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3D Finite Element Analyses for a Laterally Loaded Pile Wall in Marine Environment– Case History

Analyses 3D par éléments finis pour un mur de quai chargés latéralement dans un port – Etude de cas

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ABSTRACT: This paper presents a 3D finite element study on a model to simulate an horizontal load test on a retaining pile wall. The piles wall was constructed at the site of Port Ghalib marina on the Red-Sea coast of Egypt which is considered as an active seismic area. The subsoil layers consist of 2 m to 3 m gravelly sand followed by a deep clayey silt layer. The ground water was observed at a depth of about 1.10 m below ground surface. The purpose of the test is to evaluate the pile displacement characteristics under exposed loads. Numerically a 10 m – length pile was modelled to simulate the actual case. Effect of surcharge, earth pressure and earthquake loads were taken into consideration. The numerical analysis was performed and the results have been found to be in good agreement with the measured field test results. In addition the finite element method make an ability to predict the deflection along the pile length.

RÉSUMÉ : Cet article présente un modèle 3D éléments de dimension par élément finie pour' simuler un chargement horizontal d'un mur de quai du port de plaisance de Port Ghalib sur les côtes égyptienne de la mer Rouge qui est une zone sismique. La stratigraphie est constitué d'une couche de 2 à 3 m de sable graveleux, en surface, suivie d'une couche de limon argileux, en profondeur. La nappe phréatique est située à 1,1 m de la surface. L'objectif de l'analyse est de caractériser le déplacement latéral du mur en fonction du chargement. Le modèle numérique a été construit pour simuler le cas réel. Les effets de la surcharge, pression des terres et effets des seismes, ont été pris en compte dans le modèle. L'analyse numérique et les résultats sont en accord avec les résultats des expérimentaux de terrain. En outre, la méthode des éléments finis donne une prédiction de la déviation le long du mur.

KEYWORDS: 3-D FEE model, analysis, earthquake load, lateral loading, pile wall, Red sea.
MOTS-CLÉS : modèle FEE 3-D, analyse, la charge tremblement de terre, chargement latéral, palplanches, Mer Rouge.

1. SUBSOIL PROFILE CONDITIONS AND PILE GEOMETRY

Soil investigation showed that the soil profile at the site is as follows:

Top layer (yellowish brown, gravel and sand) from ground surface with depth ranging from 2 to 3 m, followed by a layer of grey clayey silt, some fine sand, traces of broken shells, extended to the end of executed boreholes (at depth of about 20 m).

The Standard penetration test (SPT) shows the N values as follows:

- From depth of 2 m to 7 m level N has values between 2 and 13
- From depth of 7 m to 11 m level N = 3
- From depth 11m to the end of boring N has values between 7 and 11

Ground water was observed e at 1.10 m below ground surface. The pile wall consists of contiguous bored piles of 1.0m diameter and 10m length.

2. FINITE ELEMENT MODELLING

The finite element mesh considered in three dimensional nonlinear finite element analysis as discussed in Abouzaid et. Al. (2010) is shown in Figure (1-a). Based on symmetry, only one pile of the model is meshed. 20 nodes brick element Solid 95 were used to simulate both soil, and pile with cap. It should be noted that these quadratic elements exhibit high accuracy even for high aspect ratios and can model accurately bending of solid piles. During mesh design stage, a study was performed to decide on appropriate (balanced) mesh size. The study showed that a much larger mesh, with more elements (of lower aspect ratios) would account for a fairly small change in results, so the current mesh is sufficient for analysis.

The concrete pile section, with a diameter of 1.0 m and pile cap beam have been meshed by Twenty node brick elements as shown in figure (1a-1b) with the elastic property of concrete. The soil domain has been simulated by strip of 1 m width with symmetry conditions on both sides.. The depth of soil considered below the pile tip 10 times the pile diameter. The domain of soil considered has been found very much suitable for the analysis of the laterally loaded pile as when loaded till failure the soil elements at and near boundary do not experience any deflection. Also the soil elements at and near to the bottom boundary do not experience any deflection. The soil has been modeled as elastoplastic medium following Drucker-Prager (1952) .

Soil domain has vertically been divided to 20 layers, each of thickness 1/20 of the pile embedded length to allow the soil variation with depth. The elastic modulus is taken proportional to strength parameter (c).

The boundary conditions considered are shown in Figure (6-8a), the translations UX have been constrained in outer YZ plans, and only UZ and UY have been permitted whereas UY have been constrained in outer XZ plans, and only UZ, and UX have been permitted, also the translation UZ have been constrained over the area the soil block bottom and the translations UX, and UY have been permitted, this have been done to overcome the singularity of matrices and to help to get convergence. All nodes of the symmetry plane have been constrained in direction perpendicular to the plane of symmetry.

The interface between the pile and soil have been represented by a couple of 8 node contact element named CONTACT 170 and 8 node target elements named TARGET 174, that was described in the chapter 3. The purpose of this couple is to mimic the installation effects on piles (drilled or driven). It also serves a purpose of a simplified interface which allows for tension cut-off (gaping) and controlled, coupled horizontal and vertical stiffness. The contact between pile and soil was supposed to be rough and were simulated by Drucker–Prager model with a friction angle of value corresponding to each layer.

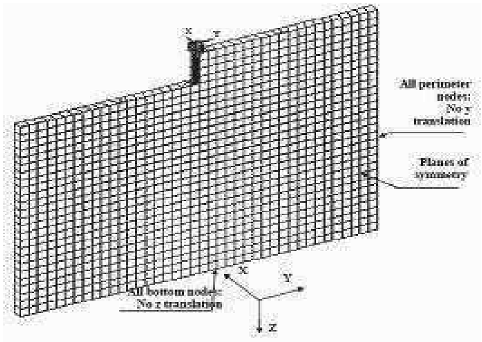


Figure (1-a): 3D Finite Element Model for Contiguous Piles Wall.

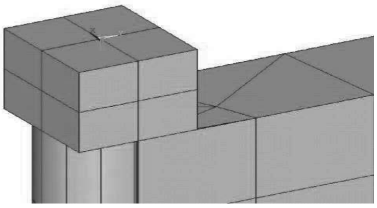


Figure (1-b): Pile Cap Mesh.

3. LOADING CONDITIONS

Loading for this case is presented in Table (1). The pile cap has been proposed to laterally load P at the pile head in the negative direction of y axis, in addition to surcharge load, with excavation at various stages. Ten load cases were performed to simulate the lateral load test loads and study the pile behaviour under different load cases and compare with measured results

Table (1) Applied Load in Each loading Case for Contiguous Piles Wall.

Load case No.	Applied load (P) (kN)
1	Before Applying surcharge load of 20 kN/m
2	Applying surcharge load of 20 kN/m
3	After excavation to -2.5 m from ground level
4	After excavation to -5 m from ground level
5	24 hrs after excavation to -5 m from ground level
6	Applying 21 ton horizontal load
7	After releasing 21 ton horizontal load
8	Just after Applying 300 kN horizontal load
9	24 hrs after Applying 300 kN horizontal load
10	After releasing 300 kN horizontal load

4. RESULTS AND DISCUSSION

4.1 Pile-Soil Deformation

Figures (2-a, b, c, d, and e) show the contour of pile and soil movement in direction Y axis, the deflection along the pile for the load cases no 2, 3, 4, 6, and 8.

In figure (2-a), after applying a vertical surcharge It is interesting to note that the plastic zone propagates deeply with a high densification in top layers till reaches the minimum values at the end of the model and extended below, this means that the settlement under the surcharge induced a lateral movement to the pile towards the settled side (right side), but the pile was rigid enough to retain the other side without movement especially the movements was very low so it does not extend far from the pile. Moreover, the instrumented side (right side) features much larger plastic zone while the plastic zone for the extension side (left side) is confined to the interface layer.

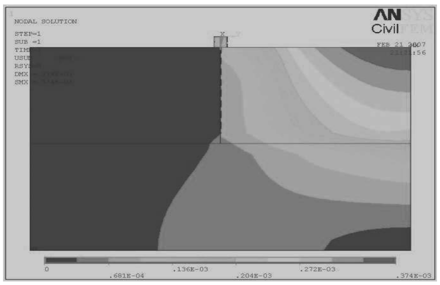


Figure (2-a) Contour of Deflections along the Pile under Surcharge Load .

In figure (2-b), after excavation to -2.5 m from ground level, It is noted that the excavation process resulted in a lateral movement of pile towards the excavation, and a small wedge of soil in front of the pile (left side) exhibits a small movement mobilizing a passive resistance in the front of the pile, but the right side is still affected by the surcharge load settlement which moves the soil very slightly in opposite direction

In figure (2-c), after excavation to -5.0 m from ground level, It is noted that the increase of excavation process resulted in increasing the lateral movement of pile towards the excavation, increasing the wedge of soil in front of the pile (left side) exhibits a bigger movement mobilizing a passive resistance in the front of the pile than the previous case, but the right side is still affected by the surcharge load settlement which moves the soil very slightly in opposite direction but less than the previous case.

In figure (2-d), Applying 21 ton horizontal load, It is noted that applying lateral load in increasing the lateral movement of pile towards the excavation, resulted increasing the wedge of soil in front of the pile (left side) exhibits a bigger movement mobilizing a passive resistance in the front of the pile the movement propagates deeper than the previous case and, but the right side is still affected by the surcharge load settlement which moves the soil very slightly in opposite direction but less than the previous case .

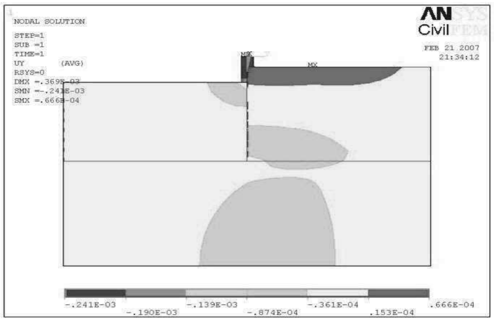


Figure (2-b) Contour of Deflections along the Pile After Excavation to -2.5 m .

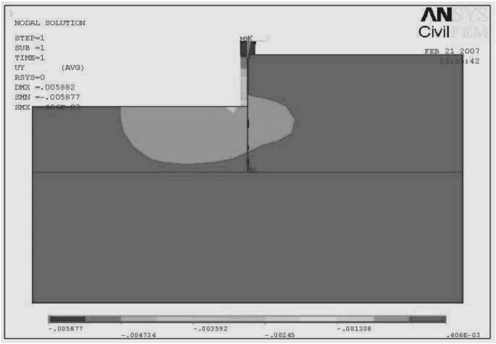


Figure (2-c) Contour of Deflections along the Pile After Excavation to -5 m .

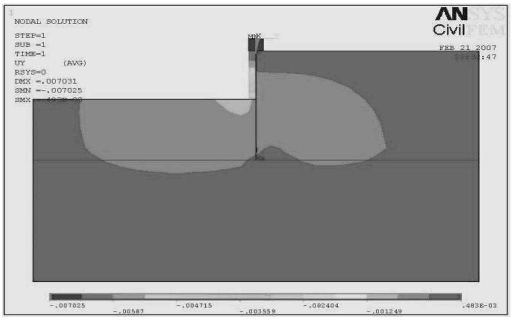


Figure (2-d) Contour of Deflections along the Pile after applying 210 kN Horizontal Load .

In figure (2-e), Applying 30 ton horizontal load, It is noted that increasing the applied lateral load resulted in increasing the lateral movement of pile towards the excavation, increasing the wedge of soil in front of the pile (left side) exhibits a bigger movement mobilizing a passive resistance in the front of the pile the movement propagates deeper than the previous case, the surcharge load settlement effect began to finish and a small passive resistance induced at the pile tip.

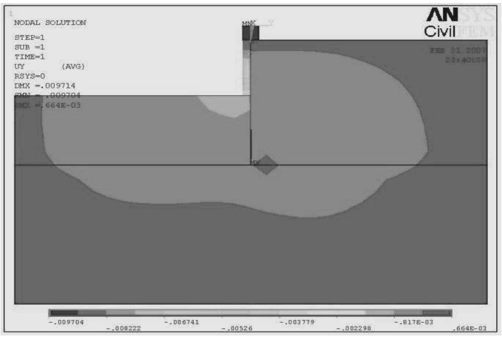


Figure (2-e) Contour of Deflections along Pile for 300 kN Horizontal Load .

figure (3 -a) shows the deformed shape of pile and soil along the pile at failure, and figure (3 -b) shows the vector plot of the deflection of pile and soil along the pile at failure,

It is noted that reaching the ultimate lateral load resulted in increasing the lateral movement of pile towards the excavation, increasing the passive resistance wedge of soil in front of the pile (left side), all these resulted in reaching the pile its yielding and pile rotation increased, consequently, followed by a progressive slope failure on the right side which is clear in figures (3 -b).

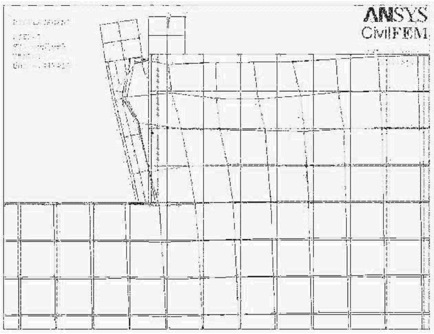


Figure (3 -a): Deformed and Undeformed Shapes near Ground Surface .

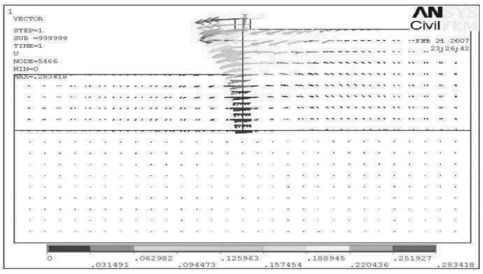


Figure (3 -b) Vector Plot of the Pile and Soil Displacements at Failure.

Considering the lateral displacement UY as the main output, numerical differentiation process were performed to get the slope , bending moment, shear force, and the soil reaction according to equations 1, 2, 3 , and 4 by changing the variable UX by UY .

Where: UY, MX and PY are deflection, bending moment and soil reaction (pressure) respectively. Direct generation of soil pressure was also performed to check results and it was found that soil pressure were within 97% accuracy.

$$MX = \frac{d(ROTX)}{dz} \tag{2}$$

$$QX = \frac{d(ROTX)}{dz} \tag{3}$$

$$PX = \frac{d(ROTX)}{dz} \tag{4}$$

4.2 Pile Head Displacement.

Figure (4) shows a comparison for the measured pile head displacement and that estimated from the present study. It is noted that a very well agreement between the two curves is existing where the R- squared value is 94%. The pile was just instrumented on the top, thus diagram column represent one case of loading.

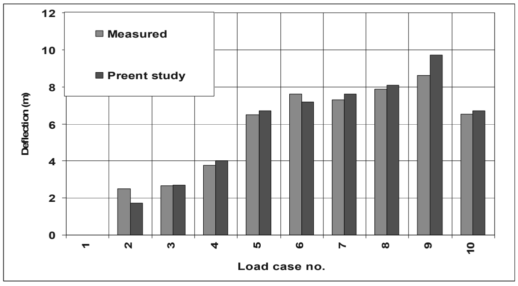
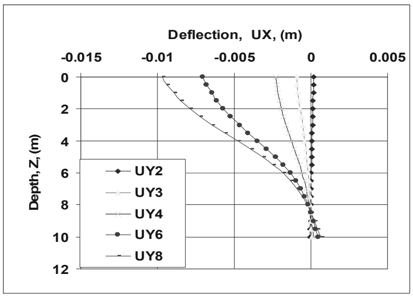


Figure (4) Predicted, and Measured Pile Head Deflection .

4.3 Pile Straining Characteristics

Figures (5- a) to (5-c), show the lateral deflection (UYn), bending moment (MYn), and soil reaction (pressure) (PYn) respectively along Pile Shaft due to the decided loading conditions illustrated in table (1). It is interesting to note that the change in location of maximum bending moment, peak zones of soil reactions, and points of hinges induced in different case of loading, where the point of maximum moment changed from -3 m to -5 m in case of excavation to -2.5m and -4 m , respectively. The beak of soil resistance is observed at -3.0 m in case of excavation to -2.5m and at -5.2 m in case of excavation to -5m. Also, the point of reversing soil reaction was observed at -7.75m.



Figure(5-a): Lateral Deflection along Pile Shaft .

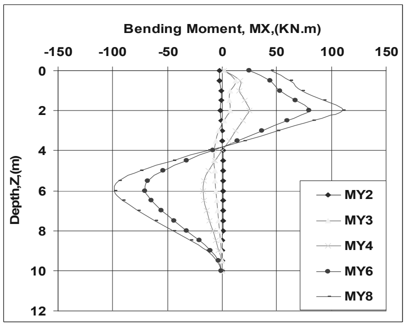


Figure (5-b): Bending Moment along Pile Shaft

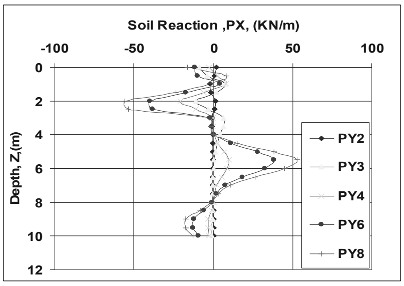


Figure (5-c): Soil Reaction along Pile Shaft.

5. CONCLUSIONS

The main findings can be summarized as follows:

- 3D finite element model gives the possibility of reaching high levels of loading until failure which is not available in full scale load tests.
- 3D finite elements can compensate for performing full scale lateral load tests with a good degree of trust to get reliable behavior of pile under loads saving time, effort , and cost.
- It is noted that good agreement between the measured and estimated from results of the finite element model. It is very important to obtain soil properties from high quality field or laboratory tests, as these will have direct effect on the analysis results.
- Pile and soil geometries must also be determined to a high degree of accuracy as these will also affect analysis outcome. Remembering the adage in computer modelling.

6. REFERENCES

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