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DYNAMIC RESPONSE OF SINGLE PILE LOCATED IN SOFT CLAY UNDERLAY BY SAND

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ABSTRACT: Piles have been extensively used for supporting axial loads and lateral loads for variety of structures including high rise buildings, transmission towers, power stations, offshore structures and highway and railway structures. Pile foundations are subjected to lateral loading due to wind action, wave action, earthquake and impact of ships in dock and harbour structures. In such cases, studying the behavior of pile foundation due dynamic loading is essential. Compare to field tests, the numerical modeling is an economical way to analyze the response of piles. This paper presents the dynamic response of a single concrete pile of 0.4m diameter, 11.5m length located in soft clay underlay by sand subjected to static vertical load as well as ground acceleration simultaneously. Finite element software PLAXIS 2D is used to analyze the pile. From the analysis, the deformation and acceleration behaviour of pile with respect to time has been studied.

Keywords: Single pile, Dynamic response, Plaxis 2D, Deformation,Acceleration

1. INTRODUCTION

Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weak compressible strata or less compressible soils onto rock. Piles used in marine structures are subjected to lateral loads from the impact of berthing ships and from waves. Piles used to support retaining walls, bridge piers and abutments, and machinery foundations carries combinations of vertical and horizontal loads. It is found that at various sites in the coastal region, the top layer soil is soft clay with varying thickness of 5.0 to 25m and most of the structures which are constructed on soft clay [3].The work of Matlock and Reese[12] can be considered as one of the first attempts to understand laterally loaded pile behaviour. Matlock and Reese[12] gave a generalized solution in non-dimensional form for the laterally loaded pile for both elastic and rigid behaviour assuming soil modulus variation linearly with depth. Broms [4] developed solutions for the ultimate lateral resistance of a pile assuming the distribution of lateral soil pressure and considering static of the problem. Singh and Verma [21] conducted large-scale model tests in sand under controlled density. Lateral load tests were conducted on single pile and pile groups. The load deflection curves were found to be non-linear and were flatter at higher load levels showing loss of soil resistance. Poulos and Davis [18] gave comprehensive collections of solutions for the design of pile foundations to resist static lateral load. Ernestn aesgaard [7] carried out full-scale field tests to assess the ability of the piles to withstand large lateral deformations that may be caused by earthquake-induced soil liquefaction.Rao et al. [16] carried out tests on model groups of piles to support dolphin-type structures. Static load tests have been conducted on instrumented model pile groups embedded in a marine clayey bed. The spacing between piles, number of piles in a group, and arrangement of pile group with respect to the direction of lateral loading have been varied. The results indicated that the capacity of pile group not only depends on the spacing between the piles, but also on the arrangement of piles in the group. Mezazigh and Levacher [14] conducted the centrifuge test on model single aluminum pile placed on horizontal ground and sloping ground surface in cohesionless soil by varying the distance from the crest of slope. The effect of distance to the slope, slope angle and soil properties were studied. The load versus deflection curves; bending-moment and p-y curves were derived for piles close to slopes and compared to the horizontal ground response. Rao et al. [17] conducted experiments on pile groups and studied the influence of parameters like flexural rigidity of pile material, embedment length of pile and arrangement of piles on the behavior of laterally loaded pile groups. The results indicated that the lateral load capacity of the pile group depends mainly on the rigidity of pile soil system for different arrangements of piles within a group. Rollins et al. [19] performed static lateral load test on a full-scale pile group to determine the resulting soil-pile interaction effects. A 3 × 3 pile group at three-diameter spacing was driven into a soil profile consisting of soft to medium-stiff clays and silts underlain by sand. It was observed that the pile group deflected over two times more than the single pile under the same average load and trailing rows carried lesser load than that of leading row, and middle row piles carried the lowest loads. Ilyas et al. [10] conducted a series of centrifuge model tests to examine the behavior of laterally loaded pile groups of 2, 2×2, 2×3, 3×3, and 4×4 piles with a center-to-center spacing of three or five times the pile width in normally consolidated and over consolidated kaolin clay.It was established that the pile group efficiency reduces significantly with increasing number of piles in a group due shadowing effect. And also, it was found that the front piles experience larger load and bending moment than that of the trailing piles. Boominathan and Ayothiraman [3] carried out the static and dynamic lateral load tests on model aluminium single piles embedded in soft clay to study their bending behavior. The results indicated that the maximum dynamic bending moment of pile in soft clay was about 1.5 times higher than the maximum static bending moment. Cubrinovski et al. [5] studied the pile response to lateral spreading by 3-D soil–water coupled dynamic analysis by shaking in the direction of ground flow. Liyanapathirana and Poulos [9] studied the analysis of pile behavior in liquefying sloping ground. Hasan Ghasemzadeh and Mehrnaz Alibeikloo [8] carried out the pile–soil–pile interaction in pile groups with batter piles under dynamic loads. Amin rahmani and Ali pak[2] studied dynamic behavior of pile foundations under cyclic loading in liquefiable soils.Ahmad Dehghanpoor and Mahmoud Ghazavi [1]presented a new method for analysis tapered piles under lateral harmonic vibration. The behavior of tapered piles was assumed to be as elastic and linear. The homogeneous, isotropic, and linearly visco–elastic horizontal soil layers were used. The pile was divided to some segments and thedifferential equation for a given desirable segment was obtained and solved. Then the dynamic complex stiffness parameters were derived for the pile head. Parametric studies have been performed to investigate the influence ofpile geometry, soil properties, and loading details on pile-soil system amplitudes. It has been found that underlateral harmonic vibrations, with increasing the pile taper angle, the resonant amplitude decreases. In addition, ithas been concluded that under lateral harmonic vibrations, a tapered pile experiences lower amplitude than acylindrical pile of the same length and material volume.Hayano et al.[9]conducted dynamic centrifuge model tests and finite element analyses (FEA) to investigatethe seismic behavior of quay walls backfilled with cement-treated granular soils (CTGS). The effectsof the CTGS fill depth and fill range on seismic behavior were investigated. The centrifuge model tests showedthat no liquefaction was generated in the CTGS backfills. The quay wall’s horizontal displacement induced by theseismic loading decreased with increases in the CTGS fill depth because the earth pressure acting on the quay wallwas reduced. In addition, a wedge-shaped CTGS fill was found to be effective at reducing the horizontaldisplacement of the quay wall.Rusnardi Rahmat et al.[20]investigated the 12-site microtremor array of an earthquakeof M 7.6 that occurred on September 30, 2009 in Padang city,Indonesia.The soil condition of subsurface structures in Padang has been conducted. From the dispersion curve from the array observations, It was found that the downtown Padang is underlain by soft soil conditions (Vs30<400 m/s). Consistent results concerning the soil condition were found based on predominant period observations and the soil characteristic.It also found that the Padang city has high probability giant earthquake occurrence and high level for seismic risk vulnerability for future earthquake.Darius Macijauskas and Stefan Van Baars [6]performed vibration tests in order to check the reliability of man-made vibration prediction methods, one of polders in the North-West of the Netherlands. The polder was chosen because it had a rather homogenous, thick and soft peat top layer.The shaker was designed and manufactured in order to produce harmonical vibrations at the soil surface. It consists of two counter rotating electric vibrators (with rotating eccentric masses) in order to produce a vertically oscillating force. For the recordings of the vibrations, six 2D or 3D geophones were placed on the soil surface and one 2D geophone was placed on top of the shaker. The measured vibration amplitudes of the vertically oscillating shaker were compared with 1. Two different analytical methods used for the design of vibrating machine foundations, 2.The Confined Elasticity approach and3.The Finite Element Method, for which Plaxis 2D software was used. Mahdi O. Karkush and Mahmoud S. Abdul Kareem [13]studied the impact of soil contamination on the behavior of a pile group driven into clayey soils. A mechanical model had been manufactured to study the behavior of pile group (2×2) subjected to one-way cyclic lateral loading, and embedded in contaminated soils. The tests were performed on a free headed pile group with two ratios of eccentricity to embedded length (e/L) equal to 0.25 and 0.5.

The intact soil samples were obtained from Al-Musayib city in the center of Iraq, while the industrial wastewater was a byproduct discharged from Al-Musayib thermal electric power plant, which was located in the same region where the soil samples have been obtained. The intact clayey soil samples were contaminated synthetically with four percentages of (10, 20, 40 and 100) % by weight of distilled water used in the soaking process of soil samples, which continued for 30 days. From the results, it was observed that the lateral bearing capacity of pile group decreased by 4–31% for e/L equals 0.25 and 0.5, and the ratio of permanent displacement to the total displacement increased by 18–33% with increasing the percentage of contamination in the soil. The efficiency of the pile group was observed to be 81–87% from one single pile group.

Very few researchers studied the fundamental characteristics of pile in soft clay under dynamic conditions. This paper aims to fill this gap through a comprehensive numerical analysis using PLAXIS 2D carried out on single piles embedded in soft clay underlay by sand subjected to static vertical load as well as ground acceleration simultaneously.

2. MATERIAL PROPERTIES

Single concrete pile with 0.4m diameter and 11.5m length is located in soft clay underlay by sand subjected to static vertical load as well as ground acceleration simultaneously.Thepile parameters are taken as fallow; Young's modulus of concrete (E) = 3x10^7 kN/m^2, Poisson's ratios of concrete (μ) = 0.1, Unit weight of concrete (γ_c) = 25 kN/m^{3}for dynamic analysis. The properties of soft clay are taken as γ_{unsat}=16kN/m^3,γ_{sat}=18kN/m^3,E_{ref} =15000kN/m^2, R_{inter}=0.5,C=2kN/m^2, ϕ=24°, μ=0.3 and the properties of sand were taken as γ_{unsat}=17kN/m^3,γ_{sat}=20kN/m^3,E_{ref}=50000kN/m^2, E_{oed}=50000kN/m^2E_{ur}=150000kN/m^2,P_{ref}=100kN/m^2,R_{inter} =0.67, C=1kN/m^2, ϕ=31°, μ=0.2.

3. FINITE ELEMENT MODEL

For dynamic analysis, the 1990 earthquake data of California having local magnitude (ML) 5.40 on Richter scale with peak horizontal acceleration -239.90cm/sec^2 is used. Fig.1 shows real accelerogram ground acceleration versus time graph used for analysis. It contained in standard SMC format (Strong motion CD-ROM) which can be read and interpreted by PLAXIS**.** The earth quake ismodeled by imposing a prescribed displacement at the bottom boundary. PLAXIS has convenient default setting to generate standard boundary conditions for earth quake loading using SMC files.

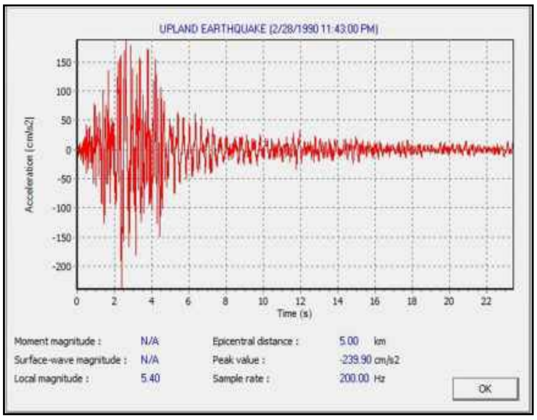

Fig.1 Ground acceleration vs. Time

The geometry is simulated by means of axisymmetric model in which the pile is positioned along the axis of symmetry. Both pile and soil are modeled with 15-noded elements. Interface elements are placed around the pile to model the interaction between pile and soil. The boundaries of model are taken sufficiently far away to avoid the influence of boundary conditions. Standard absorbent boundaries are used to avoid the spurious reflections. The presence of ground water table is neglected. Fig.2 shows the geometry model of pile. The pile is considered to be linear elastic.

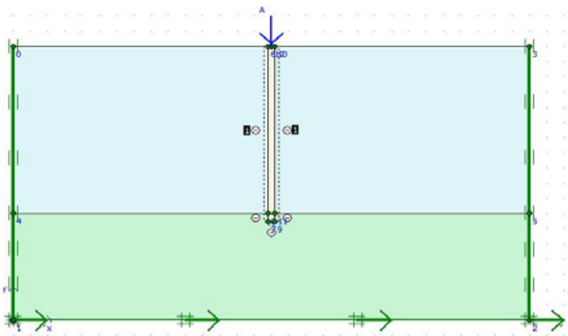

Fig.2 Geometry model of pile

The top layer of soil (clay) is modeled with simple Mohr-Coulomb model with undrain condition and the bottom layer of soil (sand) is modeled by means of hardened soil model in order to model the nonlinear deformations below the tip of pile. The pile is subjected to vertical load of 700 kN and earthquake ground excitationsimultaneously. Fig.3 shows the finite element mesh generated. The mesh near the pile is observed with high concentration of stresses.

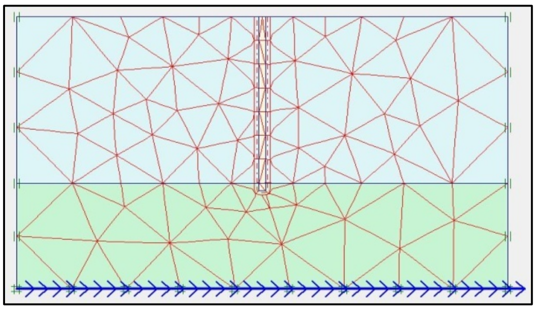

Fig.3 Finite element mesh

4. RESULTS AND DISCUSSION

The fig.4 shows the deformation versus time plot at top of pile surface and fig.5 shows the deformation versus time at bottom of pile surface when it is subjected to vertical load of 700 kN and earthquake ground excitation (both static and dynamic loading simultaneously).The maximum displacement of pile at top and bottom observed to be $10x10^{-7}$m at t=0.2 Seconds and $18.6X10^{-7}$ m at t=1 Seconds.

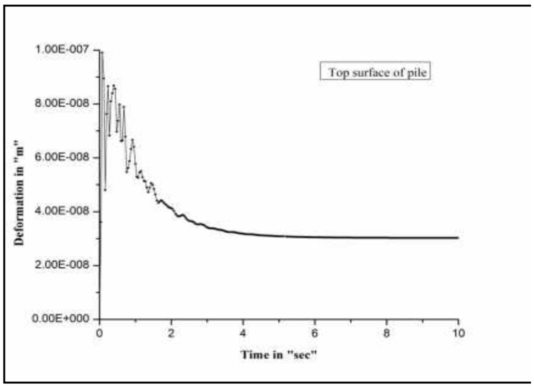

Fig.4Deformation Vs Time at top of the pile

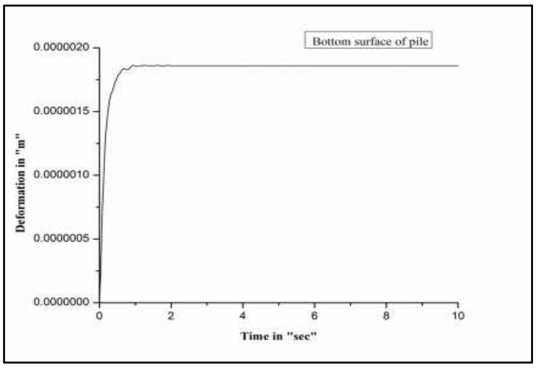

Fig.5 Deformation Vs Time at bottom surface of pile

Figs.6 and 7 shows the acceleration versus time plots at top and bottom surface of pile when it is subjected to both static and dynamic loading. The acceleration of $1.34X10^{-4}$ m/sec^2 is observed at t=0.3 sec. at top surface of pile and the acceleration of $7.7X10^{-4}$ m/sec2 observed at t=0.5sec at the bottom surface of pile.

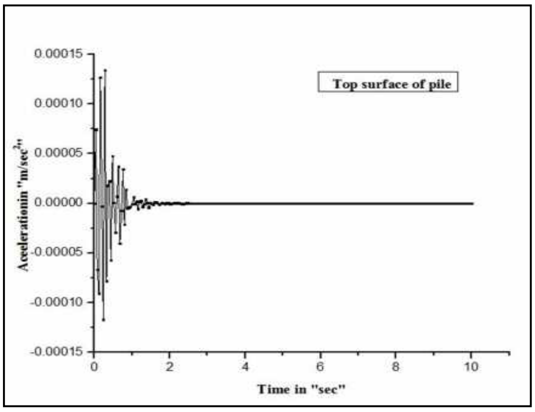

Fig.6 Acceleration Vs Time at top surface of pile

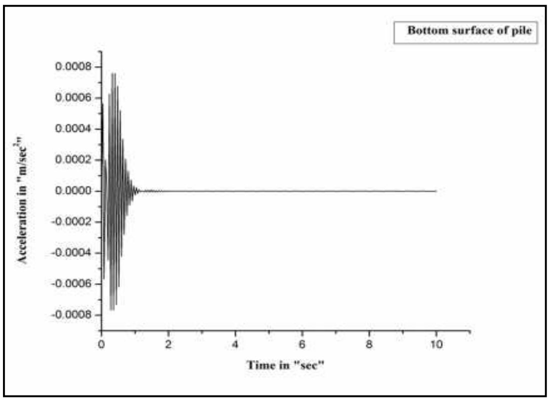

Fig.7Acceleration Vs Time at bottom surface of pile

5. CONCLUSIONS

In this paper, the results of dynamic response of a single concrete pile of 0.4m diameter, 11.5m length located in soft clay underlay by sand subjected to static vertical load as well as ground acceleration simultaneously was presented. A Finite element software PLAXIS 2D is used to analyze the pile.

From the analysis, the deformation and acceleration behaviour of pile with respect to time has been.The maximum displacement of pile at top and bottom was observed to be $10x10^{-7}$m at t=0.2 seconds and $18.6X10^{-7}$ m at t=1 seconds respectively.The acceleration of $1.34X10^{-4}$ m/sec^2 was observed at t=0.3 sec. at top surface of pile with less number of cycles and the acceleration of $7.7X10^{-4}$ m/sec2 observed at t=0.5sec at the bottom surface of pile with more number of cycles.

From the results it can be concluded that the top tip of the pile is more susceptible for damage compare to bottom of pile.

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