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BEHAVIOUR OF AN OPEN TYPE BERTHING STRUCTURE UNDER EARTHQUAKE CONDITION –A NUMERICAL APPROACH

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ABSTRACT: Piles and diaphragm wall supported berthing structure on marine soils are loaded laterally from horizontal soil movements generated by dredging. The literature on the adequacy of the finite element method modeling of berthing structure to analyse their behaviour during dredging and under earthquake condition is limited. This paper describes the finite element approach for analysing the lateral response of pile and diaphragm wall during dredging and seismic loading on the dredged soil. Piles are represented by equivalent sheet pile walls and a plain strain analysis using the finite element method is performed. Results of static and earthquake analysis are compared.

1 INTRODUCTION

Construction of piles and diaphragm wall supporting open type berthing structure on marine soils results in development of time dependent vertical and horizontal sub soil displacement. Where the land side forms an approach to the berthing structure the sub soil displacement may generate axial and lateral loads on the piles and diaphragm walls. Additional lateral loading may also be derived from landside earth pressure during dredging. While the induced axial loading due to dredging is often minimized by placing a suitable coating on the piles and diaphragm wall, lateral loading from subsoil displacement generated by dredging generally cannot be avoided or reduced in this way. Sometimes the lateral loading may lead to structural distress or failure of the structures. Hence the study of dredging effect on the piles and diaphragm wall supported berthing structure is necessary.

The design of pile and diaphragm wall supported berthing structure subjected to lateral loading from horizontal soil movements may be based on semi-empirical or theoretical analysis. The literature on the adequacy of the finite element method (FEM) modeling of berthing structures to analyse their behaviour during dredging is limited. The available data are generally limited in extent and complicated by variations in geometry or soil conditions. Hence there are many uncertainties in the estimation of bending moments and lateral deflections induced in piles and diaphragm wall under these conditions. The effects of the pile and diaphragm wall supported berthing structure to the seismic loads (dynamic analysis) are also studied. If the bending moments and deflections induced in piles and diaphragm wall can be accurately estimated, then more cost effective construction procedures may be confidently implemented to take advantage of sizes and configurations of an alternative pile and diaphragm wall.

The magnitude of the soil movement is related to many factors such as soil properties, structural properties and dredging sequence. A number of case studies have been reported in the literature which gives the relationship between those factors and wall deflection. Among these are Dibiagio and Myrvoll (1972) Davies (1982), Tedd et al (1996), Clough and Rourke (1990) and Tamano et al (1984). The aspects of their studies included effects of wall construction on ground movements and changes in lateral earth and water pressure and numerical modeling of the effects of wall construction and ground movements. In this paper, a finite element approach is described for analysis of piles and diaphragm wall supported berthing structure influenced by lateral soil movements generated by dredging and then subjected to seismic load. The approach is based on a plane strain representation of the problem.

2 DETAILS OF BERTHING STRUCTURE

Typical cross section of the berthing structure is shown in fig. The width of the berthing structure is 31m. The berth is supported by 1100mm thick diaphragm wall and five rows of 1400mm dia. piles. The diaphragm wall is terminated at a depth of -25.5m and the piles are terminated at a depth of -20.5m. The natural slope of the soil is represented in the Fig.1. To satisfy the berthing facility of the vessel, the ground level is required to be dredged up to -9.5m level.

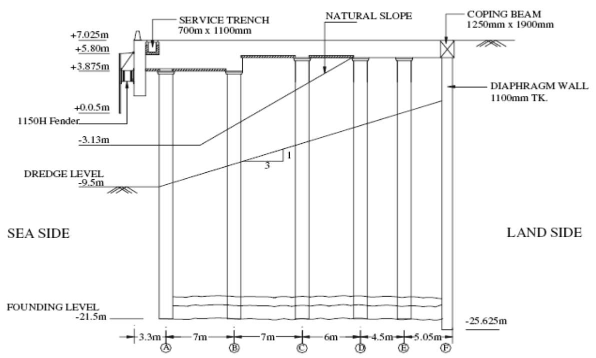

Fig. 1 Typical cross section of the berth

3 NUMERICAL MODELING

3.1 Governing factors

Numerical models involving FEM can offer several approximations to predict true solutions. The accuracy of these approximations depends on the modeller's ability to portrait what's happening in the field. Often the problem being modelled is complex and has to be simplified to obtain a solution. Two of the major factors which have a vast impact on both the real and model piles are 1) the constitutive properties of the sand and 2) the soil structure interaction at the interface over the structural surface.

3.2 Constitutive models

Finite element method has become more popular as the soil response prediction tool. This has lead to increased pressure and researchers to develop more comprehensive descriptions for soil behaviour, which in turn leads to more complex constitutive relationship. Prevost and popescu (1996) state that for a constitutive model to be satisfactory it must be able to 1) define the material behaviour for all stress and strain parts 2) identify model parameters by means of standard material tests and 3) physically represent the material response to changes in applied stress or strain.

Previous studies have explored constitutive models and found that the use of isotropic models such as elastoplastic Mohr-Coulomb and Drucker-Prager models are sufficiently accurate. In the past, linear elastic constitutive models have been commonly used in developing pile design methods.

4 DESCRIPTION OF APPROACH

For this study, the model tests are analysed using a plain strain finite element approach, with the piles represented as equivalent sheet pile wall. Plain strain analysis is the most straight forward of the finite element approaches and allows good representation of the pile group configuration and geometry, without being unduly complicated. The equivalent sheet pile walls are modelled with beam column elements connected to the finite element mesh, and the soil strata is represented by 15 noded triangular elements of elastic-plastic Mohr-Coulomb model. Soil structure interaction is modelled by means of a bilinear Mohr-Coulomb model. The finite element program PLAXIS is used for the study.

In the model study, the same dimensions of the field berthing structure are adopted. The boundary of stratigraphy of the model is taken as two times greater than the structural area. The soil strata are modelled with 15 noded triangular elements and the equivalent sheet pile walls and pile cap are defined by 5 noded beam column elements with nodes separate from those defining from the soil.

The soil nodes and pile nodes are connected by bilinear Mohr-Coulomb interface elements. This allowed an approximate representation of the development of lateral resistance with relative soil pile movement and ultimately the full limiting soil pressure acting on the piles. The stratigraphy is represented using finite elements. Then the self weight load is applied to the mesh for generating the initial stress condition, allowing the excavation (dredging) procedure to be modelled.

The typical finite element discretization of the berth is shown in Fig.2 The soil stratum is idealized by 15 nodes triangular elements with elastic-plastic Mohr Coulomb model and the structural elements are idealized by beam elements

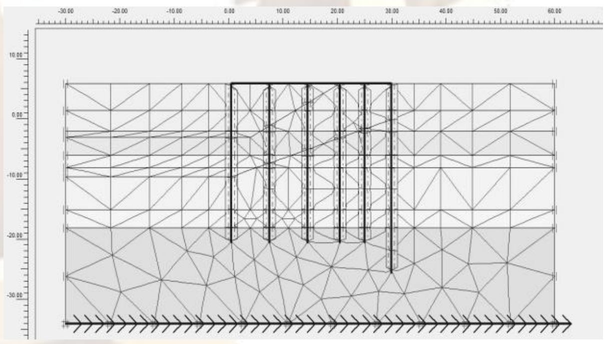

Fig.2 Discretization of Finite element Mesh

5 MATERIAL PARAMETERS

5.1 Soil and Structural properties

The analyses are conducted with moorum fill soil, soft to hard marine clay and basalt represented by Mohr Coulomb model. The Mohr Coulomb model is used for the proposed (linear elastic plastic) model, with plastic flow governed by an associative flow rule. The input parameters for soil and structural elements are taken from Muthukkumaran and Sundaravadivelu (2007). The input values of soil and structural elements are presented in Table-1 & 2 respectively. Initial stresses are generated for each clay layer of elements by appropriate density, which is also included in table. Initial stresses are generated in moorum fill layer by specifying the constant value of K_0=0.4 (initial stress at rest condition, for φ=40°).

The piles, diaphragm wall and pile cap are represented by 5 noded beam column elements. The beam elements are based on Mindlin's beam theory. This theory allows for beam deflection due to shearing as well as bending. In addition, the element can change length when an axial force is applied. Bending (Flexural rigidity) stiffness EI and axial stiffness EA are input as the average of the soil and pile properties over an equivalent 1m thickness of the mesh. Thus the bending moments and shear forces resulting from the analysis are factored up by the pile spacing to obtain the bending moments and shear forces per pile. As the soil stiffness is much lower than the structural stiffness. The equivalent wall properties are effectively independent of the soil properties and do not vary with depth.

Table 1 Structural member properties

Description	(EA) (kN/m)	(EI) ($kN/m^2/m$)	(ν)	Equivalent Thickness (t) (m)
Pile	$4.552x10^7$	$5.57x10^6$	0.15	1.212
Pile cap	$1.775x10^7$	$5.324x10^5$	0.15	0.6
Diaphragm wall	$3.253x10^7$	$3.28x10^6$	0.15	1.1

Table 2 Soil properties

Description	Density (γ_{sat}) (kN/m^3)	UCC (kN/m^2)	(φ) (degree)	(E) ($kN/m^2/m$)	(ν)
Moorum fill	20	0	40	$100x10^3$	0.35
Softy marine silty clay	16	20	0	$87.1x10^3$	0.4
Medium stiff clay	17	50	0	$197.71x10^3$	0.45
Very stiff clay	19	112	0	$378.25x10^3$	0.45
Hard marine silty clay	20	200	0	$578.68x10^3$	0.4
Basalt rock	22	700	0	$1.25x10^6$	0.25

5.2 Soil structure interface

Fifteen noded soil elements and five noded structural elements connected with five pairs of interface elements as shown in the Fig. In the figures, the interface elements are shown to have a finite thickness, but in the finite element formation the coordinates of each node pair are is identical which means that the element has zero thickness. The virtual thickness is defined as the virtual thickness factor times the average element size. The value of virtual thickness factor is 0.1. The average element size is determined by the global coarseness for the mesh generation.

5.3 Seismic data

For the present study, the ANZA earthquake data are given as input parameter for earthquake analysis. The data are presented in Table 3.

Table 3 ANZA earthquake data

Date	1980/02/25
Location	30km East of Anza, CA
Depth (km):	14.1
M_w:	5.5

6 ANALYSIS SEQUENCE

The analyses are carried out in total stresses by generating the initial stresses using the structural parameters represented in Table 1 and the undrained parameter of soils presented in Table 2. In this, the analysis is carried out in two phases. The first phase deals with the static analysis of the pile group and diaphragm wall influenced by lateral soil movements generated by dredging. These analyses correspond to the case immediately after dredging. Then the second phase deals with the dynamic analysis of the pile group and diaphragm wall subjected to earthquake loads.

7 RESULTS AND DISCUSSION

Figure 3 & 4 shows the soil displacement of the berthing structure after –9.5-m dredging under static and dynamic conditions respectively it is observed that the soil movement is much greater in top layers of moorum fill and soft marine clay. From Fig.3 we can see that the maximum displacement due to dredging, takes place at the interface of the dredge level with the diaphragm wall. From Fig.4 we can see that maximum displacement due to seismic effects occurs at the top right portion of the soil block.

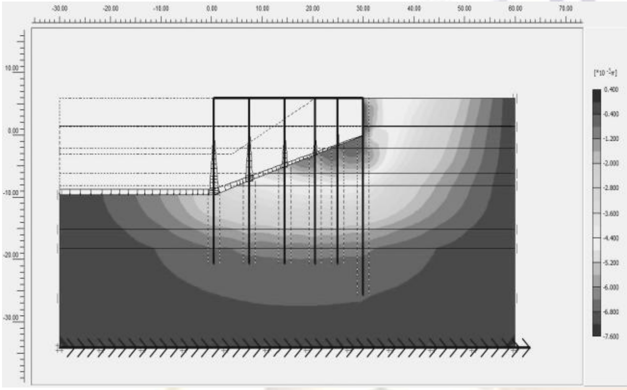

Fig.3 Extreme total displacement in static analysis (Extreme total displacement $8.25*10^{-3}$ m)

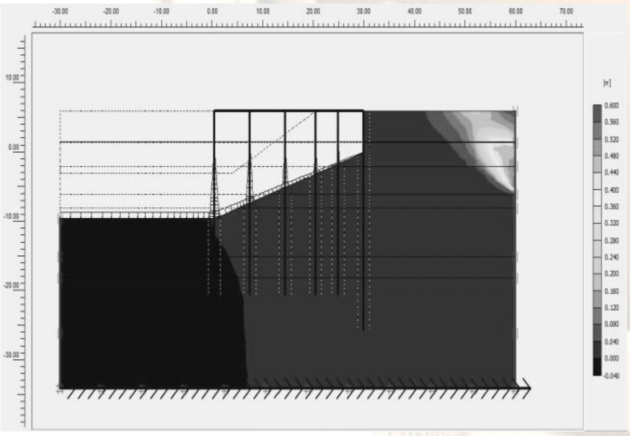

Fig.4 Extreme total displacement in dynamic analysis

(Extreme total displacement $690.53*10^{-3}$ m)

From Fig. 5 we can see that the displacement curves for both diaphragm wall and outer pile are similar under dredging. In both the cases maximum displacement occurs at the top.

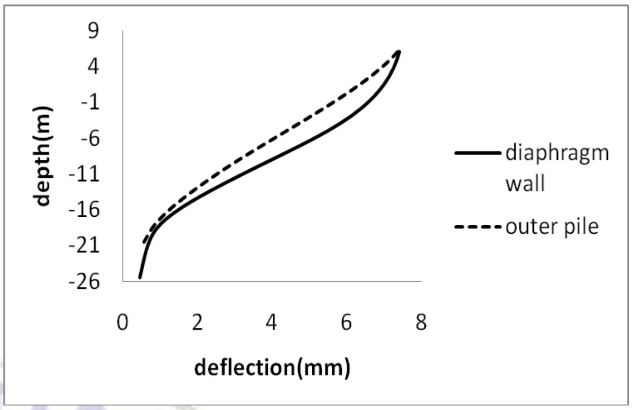

Fig.5 Comparison of displacements of the diaphragm wall and pile after -9.5m dredging

From Fig. 6 the maximum deflection due to seismic load for the diaphragm wall occurs at -7.5m which is in medium stiff clay layer and that of the outer pile occurs at the top.

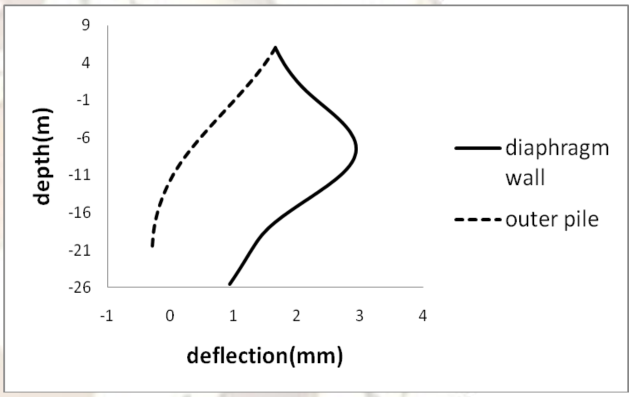

Fig. 6 Comparison of displacements of the outer pile and diaphragm wall under seismic effects

Fig.7 shows that the maximum positive bending moment in diaphragm wall occurs at a depth of -18m which lies in the interface of basalt rock and hard marine silty clay and maximum negative bending moment occurs at -3m which lies in the softy marine silty clay. The maximum positive bending moment in the outer pile occurs at -18m and maximum negative bending moment occurs at the top which lies in the moorum fill.

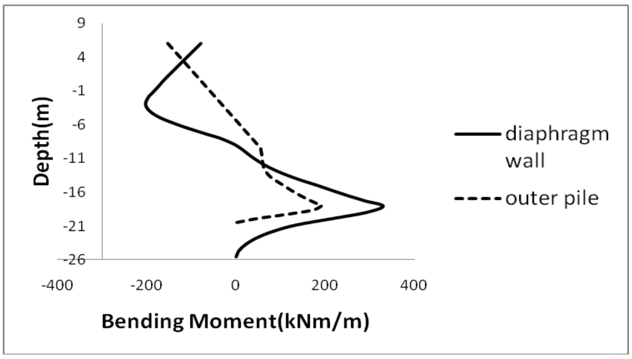

Fig.7 Comparison of bending moments of the diaphragm wall and outer pile due to dredging effects

Fig.8 shows that the maximum positive bending moment in diaphragm wall occurs at a depth of -8.875m which lies in the very stiff clay layer and maximum negative bending moment occurs at +0.375m which lies in the moorum fill. The maximum positive bending moment in the outer pile occurs at -18m which lies in the interface of basalt rock and hard marine silty clay and maximum negative bending moment occurs at the top which lies in the moorum fill.

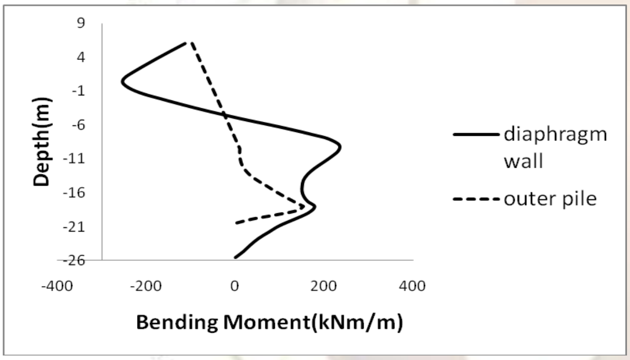

Fig.8 Comparison of bending moments of the diaphragm wall and outer pile due to seismic effects

8 CONCLUSIONS

The paper described the numerical work behind the analysis of the pile and diaphragm wall supported berthing structure for the dredging and earthquake conditions. From this analysis, we conclude that the lateral response of the berthing structure is significantly affected by dredging and under earthquake conditions. A maximum of 7.3mm lateral deflection was observed under dredging and around 3.2mm under seismic condition. However, under seismic condition the lateral displacement of ground was observed to 700mm. the bending moment behaviour also changed significantly under the seismic condition. A maximum bending moment of 230kNm was observed under seismic condition.

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