096KN/m

4.1.6 Wind load

Wind contributes primarily to the lateral loading on a pier. It blows from many directions and can change without notice. The wind impinging upon a surface increases the pressure on that surface and results in a force loading. Design wind speed (V_z) = $V_b k_1 k_2 k_3$

V_b = basic wind speed

k_1= probability factor (Risk coefficient)

K_2= terrain, height and structure size factor

K_3= topography factor

V_z = (50)(0.92)(1.05)(1)

= 48.3m/sec

Design wind pressure = $0.6(v_z)^2$

p=1400N/m^2

=1.4kN/ m^2

Now the design wind pressure is resolved as nodal loads on structure

=1.4X 33X1 =46.2/12 =3.85 kN

4.1.7 Seismic load

Design seismic base shear V_B= A_hW

A_h = horizontal seismic coefficient

W = seismic weight of structure

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)\left(\frac{I}{R}\right)$$

Z= zone factor = 0.16

I= importance factor = 1.5

R= response reduction factor = 5

$\left(\frac{S_a}{g}\right)$=2.50(hard rock)

$$A_h=\left(\frac{0.16}{2}\right)\left(\frac{2.50}{}\right)\left(\frac{1.5}{5}\right)=0.06$$

W= seismic weight of the structure=55318.5kN

V_B= 4500.5kN

The approximate fundamental natural frequency period of vibration ($T_s$in sec) = $\frac{0.09h}{\sqrt{d}}$

H= height of the structure in meter

D= Base dimension of structure at plinth level in m

$$T_s=\frac{0.09\,X\,23.25}{\sqrt{33}}=0.35\sec$$

4.1.8 Earth pressure

P_a= $K\gamma h$

K = coefficient of earth pressure

γ= unit weight of soil=kN/m^3

H= height of the structure =m

$$K=\frac{1-\sin\phi}{1+\sin\phi}$$

ϕ= angle of internal friction of the soil

$$p_a=\left(\frac{1-\sin 33^0}{1+\sin 33^0}\right)(20)(3)=0.29\,X\,20\,X\,3=17.4kN/m^2$$

= 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

TABLE 4.1.8

Level wise earth pressure on piles

Level (m)	Pressure kN/m	On each pile kN/m
0-3	17.4	47.85
3-4.5	28.7	78.92
4.5-7.5	19.14	52.6
7.5-9	9.57	26.31

4.1.9 Water pressure/hydrostatic pressure

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

γ =unit weight of water=10kN/m^3

H= water head on structure; m

P=10 X 18 =180kN/m^2

= 180X1.57=270kN/m on each pile

- BASIC LOAD COMBINATIONS
- 1.5DL+1.5LL+1(EARTH PRESSURE)+1(HYDROSTATIC PRESSURE)+1.5(BERTHING LOAD)+1.5(MOORING LOAD)
- 1.2DL+1.2LL+1E.P+1.2H.P
- 1.2DL+1.2LL+1EP+1HP+1.5(WIND LOAD)
- 1.2DL+1.2LL+EP+1HP+1.5(SEISMIC LOAD)

V. DESIGN OF THE STRUCTURE

5.1 SLAB DESIGN

5.1.1 Design

1. Data

L_x =2.62m Ly=2.62m

F_{cK}= 40N/mm^2

F_y=415 N/mm^2

2. Depth of the slab

Overall depth is taken as D=300mm

Effective depth d=217mm

Effective coverd^1 = 83mm

Clear cover = 75mm

3. Loads

Self weight of slab = 0.30 X 25 =7.5 kN/ m^2

Apron cover = 0.20 X 25 =5 kN/ m^2

Service load = 50 kN/ m^2

Design ultimate load = w_u= 1.5 X 63 =94 kN/ m^2

4. Ultimate design moments and shear forces

M_u=wl^2/8 = 80.65kN.m

V_u=wl/2= 123Kn

5. $\dfrac{M_u}{bd^2} = 1.68$

Percentage of steel required p_t = $(50)\left[\dfrac{1-\sqrt{1-\dfrac{4.6}{f_{cK}}\dfrac{M_u}{bd^2}}}{\dfrac{f_y}{f_{ck}}}\right]$

= 0.62%

A_{st} = $\dfrac{0.62}{100}(1000X\,217) = 1345.4mm^2$

Provide 1460 mm^2 Area of steel.

Diameter of the bar is 16mm is taken

Area of the bar = $\dfrac{\pi}{4}d^2$ =200mm^2

Required spacing between bars = $\dfrac{200X1000}{1460} = 136.98mm$

Number of bars required per meter = $\dfrac{\text{Ast}}{\text{area of the bar}}$ = $\dfrac{1460}{200} = 7$

Check for shear stress

Consider the unit width of slab

$$\tau_v = \frac{V_u}{bd} = \frac{123}{1000X\,217} = 0.56N/mm^2$$

$$P_t = \frac{100A_{st}}{bd} = \frac{100X1460}{1000X\,217} = 0.67N/mm^2$$

Refer Table 19 of IS:456 and read out:

$$K\tau_c = 0.58N/mm^2 > \tau_v$$

Hence the Shear stresses are within the safe permissible limits

Check for deflection control

$$(L/d)_{\max} = 32$$

$$(L/d)_{actual} = 12.78$$

$$(L/d)_{\max} > (L/d)_{actual}$$

Hence deflection control is satisfied.

Reinforcement in edge strips

A_{st} = 0.12 percent of effective depth =0.0012 X 1000 X 217 =261mm^2

Provide 12mm diameter bars at 78 mm

Torsion reinforcement at corners

Area of torsion steel at each of the corner in 4 layer = (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.

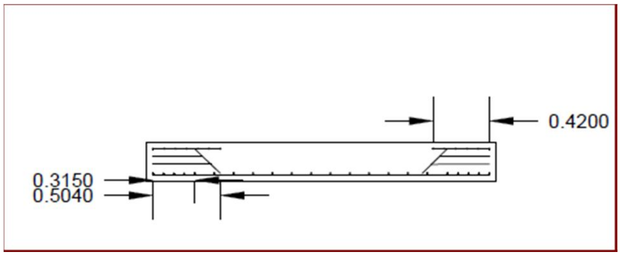
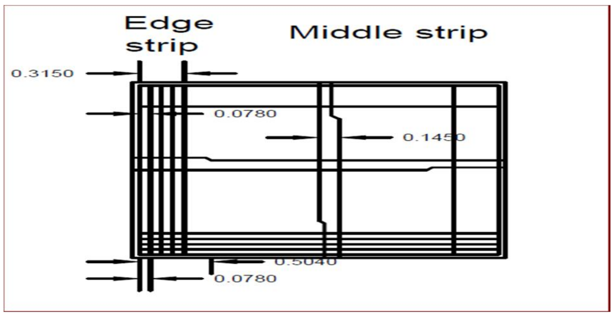


Fig: 5.1 .1.1 slab side view with reinforcement details



Fig; 5.1.1.2 slab top view with reinforcement details

5.2 LONGITUDINAL BEAM DESIGN

Grade of concrete : M30
Grade of steel : Fe415
Cover : 50mm
Spacing between bars : 125mm
Longitudinal reinforcement : 20 mm diameter bars used
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 : 600mm X 1100mm
Area of top reinforcement : 1280.60mm^2
Area of bottom reinforcement : 2304 mm^2
Skin reinforcement is provided : 4 bars with 20 mm diameter with spacing 250 mm
Number of bars used in top : 4
Number of bars used in bottom : 4

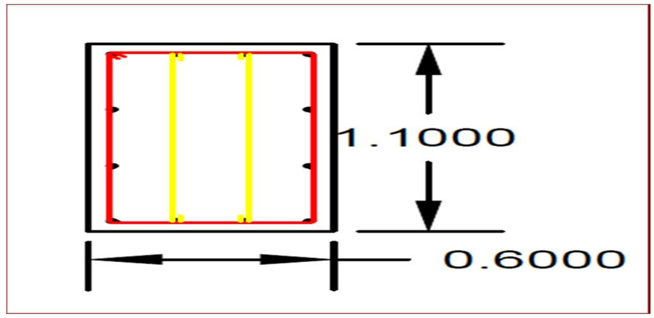
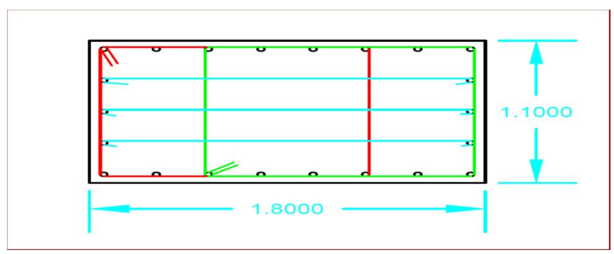


Fig: 5.2.1 Beam cross section view

5.3 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 : 6065.81mm^2
Area of bottom reinforcement : 11923.18 mm^2
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



Fig; 5.3.1 longitudinal beam cross section view

5.4 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 (A_s=200mm^2)

Volume of the spiral per mm length = 0.006 X πr^2 x1=13618.80mm^3

$$\text{Pitch of the spiral} = \frac{circumferenceofspiralXA_s}{vol.ofspiral}$$

$$= \frac{\pi X 1600 X 200}{13618.80} = 74mm$$

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, A_s=200mm^2
Volume of each tie = Asx2X3.14x850 = 1068141.5mm^3

Pitch of the ties p = 1068141.5 = 0.006X πr^2 XP
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

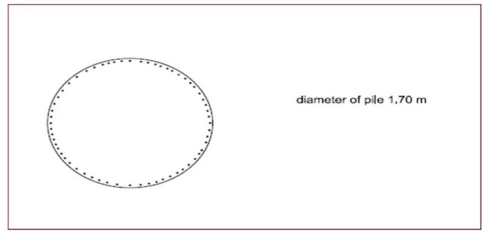


Fig: 5.4.1 Top view of pile

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

VI. CONCLUSION

Different factors are to be considered while analyzing and designing the berthing structure. Lateral loads on the berthing structures are ten times greater than those on land–based structures. Suitable environmental data, traffic forecasting and soil data should be adopted from the proposed site location, typical load distribution is induced on the shore line structures, so need to use STAAD Pro software for the analysis and design.

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.

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