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DYNAMIC ANALYSIS OF OFFSHORE PILES EMBEDDED IN ELASTOPLASTIC SOFT CLAY

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This work deals with the dynamic behavior of offshore piles embedded in soft clay, and an attempt is made to estimate the critical embedded pile length. ABAQUS finite element program is used to simulate the problem. The soil was modeled as an elastic state and elastoplastic state and represented by cam-clay model. Three dimensional elements were used to represent the interaction between pile and soil, laboratory tests are used to obtain the real properties of soil and to describe interface. The results obtained are used to develop the elastic equation used by Matlock and Reese to calculate the critical embedded pile length for pile embedded in elastoplastic soil. Also, show that the critical embedded pile length is increased by about (20 % to 40 %) due to changing soil model from elastic to elastoplastic. The pile embedded in an elastoplastic soil is dependent on soil strength, interface properties and pile rigidity. The pile head displacement is increased about 90 % while the bending moment is deceased by 10 % at pile head.

Keywords: Dynamic analysis, Pile critical embedded length, Elastoplastic soft clay.

1 INTRODUCTION

Offshore piles are subject to a certain amount of lateral loads due to wave, current, wind and impact loads in addition to overturning moments and vertical loads. In an onshore structure the lateral loads are about (10% to 15%) of vertical loads, but in the offshore and coastal structures the lateral loads are very important and may exceed 30% of the axial loads (Brebbia 1979). Piles are usually selected and designed as a cost effective for supporting the raised structures for offshore platform. Soil pile interaction system governs the response of the structure. According to the defining soil state and interface, the soil-structure interaction system is basically controls estimating the contact pressure distribution at the interaction. When the contact pressures are calculated, the displacements, moments and shear forces in the piles and the corresponding stresses and deformations in the soil medium are possible to estimate (Muthukkumaran 2015). Matlock *et al.* (1970) developed curves for soft clays, and Reese *et al.* (1974) developed curves for sands and for stiff clay (1950) (Reese 2007). Those curves were obtained from actual field measurements, which represent non-linear stiffness of soil springs which later adopted by (API 2005).

In this paper the elastic and elastoplastic solutions for soil models are used to estimate the critical embedded pile length and find the variation in response of the structure and piles when the piles embedded in elastic and elastoplastic soil.

2 FINITE ELEMENT ANALYSES

ABAQUS was used to carry out the analysis. It is used to solve engineering problems based upon the finite element method applicable to linear and nonlinear solutions (Hibbitt 2010).

2.1 Elements Selection

Two types of elements were used to represent the structure and soil element; the first element is beam element (B32), 3-node quadratic beam in space, this type of element have three node each node have six degree of freedom, three displacement and three rotations in x, y and z direction, this element was used to represent the structure element and pile element. The second element is (C3D20RP), 20-node brick with pore pressure, quadratic displacement, linear pore pressure and reduced integration which was used to represent the soil element; each node has three displacements in x, y and z. (Hibbitt 2010).

2.2 Interface Element

12-node displacement and pore pressure three dimensional cohesive elements were used to model the interface. The local 1- and 2-directions are normal to the thickness direction and, by default, are defined by the standard ABAQUS convention for local directions on surface. Transverse shear behavior is defined in the local 1–3 and 2–3 planes for these elements. Figure 1 shows the model of interface element between soil and pile (Hibbitt 2010) and (Naylor 1981).

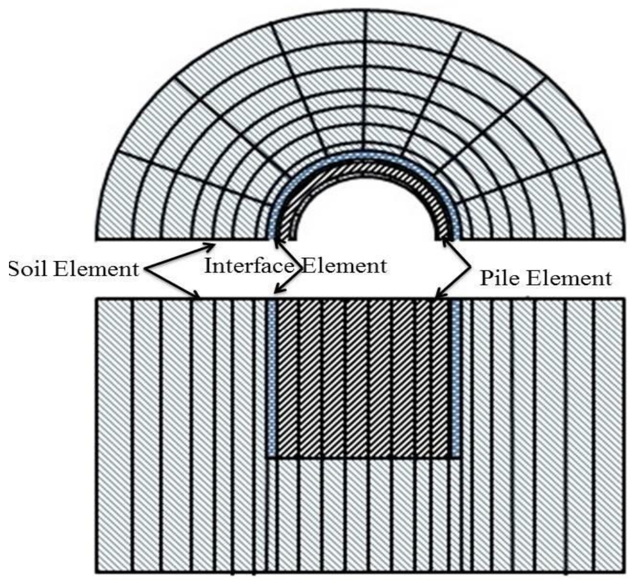

Figure 1. Interface element between soil and pile.

3 CONSTITUTIVE SOIL MODEL

Modified cam clay model is an elastoplastic model based on few and simple postulates that predicts the stress-strain behavior of soils. The model was developed initially from triaxial tests data and later extended for three-dimensional stress space. In critical state mechanics, the state of a soil sample is characterized by three parameters, effective mean stress p', deviatoric (shear stress) q, and specific volume v. Under general stress conditions, the mean stress, p', and the deviatoric stress, q, can be calculated in terms of principal stresses σ'_1, σ'_2 and σ'_3 as

$$p' = \frac{1}{3}\left(\sigma'_1 + \sigma'_2 + \sigma'_3\right) \tag{1}$$

$$q = \frac{1}{\sqrt{2}}\sqrt{(\sigma'_1 - \sigma'_2)^2 + (\sigma'_2 - \sigma'_3)^2 + (\sigma'_3 - \sigma'_1)^2} \tag{2}$$

The specific volume is defined as $v = 1 + e$ where e is the void ratio. The yield functions of modified cam clay model are determined from the following equation (David 1990).

$$\frac{q^2}{p'^2} + M^2 \ln\left(1 - \frac{p'_0}{p'}\right) = 0 \tag{3}$$

4 SOIL TESTS

4.1 Triaxial Test

In a conventional triaxial compression test, a cylindrical core sample is loaded axially to failure, at constant confining pressure. Conceptually, the peak value of the axial stress is taken as the confined compressive strength of the sample. In addition to axial stress, axial and radial strains may be monitored during this test, to determine basic elastic constants (Young's Modulus, E, and Poisson's ratio, ν) and shear strength of soil (cohesive and internal soil friction). Test results of three samples as shown in figure 2 and figure 3 (BS5930).

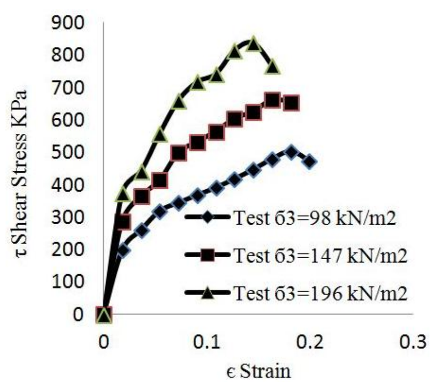

Figure 2. Stress strain curve from triaxial test of soil.

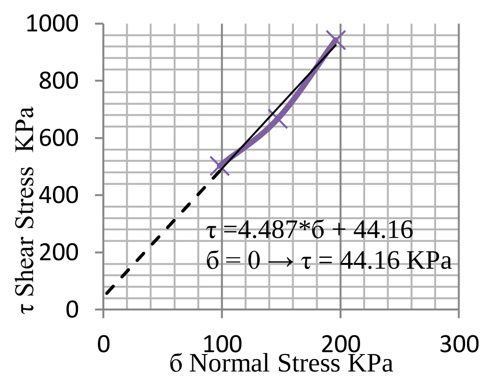

Figure 3. Soil strength parameter from triaxial test of soil.

4.2 Consolidation Tests

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve can be plotted. This data is useful in determining the compression index, the recompression index and the reconsolidation pressure of the soil. Test results are shown in figure 4 (BS5930).

4.3 Shear Box Test (Interface Test)

The interface shear tests were conducted at the Geotechnical Engineering Laboratory. A square base direct shear box (100 mm x 100 mm) split horizontally at mid-height was used in contact with steel plate. Normal stress is applied by placing dead weights on a hanger, horizontal displacements are monitored. Most importantly, the purpose of the test was to investigate the mechanical properties of interface between clay soil and steel plate which represent the pile wall, Figure 5 (BS5930).

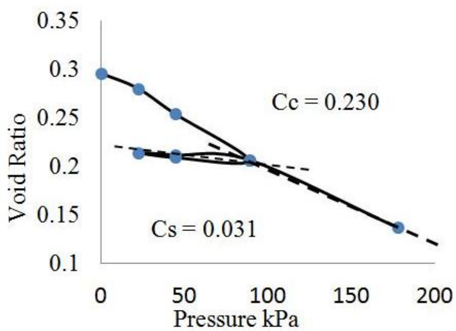

Figure 4. Consolidation test for soil sample.

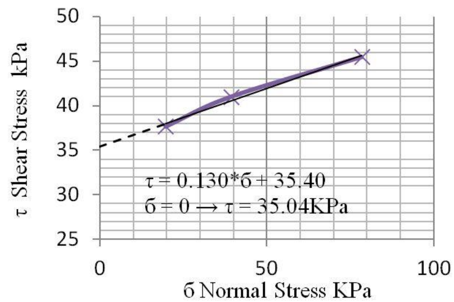

Figure 5. Shear and normal stress for interface from direct shear test.

4.4 Cam Clay Parameter

Figure 6 shows the initial or past yield surface. The three mean stresses computed above are marked on the diagram. The maximum q value occurs where the yield surface passes through the CSL (critical state line), as it properly should. Figures 7 show the deviatoric relation with volumetric strain.

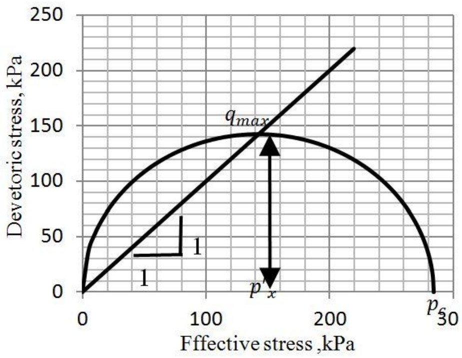

Figure 6. Initial yield surface for the past stresses.

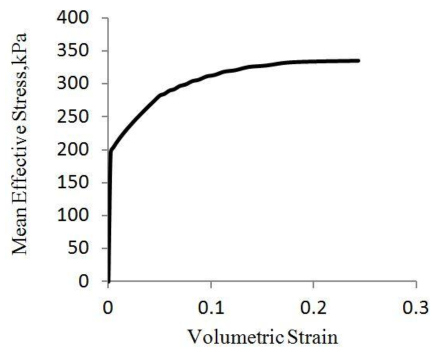

Figure 7. Mean effective stress-volumetric strain relationship.

5 DYNAMIC OF STRUCTURES

The dynamic response of the offshore structure under regular wave is given below

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = \{F\} \tag{4}$$

where [M] is the total mass matrix of the system, [C] is the damping matrix,[K] is the structural stiffness matrix, {U} is the nodal displacements, {U} is the nodal velocities, {U} is the nodal accelerations, and {F} is the hydrodynamic force (Brebbia 1979).

6 RESULTS AND DISCUSSION

In this paper, Um- Qaser container terminal Figure 8 is taken as a case study to analyze impact load that is given by (Al-Jasim 2000). The results show that the deck displacements at point A as shown in Figure 9 for pile embedded in elastoplastic clay is large than the pile embedded elastic clay by 10 %, but the pile head displacement is increased from 14.3 mm for pile embedded in elastic soil model to 29.1 mm in elastoplastic condition due to a reduction in the domain stiffness of soil. The critical embedded pile length is the length from the seabed to the first zero deflection, this length is increased by 40 % from pile embedded in elastic soil to the pile embedded in elastoplastic soil, Figure 10. For piles embedded in the elastic soil the critical length about 5 pile diameter and this ratio increased to reach 8 pile diameter for pile embedded in elastoplastic soil, while the bending moment is decreased about 10 %, for same reason, Figure 11.

7 CRITICAL EMBEDDED PILE LENGTH

The proposed equation to estimate the critical embedded pile length for soft clay is based on modifying the Reese solution. The proposed equation is based on the followings:

1. The critical embedded pile length is expressed by the undrained shear strength between the clay and steel pile, soil cohesion, and the properties obtain from the elastoplastic model of soil represented by cam clay model.
2. The elastic modulus of pile and second moment area of pile cross section remain unchanged in proposed solution as in Reese equation. According to the above assumptions, the proposed critical embedded pile length becomes (David, 1990);

$$Lcr_{plastic} = 0.21 * \sqrt[3]{\frac{Ep\ Ip}{Cu}} \quad (5)$$

Where:
$Lcr_{elastoplastic}$ = Proposed critical embeded pile length for pile.
0.21 = Factor is found from obtained results.
Cu = The undrained shear strength between the clay and steel pile, soil cohesion.

It is found that a very good agreement is obtained for the proposed critical length which may be used to introduce a new solution for bending and deflection of pile foundation.

8 CONCLUSIONS

The main conclusions are:

1. The dynamic structure response is increased by changing soil state from elastic to elastoplastic.
2. The deck displacement is small while pile head displacements are sensitive to the soil state.
3. The critical embedded pile length is increased for elastoplastic soil model.
4. The elastoplastic soil model is decreasing the damping of structure.

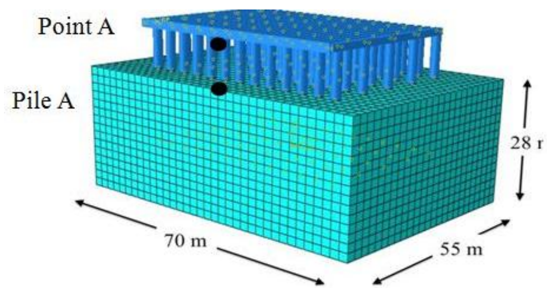

Figure 8. 3D Modeling of Um-Qaser container terminal with ABAQUS.

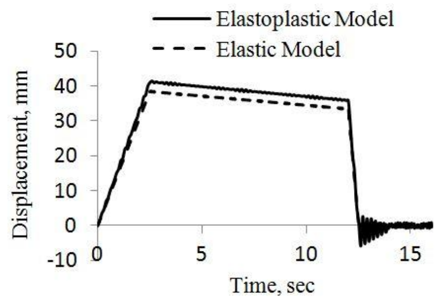

Figure 9. The variation of deck displacement at point A for two soil models.

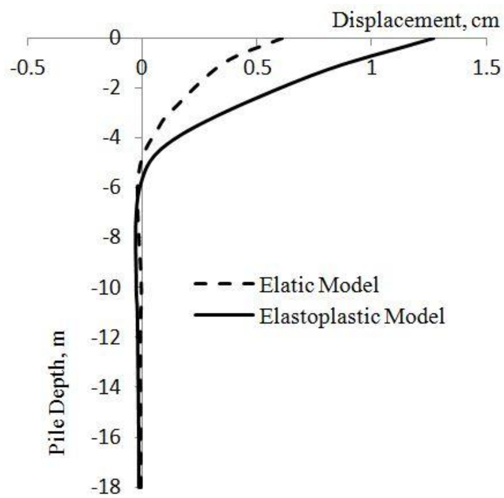

Figure 10. Pile displacement.

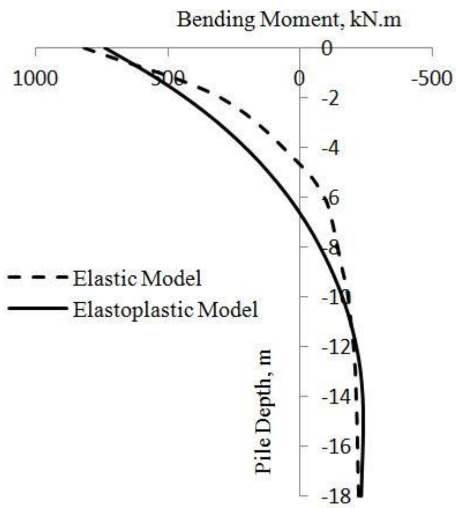

Figure 11. Pile bending moment.

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