# Comparative Analysis and Design of Wharf structure for Front & Rear Diaphragm Walls

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***Abstract**: This paper presents analysis & design procedure for two types of berthing structures comprising different load conditions and combinations. Since the marine structure is strongly influenced by empirical knowledge, the analysis component - as compared to other refined analysis available for buildings/bridges - is still in the embryonic stage. Hence the structure tends to be bulky. However, with the advances in computational ecosystem, optimized and slender structure is possible; which is also the motive behind this paper. The data was adopted from an all-weather port located in southern part of India. Two types of berth structures were analysed: A diaphragm wall near the seaside & the other with diaphragm wall on hinterland side. The results proved that Rear diaphragm wall type is more advantageous in terms of ease of construction, and more economical.*

**Keywords: Wharf, STAAD, Grillage, Seismic**

## Introduction

Maritime transport constitutes a major chunk of India's trade. About 95% by volume and 70% by value is done through this means. Designing and maintaining port infrastructure plays a pivotal role in the growth of country's trade and commerce. Also, in terms of global scale India ranks number sixteen – largest maritime countries in the world. The focus of this paper is on comparing the quantities required for commonly used Solid berth type structures: Front diaphragm wall type design & Rear diaphragm wall type design. Figure 1. & 2. together shows the details of these type of structures.

## Parametric study

The generic wharf structure discussed in this paper will be assessed in terms of ease of construction, concrete quantity required for diaphragm wall, piles & superstructure beam and slab. Reinforcing steel for the respective structural components is also calculated. A three-dimensional analysis is performed using STAAD pro software for front end diaphragm wall & Rear end diaphragm wall type structures. Rendered view for these two types is shown in figures 6 & 7 respectively. Annexures A & B shows reinforcement details.

## Design Data & STAAD model

The total length of wharf is around 500m with ten units of 50m each. Expansion joints are provided at 50m intervals. Figure 2. shows the part plan of the unit. A 3-Dimensional model is generated in STAAD pro software for one unit for both FDW type and RDW type. At the start of socketing the supports are affixed in the model.

- Grade of concrete: M35
- Grade of steel: Fe500
- Depth of socketing in hard rock: 1.0m

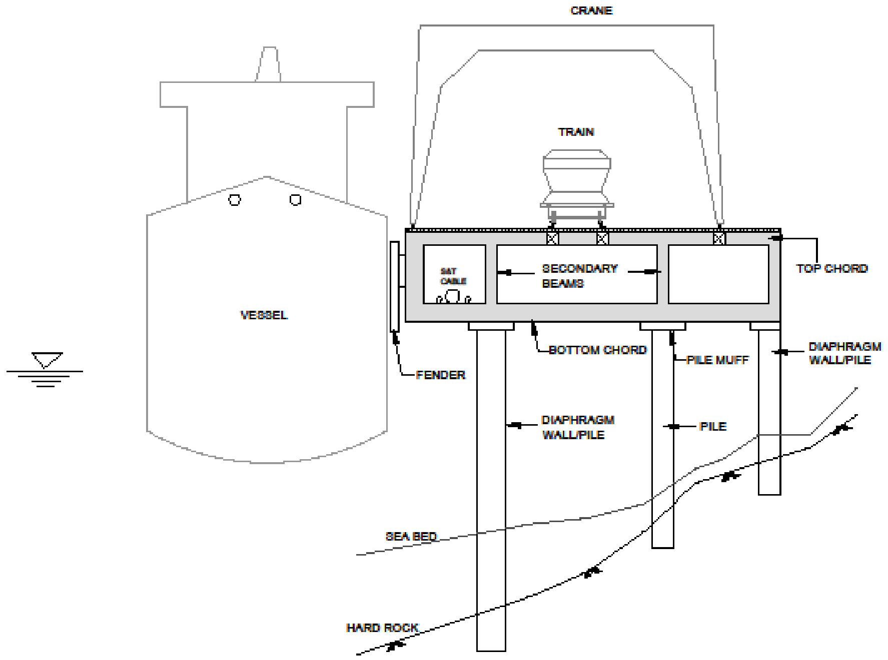


**Figure – 1:** showing Front/Rear Diaphragm wall

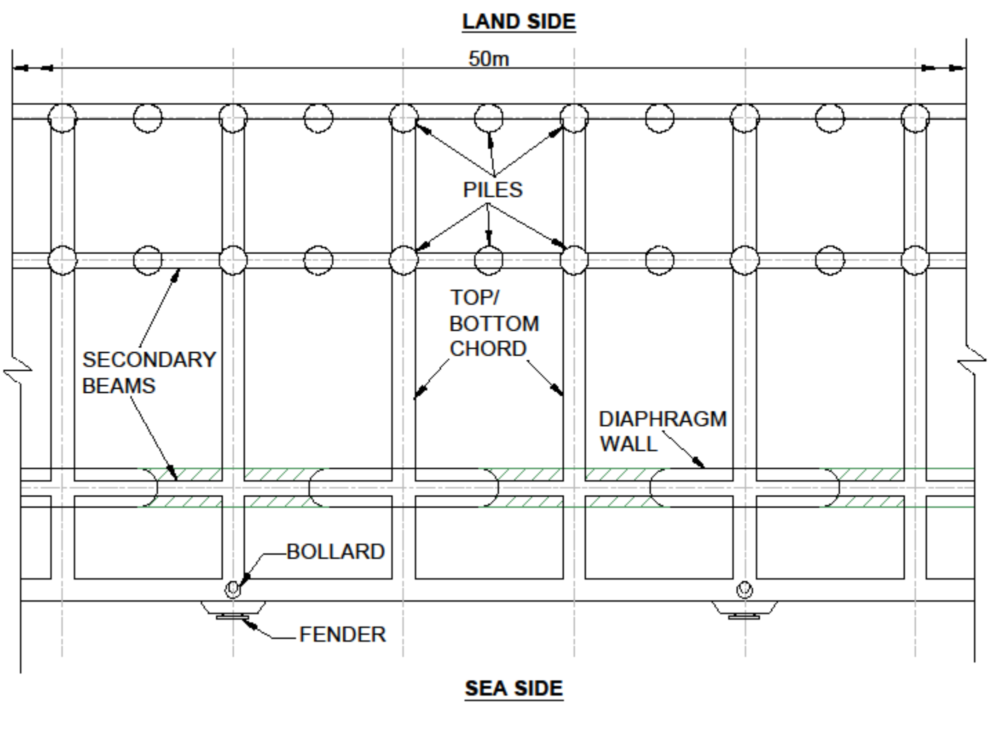


**Figure - 2**: showing plan of Grid

- Type of vessel – Mixed Cargo Freighters
- Fender type – Cylindrical rubber(provided at every 13.5m)
- Bollard type – T head type steel (provided at every 13.5m)

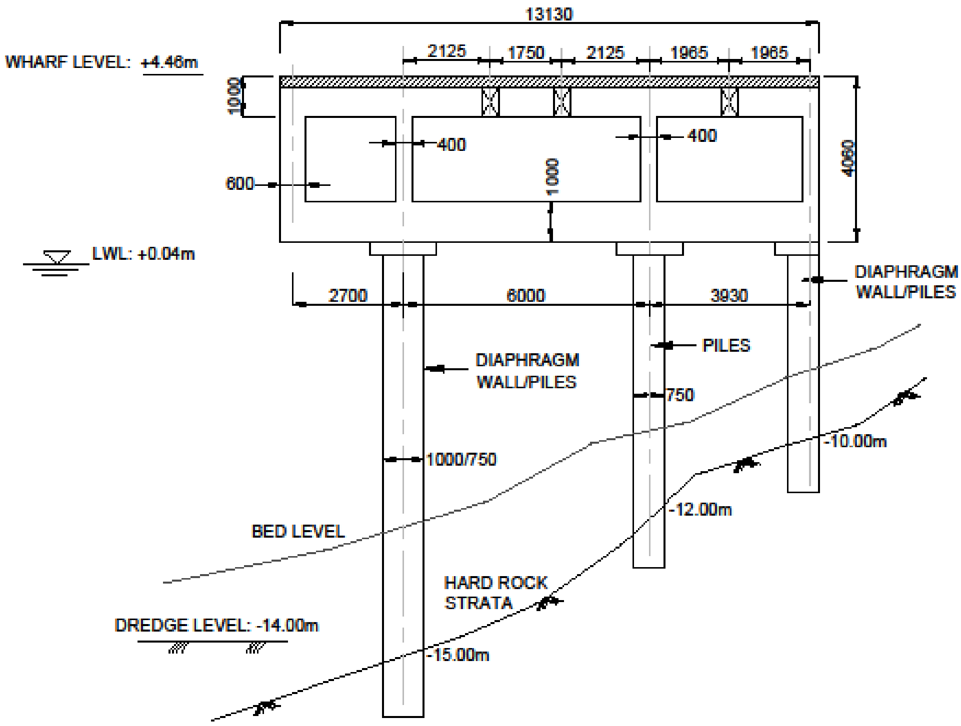


**Figure – 3:** showing levels and dimensions of wharf

## Loads considered

Since a Wharf/Quay wall is structure built along the shoreline and is quite long, a myriad loads acts on these structures. Prominent loads among these are:

- Dead Loads

This includes self-weight of the structure, loads due to signal & telecommunication cables and wearing coat.

Thickness of deck slab = 300mm
Weight due to deck slab = 0.3*25 = 7.5kN/$m^2$
Thickness of wearing coat = 100mm
Load due to wearing coat = 0.1*22 = 2.2kN/$m^2$

- Live Loads

Three types of live loads are acting on a berth structure: loads due to crane, loads due to goods train & cargo loads. Each load is separately combined with load combinations to get the worst effect.

Live load for Cargo Berth = 35kN/$m^2$ (IS 4651 vol 3)
Mobile crane load = 500kN capacity & 1500kN self-weight
Axle Load for goods train = 250kN (IRS Bridge Rules)

- Berthing loads

Berthing force is a kinetic energy imparted by a moving ship on fenders. These fenders and Bollards are spaced at 13.5m centres. Mixed cargo type of vessel is considered for design.

Kinetic Energy $E = (W_D V^2/2g) * Cm * Ce * Cs$

$W_D$ = displacement tonnage = 20000T
V = velocity of approaching vessel = 0.15m/sec
g = acceleration due to gravity = 9.81m/$sec^2$
Cm = Mass co-efficient = 1 + 2D/B
Where D = draft of the vessel – 9.5m
B = Beam of the vessel – 21.5m
Cm = 1.88m
Ce = Eccentricity co-efficient
= $\{1 + (l/r)^2 \sin^2\theta\} / 1 + (l/r)^2$
Where l/r = ratio = 1.25
Θ = angle of approach = 10deg
Ce = 0.409
Cs = softness co-efficient = 0.9
**Kinetic Energy E = 159kN.**

*This value is used in STAAD analysis model.*

- Mooring loads

These are the lateral loads caused due to mooring lines when the vessel is subjected to a pull into or along the berth. Maximum mooring forces is typically observed when wind forces act on exposed area (broad side) of the ship.

The line pull generated by a vessel of 20000T displacement is **60T**. This force is applied as nodal load in STAAD pro.

- Seismic loads

Earthquake forces is a predominant lateral load which can cause failure of piles if not addressed properly. The reason why the piles are not raked is due to high axial force that can cause failure of piles in compression/tension or superstructure itself. 50% of Live load is considered here.

Zone category – III
Zone factor Z – 0.16
Importance factor – 1.5
Response reduction factor R – 3
Average response acceleration co-efficient Sa/g – 2.5
Horizontal seismic co-efficient, $A_h$ = (Z/2) *(I/R) *(Sa/g) = 0.10

Weight of bottom chord = 1.0 * 0.7 * 13.13 * 25 = 229.77kN
Weight of top chord = 1.0 * 0.7 * 13.13 * 25 = 229.77kN
Weight of secondary beams = 4 * 0.4 * 4.5 * 1.26 * 25 = 227kN
Weight of cross beams = 3 * 0.6 * 0.7 * 4.5 * 25 = 141.75kN
Weight of slab = 0.32 * 4.0 * 11 * 25 = 352kN

Total dead load = 1180KN

Live load = 0.5 * 35 * (4.50 * 13.13) = 1024kN

**Seismic Force = 0.10 * (1180+1024) = 220KN**

*This force acts at CG of deck structure for every 4.5m intervals and the same is applied in STAAD model.*

Wave Forces

Minikins method is adopted for calculating force due to breaking wave. It is assumed that the wave is at right angles to the wall. Pressure caused by breaking waves is a combination of dynamic and hydrostatic pressure. Non overtopping condition is assumed.

pressure due to wave force R = Rm + Re
$= P_m h_c + P_s(d+h_c/2)$
$= w d_b h_c/2 + w\,(d + h_c)^2/2$
Where w = density of sea water = 10.3kN/m$^3$
$d_b$ = max water depth = 15.04m
d = water depth at diaphragm face = 14.04m
$h_c$ = height of wave = 2.29m
***Wave thrust R = 1551kN*** *& is applied the same in STAAD model*

- Earth Pressure

Active earth pressure using coulombs theory is calculated on the landside for both FDW type and RDW type as shown in fig 4. Density shown in figure is in kN/m$^3$ and height in m; consequently earth pressure is in kN/m$^2$ units. These values form input in STAAD model and applied as linearly varying load on beams.

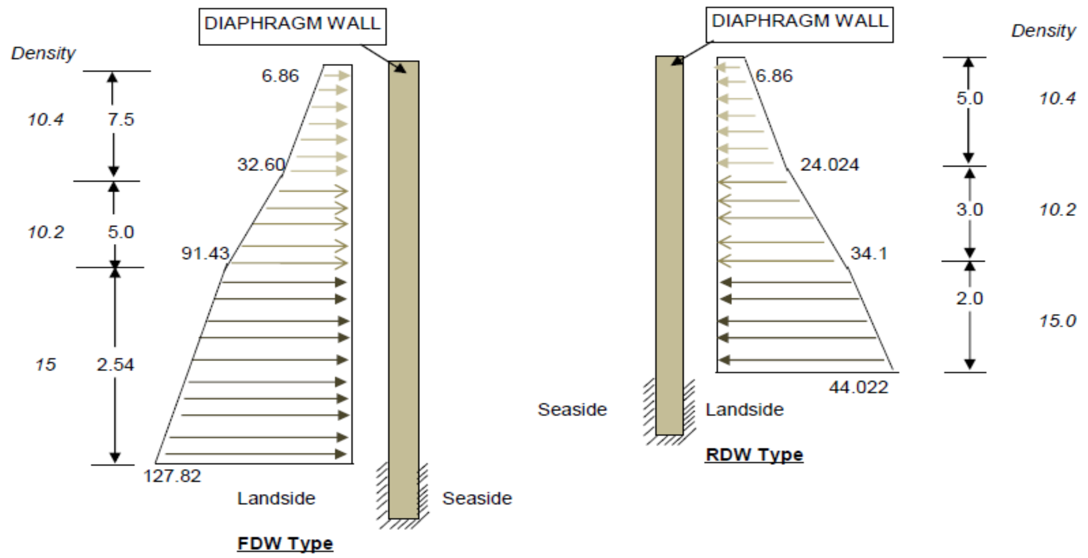


**Figure – 4:** showing Earth pressure variation

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- Differential water pressure

The pressure differential caused due to seaside and fill-side must be accounted in the design. For calculation purpose the height is considered from Mean low water level to start of socketing. The pressure calculation with diagram is as shown in fig. 5.

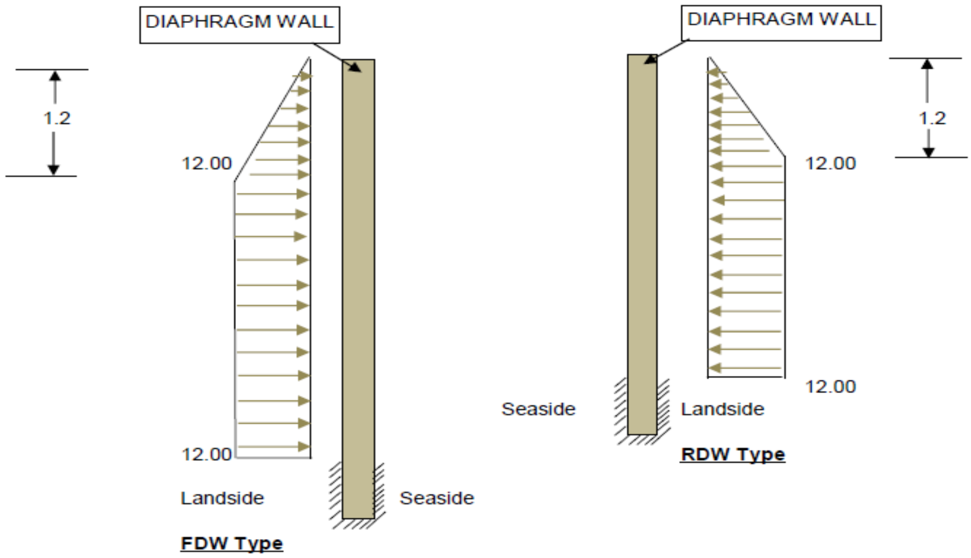


**Figure – 5:** showing pressure diagram on diaphragm wall

## Load combinations

As per clause 6 of IS-4651 part III – 1974 code of practice for design of ports and Harbours- loading, the combinations of loads for design are:

1. Dead load + vertical live load + Earth pressure + Berthing load
2. Dead load + vertical live load + Earth pressure + Line pull
3. Dead load + vertical live load + Earth pressure + Earthquake
4. Dead load + vertical live load + Earth pressure + Wave pressure

Fifteen load combinations are possible. The worst combination should be taken for design. Working stress method of design philosophy is followed.

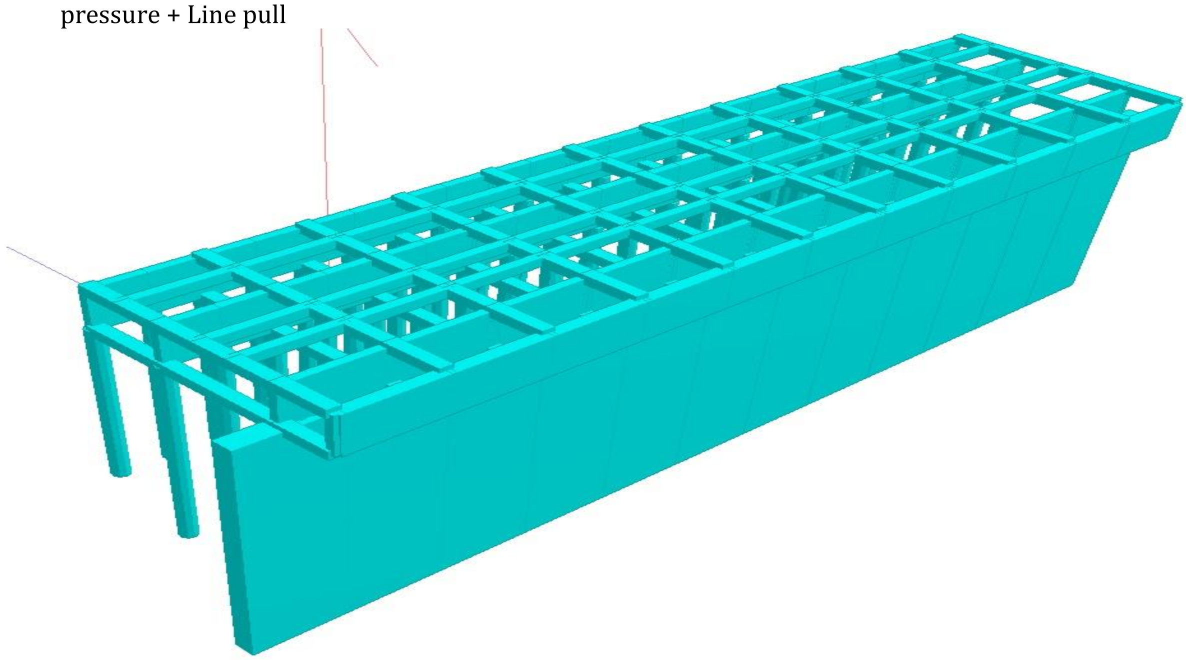

**Figure – 6:** showing rendered view & loads acting for FDW type

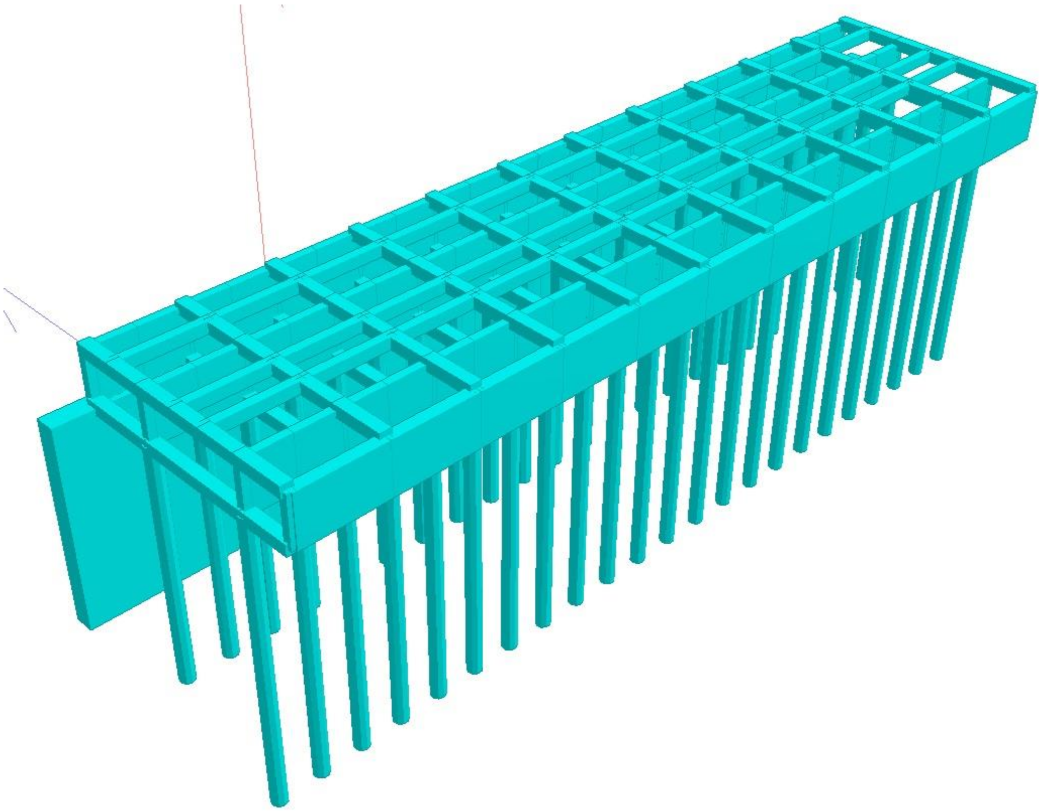

**Figure – 7:** showing rendered view & loads acting for RDW type

**Table - 1:** Summary of Forces and designs

| Description | Front Diaphragm wall (FDW) type | | | | Rear Diaphragm wall (RDW) type | | | |
|---|---|---|---|---|---|---|---|---|
| *Combination* | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) |
| **1. Piles** | | | | | | | | |
| Bending moment (kNm) | 438 | 503 | 613 | 869 | 185 | 210 | 263 | 361 |
| Shear force (kN) | 82 | 94 | 114 | 165 | 30 | 34 | 43 | 60 |
| Area of steel reqd (mm$^2$) | 3245 | 3727 | 4542 | 6438 | 3142 | 3142 | 3142 | 3142 |
| **2. Diaphragm wall** | | | | | | | | |
| Bending moment (kNm) | 5988 | 6144 | 7561 | 3877 | 2697 | 2797 | 3921 | 4737 |
| Shear force (kN) | 1425 | 1440 | 1576 | 462 | 1646 | 1664 | 1860 | 298 |
| Area of steel reqd (mm$^2$) | 44365 | 45521 | 56020 | 28725 | 19982 | 20723 | 29051 | 35097 |
| **3. Top Chord** | | | | | | | | |
| Bending moment (kNm) | 721 | 779 | 836 | 1040 | 779 | 832 | 877 | 915 |
| Shear force (kN) | 604 | 609 | 663 | 745 | 544 | 546 | 580 | 589 |
| Area of steel reqd (mm$^2$) | 5342 | 5772 | 6194 | 7705 | 5772 | 6164 | 6498 | 6779 |
| **4. Bottom Chord** | | | | | | | | |
| Bending moment (kNm) | 387 | 478 | 586 | 988 | 397 | 508 | 643 | 1172 |
| Shear force (kN) | 267 | 281 | 395 | 781 | 330 | 348 | 550 | 972 |
| Area of steel reqd (mm$^2$) | 2867 | 3542 | 4342 | 7320 | 2941 | 3764 | 4764 | 8683 |

## Mode Shapes

A Mode shape is the deformation the structure would exhibit when vibrating at natural frequency. Eigen value extraction method is adopted in calculating frequency of the structure. 10 mode shapes each for FDW & RDW type walls are extracted from STAAD pro. Fig 8. shows comparison between modes shapes for FDW & RDW type structures.

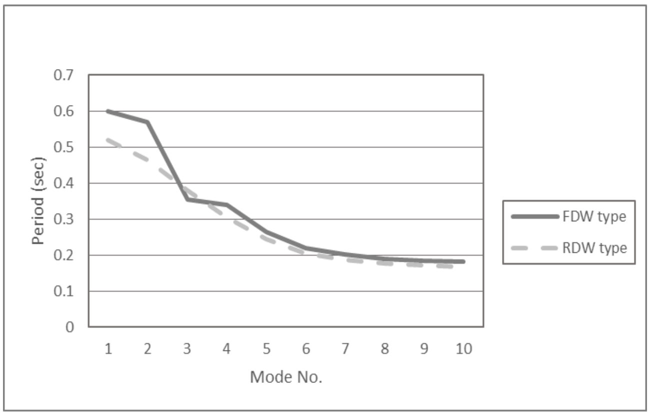


**Figure – 8:** Modal Period for FDW & RDW type

**Table - 2:** Concrete and Steel quantity comparison per unit (50m length)

| Structural Components | Front End Diaphragm wall (FDW) type | Rear End Diaphragm wall (RDW) type |
|---|---|---|
| Concrete | | |
| a. Diaphragm wall (cum.) | 850 | 600 |
| b. Piles (cum.) | 264 | 314 |
| c. Superstructure (cum.) | 411 | 411 |
| **Total (cum.)** | **1525** | **1325** |
| Steel | | |
| a. Diaphragm wall (t) | 243 | 133 |
| b. Piles (t) | 30 | 20 |
| c. Superstructure (t) | 60 | 60 |
| **Total (t.)** | **333** | **213** |

## Conclusion

1. From table 2. above it can be seen that concrete quantity required is about 85% for Rear Diaphragm wall as compared to Front diaphragm wall type. Similarly steel quantity required for Rear diaphragm wall is about 65% of what is required for Front diaphragm wall type. Hence Rear diaphragm wall type construction is more economical.
2. Also, in terms of construction ease RWD type is a more preferred choice.
3. RDW type is a stiffer structure in transverse direction as compared to FDW type. Hence attracts higher seismic force.
4. In a nutshell, RDW type outweighs the pros and hence is a preferred choice among designers and contractors.

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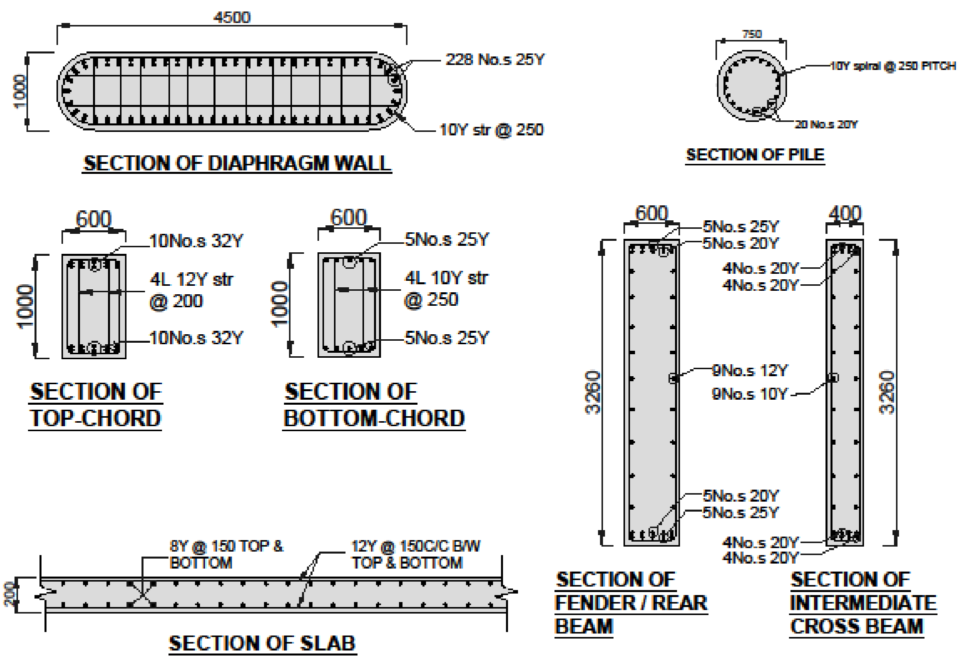
## Annexure A

*(Reinforcement Details of Front Diaphragm wall type design)*




## Annexure B

*(Reinforcement Details of Rear Diaphragm wall type design)*