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Effect of stiffness on performance of a diaphragm wall with irregular configuration

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Present study investigates the influnces of the stiffness on the performance of a lateraly loaded R.C.C diaphragm wall and an inter-comparison has been made between the actual and compound sections by modelling the wall using Plaxis 3D software. Displacement and bending moment are found out for diaphragm walls and results are compared with the actual diaphragm wall section having 1.1m thick.The study concludes that when two sections of different stiffness are coupled to form a single section , the stiffer member takes higher bending moment and the magnitude depends the stiffness of the thinner member.

[**Keywords:**Keywords: Diaphragm wall, Anchor rod, berthing structure, static, lateral earth pressure]

Introduction

Berthing structures are constructed in ports and harbours to provide facilities for berthing and mooring of vessels, loading and unloading of cargo and for embarking and disembarking of passengers and vehicles [1,2].

When there is a difference in stiffness between the installed structure and the surrounding soil, arching occurs. If the structure is stiffer than the soil then load arches onto the structure[3]. Otherwise, if the structure is less stiff than the soil then load arches away from the structure. For instance, if part of a rigid support of soil mass yields, the adjoining particles move with respect to the remainder of the soil mass. This movement is resisted by shearing stresses which reduce the pressure on the yielding portion of the support while increasing the pressure on the adjacent rigid zones. Differing stiffness of wall components may lead a three dimensional stress flow in the surrounding soil[4,5]. Current conventional design procedures for flexible or rigid diaphragm walls do not take in to account the 3-D stress flow in the surrounding soil mass. This phenomena have significant effect on distribution of earth pressure and consequently bending moments and displacements of a structure.

FEM adopt to get several approximations to predict true solutions considering the nonlinear behaviour of soil. Finite element method has become more popular as a soil response prediction tool. This has led to increased pressure on researchers to develop more comprehensive descriptions for soil behavior, which in turn leads to more complex constitutive relationship. A constitutive model to be satisfactory it must be able to: (i) define the material behaviour for all stress and strain paths; (ii) identify model parameters by means of standard material tests; and (iii) physically represent the material response to changes in applied stress or strain[6,].

In the present study, three-dimensional finite element approach is adopted. A common practice in design of diaphragm wall is to design a thick section of uniform stiffness throughout. But it may not be economical always. In this paper diaphragm wall sections of non-uniform stiffness and irregular configuration are analysed using finite element software PLAXIS 3D and the displacement, and bending moment of the structure subjected to static loads are investigated and the results are compared.

Materials and Methods

For the purpose of analysis, diaphragm wall constructed in the deep draft multipurpose berth of New Mangalore Port, Karnataka, India is considered. The cross section of berthing structure is shown in Fig. 1.

Pre-stressed anchor is aligned with an inclination 45°. Dredge level varies from -10 m to -17 m. Hard

rock bed layer is at a depth of -30 m. Chart datum is at 0.0 m. Width of the berthing structure is 33 m. Berth is supported by a diaphragm wall and 4 rows of 1000 mm diameter piles. Piles are terminated at a depth of -30 m. Dredge depth is -10m near the diaphragm wall and -17 m near the first pile. In addition, anchor rods are also provided at every 2.5 m.

The cross-section of the diaphragm wall is modelled in the PLAXIS 3D as shown in Fig. 2.

After the loads have been defined, the next step is the generation of mesh as shown in Fig. 3. The basic element type used here is the 15-node triangular element.In PLAXIS 3D, first 2D meshes are generated then it is extended in other direction using 3D mesh generation option. If the soil layer thickness varies, the element distribution in vertical direction may also vary.

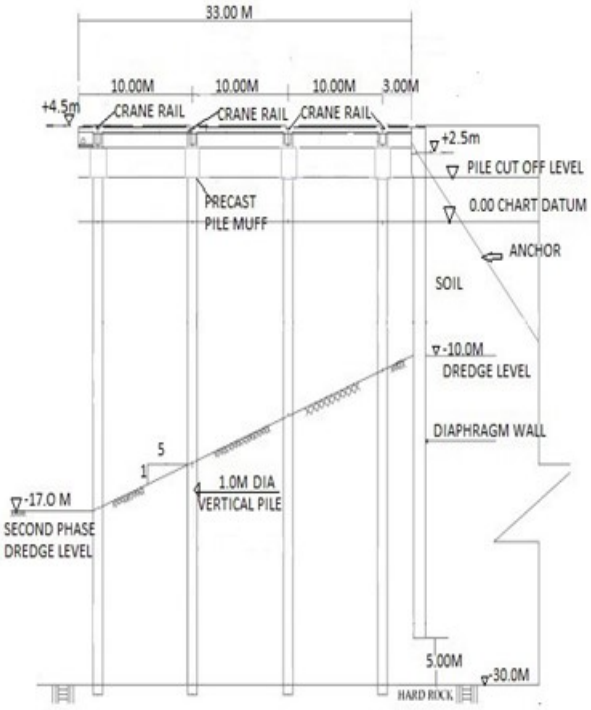

Fig. 1 — Cross-section of deep draft berth

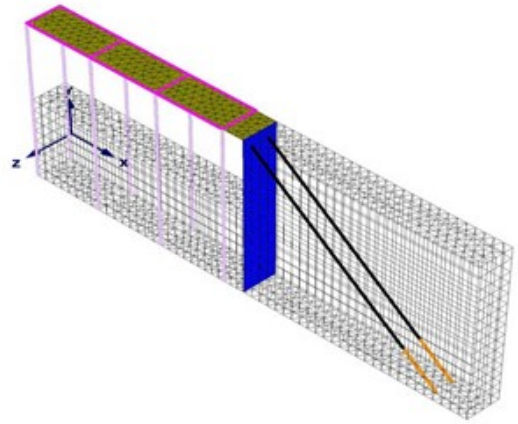

Fig. 2 — Model of diaphragm wall with anchors.

As a result of different numbers of element layers in vertical direction, 15-node wedge elements may be degenerated to 13-node pyramid elements (single degeneration) or to 10-node tetrahedral elements (double degeneration) at the point where the number of elements in vertical direction changes.Thewell known Mohr - coloumb model is used as a first approximation of soil behaviour. Mohr - coloumb model requires five basic input parameters,namely Young's modulus (E), Poisson's ratio (ν), Cohesion(c), friction angle (φ), and dilatancy angle (ψ). Different parameters to be input to the PLAXIS software include the structural details of the different elements and also the properties of the different soil layers are as shown in Table 1 & 2. Stiffness of the sections are shown in table 3.

The boundary conditions are vertical model Boundaries with their normal in x direction (i.e. parallel to the y-z plane) are fixed in x direction (u_x = 0) and free in y and z direction. Vertical model boundaries with their normal in y direction (i.e. parallel to the x-z plane) are fixed in x direction (u_y = 0) and free in x and z direction. Model bottom boundary is fixed in all directions ($u_x = u_y = u_z = 0$). Ground surface of the model is free in all directions.

Results and discussion

Analysis of actual section (1.1m thick) with anchor.

When the anchor is placed at +4.5 m, the maximum displacement of the wall of -0.00568 m is obtained at

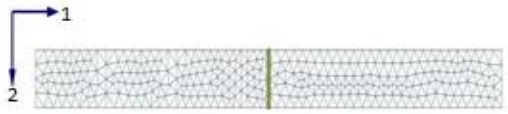

Fig. 3 — Finite element mesh of diaphragm wall.

Table 1 — Input Parameters of structural elements

Component	Material	Model	Modulus of Elasticity(E) (kN/m^2)	Poisson's Ratio μ
Embedded Pile	RCC	Elastic	4.025×10^7	0.15
Diaphragm Wall	RCC	Elastic	5.9×10^8	0.15
Beam	RCC	Elastic	1.233×10^7	0.15
Slab	RCC	Elastic	2.958×10^7	0.15
Anchor Rod	steel	Elastic	1.351×10^8	0.15
Steel Pile	steel	Elastic	2.10×10^8	0.15

Table 2 — Input Parameters of Soil Properties

Material	Model	Young's Modulus E(kN/m^2)	Saturated Density Υ_{sat} (kN/m^3)	Poisson's Ratio,μ	Cohesion (C) kN/m^2	Φ in degrees
Fine Sand	Elastic	80000	18	0.3	0.5	30
Medium Sand	Elastic	70000	18	0.3	0.45	30
Marine Clay	Elastic	20000	18	0.49	17	0
Coarse Sand	Elastic	60000	18	0.25	0.4	30

Table 3 — Stiffness of various cross- sections

Different sections	Young's Modulus (concrete) (kN/m2	Moment of Inertia (I)M^4	Stiffness (EI) (kN-m2)
Actual section	31.62×10^6	0.5545	17.53×10^6
Section-1	31.62×10^6	0.1829	5.78×10^6
Section-2	31.62×10^6	0.1445	4.569×10^6
Section-3	31.62×10^6	0.1147	3.626×10^6

8 m.When the anchor is placed at +4.5 m, the maximum displacement of the wall of in between the support and the position where the anchor is located. When the anchor is placed at a depth of +2.5 m, the maximum displacement obtained is -0.00446 m at -10 m which is less than the previous case. Anchor position when shifted to 0 m, the length of the diaphragm wall in between the anchor and the bottom of the diaphragm wall is reduced as a result of which the maximum displacement in between these two points is reduced. But the portion of the diaphragm wall above the anchor deflects in the opposite direction. When the anchor position is at -6 m, the diaphragm wall displacement is almost same in above and below the anchor. When the anchor position is shifted to -10 m, (at dredge level) the displacement of diaphragm wall between the anchor and the support at the bottom is considerably reduced but above the dredge level considerably increased and maximum occurred at +4.5 level. The deviation may be due to the fact that it become cantilever wall, when the anchor located at dredge level.

The variation of bending moment is shown in Fig. 4. Bending moment is initially zero at the top of the diaphragm wall for the normal case when there is no anchor rod present. At the position where the anchor is placed, the bendingmomentvalue increases in the positive direction due to load being taken up by anchor. Maximum value of bending moment is obtained when the anchor is placed at +4.5m, this is because, the diaphragm wall behaves like a propped cantilever beam subjected to point load at free end and the bending moment is maximum at the fixed end. When the anchor is placed at -6m the bending

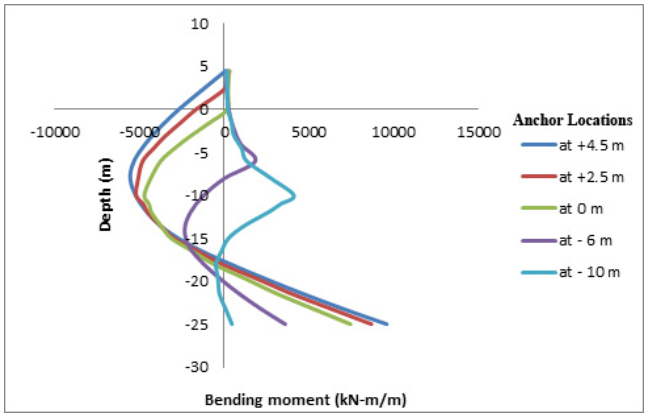

Fig. 4 — Variation of bending moment with depth for the diaphragm wall (actual section) for different anchor rod locations.

moment reduces significantly because the anchor force is applied approximately at the center of diaphragm wall and it results in less moment at the fixed end of the diaphragm wall.Table 4 shows deflection and bending moment for actual section for different anchor locations.

Analysis of diaphragm wall with different sections

Section 1

In order to check the behaviour of section when stiffness is varied, a compound section called section (Fig. 5) is designed. In this a 1.1m thick section (same as actual section) is sandwiched between 0.6m panels and studied the behaviour of diaphragm wall. The middle 1.1m thick section has the same thickness as that of actual diaphragm wall. While comparing the displacements of actual section and section 1 (Fig.6 & 7), the trend of the graph for both cases are matching for various anchor locations. While comparing the bending moment of actual section and section (Fig.4 & 8), the trend of the graph for both cases are matching for various anchor locations. Maximum bending moment is found to be acting at 1.1m thick portion of section and which was more than that of actual section even though same thickness and same loading condition.

Table 4 — Values of Displacement and bending moment for varying locations of anchor (Static analysis

Anchor Location (m)	Max. Displacement & its location		Max. Bending Moment & its location			
	Displacement (m)	Location (m)	B.M (+ve) (kNm/m)	Location (m)	B.M (-ve) (kNm/m)	Location (m)
+4.5	0.00568	-8	9560	-25	5565	-8
+2.5	0.00446	-10	8700	-25	5217	-10
0	0.00328	-12	7460	-25	4732	-10
-6	0.00092	-15.5	3600	-25	2345	-14
-10	0.00469	+4.5	4490	-10	491	-18

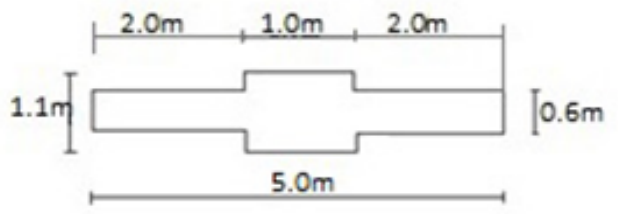

Fig. 5 — Diaphragm Wall Section 1

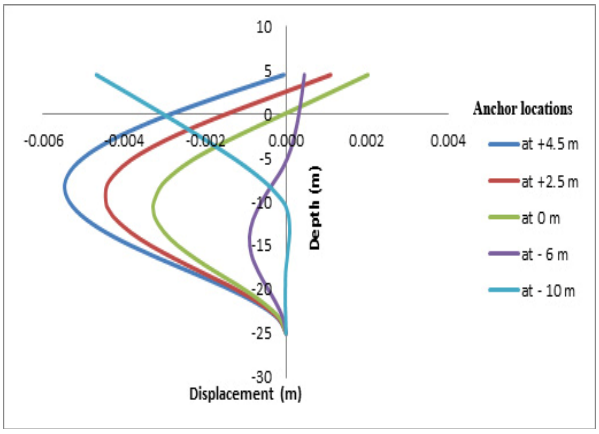

Fig. 6 — Variation of Displacement with depth for the diaphragm wall (actual section) for different anchor rod locations

Stiffness of the section1 is reduced about three times of actual section. But the maximum displacement and bending moment are increased 10.57% (0.00568m to 0.0063m) & 33.15% (9560kNm to 12730kNm) respectively for walls having same young's modulus.The variations may be due to the coupling of thinner section with thicker section. Fig. 7 & 8 shows maximum displacement and bending moment for section1. Maximum deflection and maximum bending moment of section 1 for different anchor locations shown in Table 5.

Section 2 and 3

In Section 2, rectangular hollow concrete pile section is sand witched with 0.6 m thick solid panels and in Section 3, circular hollow concrete pile section

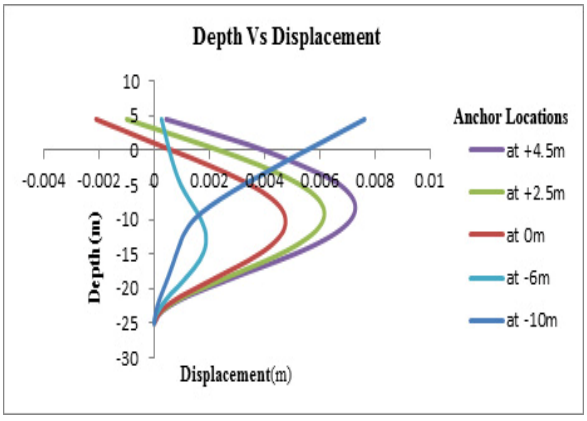

Fig. 7 — Variation of deflection with depth for Section 1.

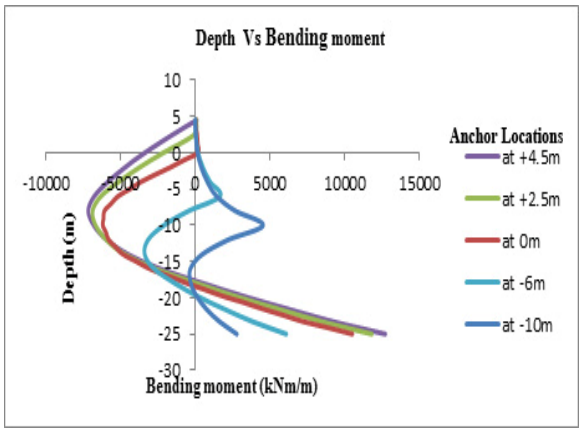

Fig. 8 — Variation of bending moment with depth for Section 1.

is provided between 0.6 m thick solid concrete panels as shown in Fig. 9**.**

From the analysis it is found that maximum displacement in section 2 and 3 are found to be 0.00663m and 0.00692m for anchor location -10 m @ +4.5m depth. Similarly maximum bending moment in section 2 & 3 are 2630 and 3640 kNm for the anchor location +4.5 at a depth, -25.0m. Among section 2 and 3, section 2 is performing betterbecause the deflection and bending moment are reduced 30% and 28% respectively.

Variation in deflection and bending moment with anchor location for both sections are shown in Table 6 & 7. Deflection and bending moment are shown in Fig. 10 &11 and Fig. 12 & 13 respectively.

From the analysis of sections 2 &3, the maximum displacements are increased 16.3% & 21.4%, and the maximum bending moments are decreased 73% & 62.6% respectively, comparing with actual section. The results shows, by introducing stiffer rectangular or circular concrete pile sections, the bending moment can be reduce evnthough the slight increase in displacement,hence the overall performance of the wall panel can be improved.

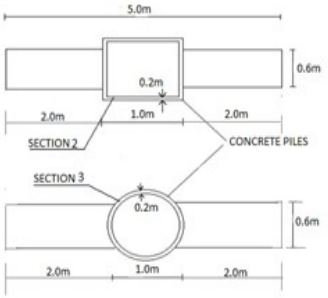

Fig. 9 — Diaphragm Wall Section 2 & 3

Three different diaphragm wall sections are studied using finite element software PLAXIS 3D. Static analysis of diaphragm was carried out using site condition existing in deep draft berth of NMPT. Each diaphragm wall is analysed for various locations of anchor rod to find out the extreme values of displacements and bending moments. Usually diaphragm walls have same stiffness throughout, but in this study stiffness of the wall is varied within the section in order to study the effect. Two composite sections are also studied by using concrete piles in between 0.6m thick concrete panels. Each diaphragm wall is analysed for – 10 m dredge depth for various

Table 5 — Maximum deflection and maximum bending moment of section 1 for different anchor locations

Anchor location	Max. Displacement & its location		Max. bending moment & its location (1.1m thick)		Max. bending moment & its location (0.6m thick)	
	Displacement (m)	Location (m)	Bending moment (kNm/m)	Location (m)	Bending moment (kNm/m)	Location (m)
+4.5m	0.00630	-8	12730	-25	4130	-25m
+2.5m	0.00617	-10	11830	-25	3810	-25
0m	0.00476	-13	10450	-25	3260	-25
-6.0m	0.00218	-15	608	-25	1505	-25
-10m	0.00763	+4.5	4540	-10	1270	-10

Table 6 — Maximum deflection and maximum bending moment of section 2 for different anchor locations

Anchor location	Max. Displacement & its location		Max. Bending moment & its location			
	Displacement (m)	Location (m)	B.M (+ ve) (kNm/m)	Location (m)	B.M (- ve) (kNm/m)	Location (m)
+4.5m	0.00663	-7	2630	-25	1285	-8
+2.5m	0.00393	-10	2440	-25	1220	-8
0m	0.00306	-11	2160	-25	1135	-10
-6.0m	0.00236	-14	1310	-25	591	-14
-10m	0.00686	+4.5	1190	-10	78	-17

Table 7 — Maximum deflection and maximum bending moment of section 3 for different anchor locations

Anchor location	Max. Displacement & its location		Max. Bending moment & its location			
	Displacement	Location	B.M (+ ve) (kNm/m)	Location (m)	B.M (- ve) (kNm/m)	Location (m)
+4.5m	0.00692	-8 m	3640	-25 m	1890	-8
+2.5m	0.00561	-10 m	3390	-25 m	1885	-8
0m	0.00433	-12 m	3000	-25 m	1676	-10
-6.0m	0.00274	-15 m	1760	-25 m	916	-14
-10m	0.00756	+4.5 m	1570	-10 m	87	-18

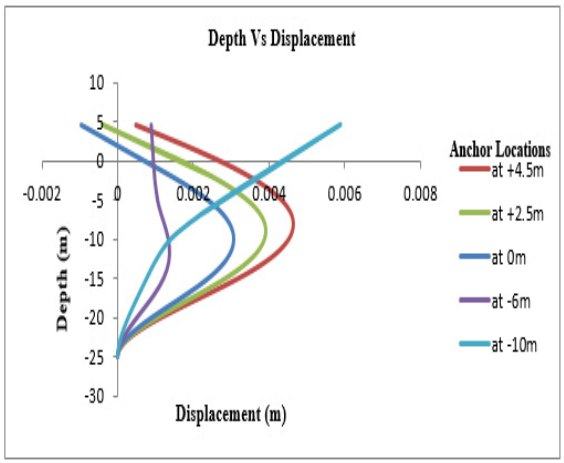

Fig. 10 — Variation of displacement with depth for Section 2.

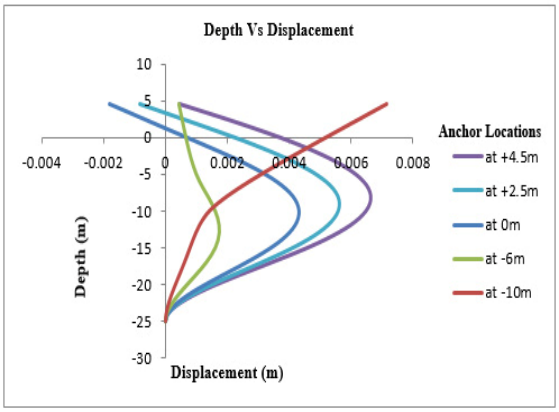

Fig. 11 — Variation in displacement with depth for section 3.

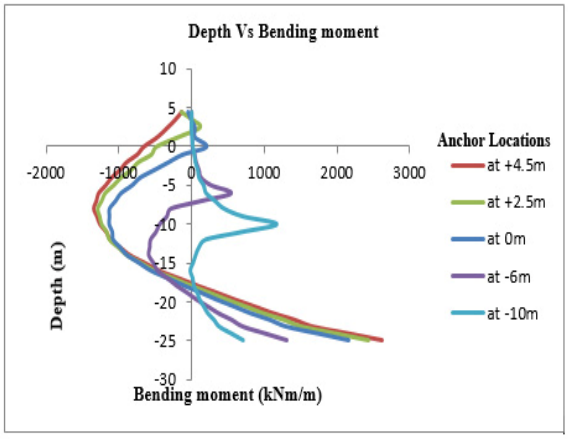

Fig. 12 — Variation in bending moment with depth for section 2

locations of anchor rod. It is clear from the studies that there is significance of the position of anchor and stiffness of wall sections in performance of a diaphragm wall.

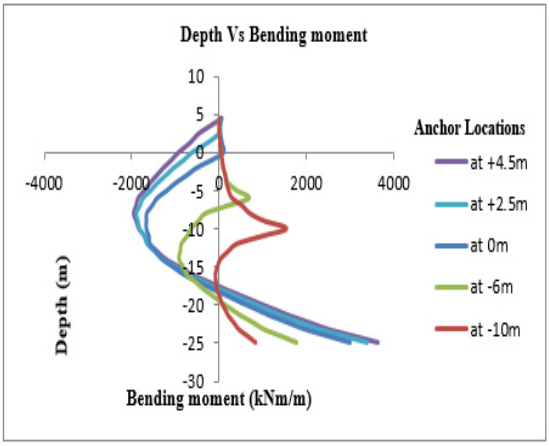

Fig. 13 — Variation in bending moment with depth for section 3.

Conclusions

When the stiffness of the section reduced by1⁄3 (section 1) of actual section the maximum displacement and bending moment are increased 10.57% & 30.5% respectively for walls having same young's modulus. Analysis of section1 shows the maximum bending moment acting at 1.1m thick panel section and which was more than that of actual section even though same thickness and same loading condition. Hence the study shows when the section of different stiffness coupled to form a single section, the stiffer member taking higher bending moment.

From the analysis of sections 2 &3, the maximum displacements are increased 16.3% & 21.4%, and the maximum bending moments are decreased 73% & 62.6% comparing with actual section. The results shows, by introducing stiffer rectangular or circular concrete pile sections, the performance of the wall panel can be improved.

For all sections, both bending moment and displacement is found to be minimum when anchor is placed at -6.0m.

Acknowledgements

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