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NUMERICAL ANALYSIS OF PILE FOUNDATION SUBJECTED TO DYNAMIC LOADS

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Abstract

The response of single pile foundations subjected to different earthquake excitations is considered in this paper. The behavior of such foundation is important specifically in case of earthquake loading through the supporting soil medium. An axisymmetric finite element model has been implemented to simulate the behavior of pile in soil deposit using Abaqus software. Eight node axisymmetric quadrilateral elements CAX8R used to simulate the soil continuum. Contact behavior between the single pile part and the part of soil was simulated using the 'surface to surface' contact method with master-slave concept. Furthermore, the pile behavior material has been simulated with a linear elastic model while soil material has been simulated with an elasto-plastic model "Mohr-Coulomb failure criterion". Three different excitation records have been adopted in the analysis: El-Centro, Halabja and Ali-Algharbi earthquake records in order to investigate the effect of various dynamic loading. The results of the analysis demonstrate alteration in the response along the pile with different soil layer with each earthquake excitation.

Keywords: Dynamic Analysis, Single Pile, Erthquake, Abaqus Software

I. Introduction

Generally, finite element method using software analysis has a major role for case of studying the behavior of many geotechnical structures. It can illustrate the effect of dynamic loading on such structures and also highlighting the aspects which are important in engineering practice [X][VII].

In general dynamic analysis, soil structure or soil pile structure analysis is considered as very important aspect as it containing two components affecting the behavior of the system, these two interactions arise during an earthquake: the kinematic interaction and the inertial interaction. The kinematic soil-pile interaction is the pile loading by the soil displacement produced by the seismic wave's propagation. Inertial superstructure-pile-soil interaction results from forces due to the superstructure actuation by the kinematic interaction [III] [IV] [VI].

Seismic analysis concerning single pile is considered as one of the more important problems in geotechnical earthquake engineering. The analysis involves modeling single-pile with pile-to-soil interaction under different earthquake excitations. The elastic continuum models are suitable for studying the response under low excitations only when the dynamic response is approximately elastic. They are not suitable for analyses under strong shaking. The reduction in soil stiffness and the increase in damping associated with strong shaking are sometimes modeled crudely in these elastic methods by making arbitrary reductions in shear moduli and arbitrary increases in viscous damping. Dynamic nonlinear finite element analysis in the time domain using the full 3-dimensional wave equations is not feasible for engineering practice at present because of the time needed for the computations. However, by relaxing some of the boundary conditions associated with an analysis, it is possible to get reliable solutions for nonlinear response of pile-soil system with greatly reduced computational effort [III] [IV] [XV].

Description of the total modeling by FEM method, including soil-structure interaction effect is incorporated in the computer program ABAQUS [II].

Numerous researchers have studied soil-pile-system responses under dynamic loads using many approaches. It is necessary to precisely predict a structure response like a pile or any other structure during an earthquake. Pile foundation response, however, is very complicated because of many effects influencing their responses and nonlinear interactions of soil and superstructure [III] [IV] [XI], [XII], [XIII].

Therefore, the objective of this paper is to investigate the effect of local site conditions in Iraq on the response of soil-pile system considering the effect of soil structure interaction. ABAQUS finite element program has been used for axisymmetric simulations including the single pile and local soil site conditions [I].

A case study foundation system of a single reinforced concrete bored pile of 1.5 m diameter with 20 m length located in Al-sodoor bridge site in Diyala Governorate subjected to static vertical load as well as ground acceleration simultaneously.

II. General Properties of the Simulated Model

Single pile selected from foundation of bridge site located in the Al Sdoor region in the diyala governorate, northeast of Baghdad in Iraq has been taken as a case study, the description of the model case studied is detailed in the recent next sections.

A. Case Study

The finite element modeling has been performed based on available design drawings for the pile and also the site survey and geotechnical reports.

Pile and Soil Model Description

The geometric modeling consists of simulating the soil continuum and the pile foundation as separated parts then ABAQUS gathering the parts in the assemble module as an axisymmetric model. Pile foundation as a structural concrete with the circular section with diameter of 1.5 m and depth for the pile is 20m. The soil and pile assembly are shown in Figure 1.

The simulation of the model was done in axisymmetric model. An axisymmetric modeling provides reasonable simplification for modeling piled-soil systems. The axisymmetric model has the advantage of simplifying the problem by reducing the size of the model. Subsequently, considerable saving in computational time can be achieved. The element used to simulate the soil is an axisymmetric quadrilateral element named CAX8. Axisymmetric elements provide for the modeling of bodies of revolution under axially symmetric loading conditions, finite element mesh is as showed in Figure.2.

B. Constitutive Models

The soil mass is modeled as an isotropic homogenous rectangular three layers, with approximately width and depth (10 m × 30 m). The concrete body of the pile is modeled using linear elastic model. The soil was considered as an elastic-perfect-plastic body by adopting the Mohr-Coulomb failure law as yielding criterion. Indeed, large number of routine design calculations are still performed using Mohr-Coulomb (MC) criterion in geotechnical area. The following equations give the relations of this criterion (Abaqus Theory Manual, 2012) [II][VIII]: and as shown in Figure 3.

$$\tau = c + \sigma tan\phi \qquad (1)$$

Where: τ is the shear stress, $\sigma\sigma$ is the normal stress. (σ is negative in compression), cc is the cohesion of the material, and ϕ is the material angle of friction.

General properties for the soil, and the concrete materials that used for simulation are showed in Table.1.

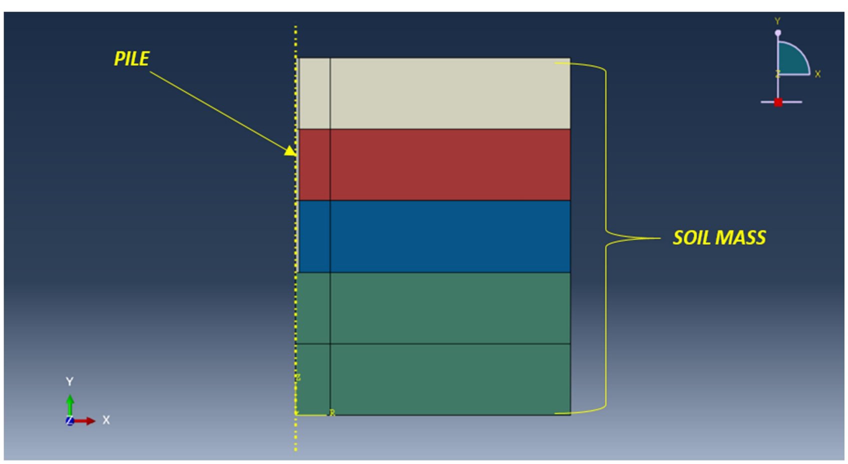

Fig. 1: Pile foundation system assembly

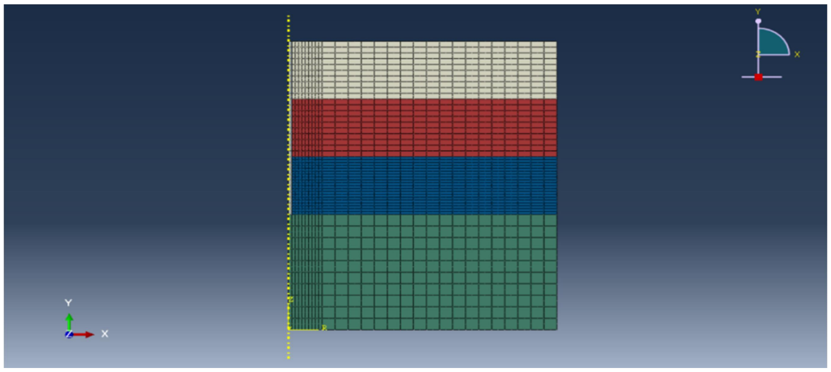

Fig. 2: Finite element mesh of the model

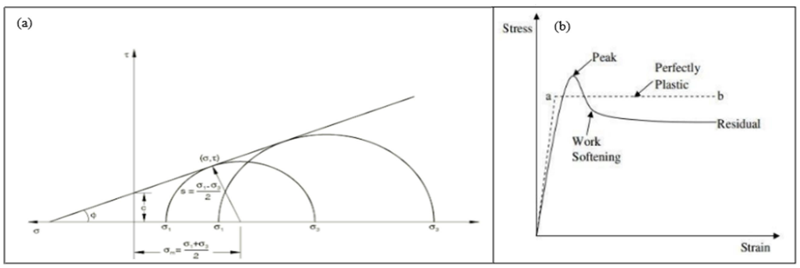

Fig. 3: (a) MC failure criterion- (b) Elastic-perfectly plastic assumption of MC model (Abaqus theory manual v6.12)

Table1: Soil and Pile Reinforced concrete properties

Property	Values	Information Reference
γ (kN/m^3)	18-20	Project site investigation report
E (MPa)	58	AASHTO, 1996
ν	0.39	
Cohesion Cu (kPa)	40,50,80	Site investigation report for depths 0-8, 8-10, 15-20 m respectively
Friction angle (Ø°)	36,46	Site investigation report for depths 6-15, 19-20 m respectively
Dilatancy angle (ψ°)	6,16	Plaxis-3D Material Manual
γ_c (kN/m^3)	24	Pile materials
Poisson's ratio (μ)	0.2	Pile materials
Modulus of Elasticity (MPa)	200	Pile materials

C. Contact Interactions

Various numerical methods for the contact problems include the formulation of the laws, the interfaces and the geometries, thus, many formulations have been developed to simulate the contact interaction problems especially for the pile and soil material interaction. For modeling the contact behavior between the soil and foundation surface material, the friction coefficient which is a function of some factors (e.g. the surface roughness, adhesion and porosity) has been defined by two components: the normal frictional component and the tangential component. [XII].

Generally, for the soil, pile master-slave concept developed by Wriggers (1995) is used for this problem, the master-slave concept that is widely used recently due to its capabilities to simulate the large deformations includes both of the tangential and normal stresses component within the area of contact including the geometrical formulation and the constitutive laws of interface. The surface to surface contact discretization methods have been used in this study. Consequently, the lateral soil around the pile is a master surface while the surface of the pile which is in contact with the soil is a slave surface [XV].

III. Load Condition

Generally, most civil structures are subjected to dynamic loading during their life cycle. Such loading type may be instant like earthquakes. Current study implemented three different earthquakes records including earthquake of the 1940 El-Centro in the Imperial Valley in southeastern Southern California near the international border of the United States and Mexico with magnitude of 7.1 and peak ground acceleration PGA = 3.50 m/sec^2 .The second earthquake was for the 2012 Ali-Al Gharbi which wastake place in Maysan province/south of Iraq with magnitude of 4.9 and PGA=1.04 m/sec^2 and finally the 2017 Halabja earthquake in Halabja in north of Iraq, [XV].

For checking purpose of the deformation of the pile-soil system, gravity loads and the dynamic loading conditions which has been applied to the system. The three earthquakes time history is shown in the Figures. 4-a, 5-a and 5-b respectively.

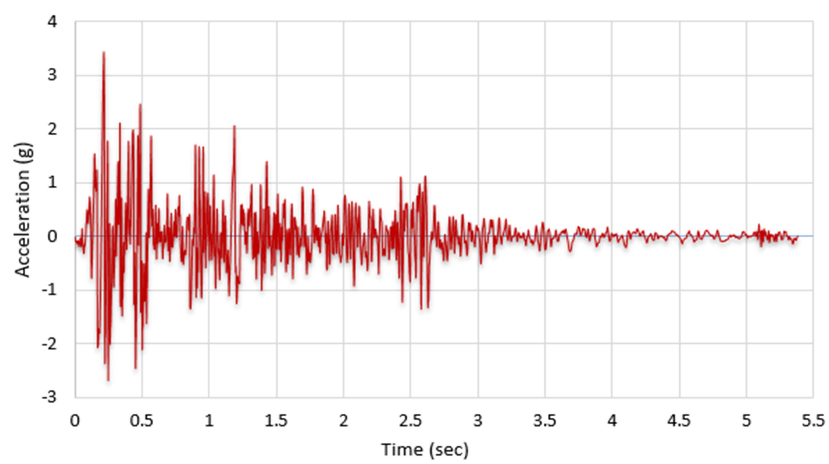

Fig. 4-a: The 1940 El- Centro Earthquake Time History

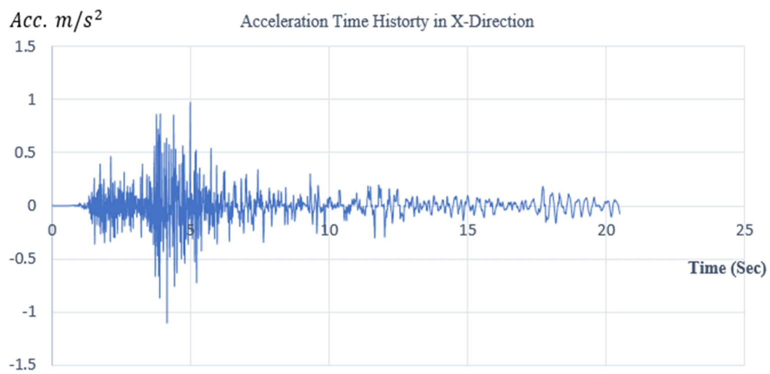

Fig. 5-a: The (2017) Halabja Earthquake Time History/Iraq [V]

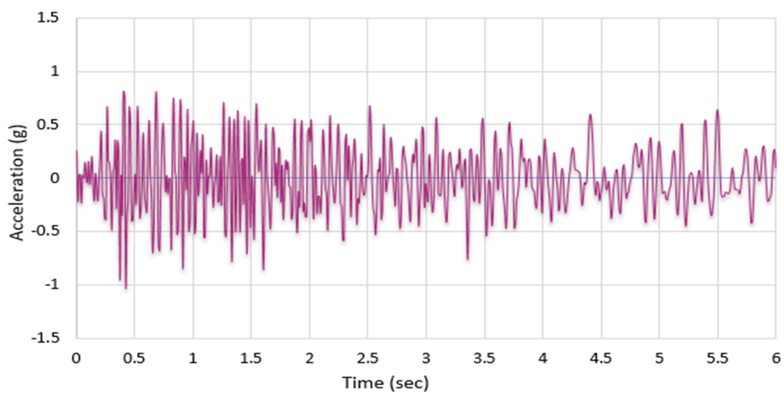

Fig. 5-b: The 2012 Ali- Al Gharabi Earthquake Time History/Iraq

IV. Result and Discussion

This study is performed in order to assess the performance and deformation of single pile-soil system under different earthquake excitations, describing the relative displacements developed in the pile-soil interface (where points in the top, mid, bottom of soil were considered).

This analysis is taking into consideration the dead and live loads as static loads applied on the pile foundation. Additional to the seismic loading condition.

The analysis steps were divided into three models (i.e. model No.1 is for Ali-Algharbi earthquake record, model No.2 is for El-Centro earthquake record and model No.3 is for Halabja earthquake record. In general, the deformed shapes of the displacement under each loading case (same deformation for earthquake loading) are shown in Figure 6.

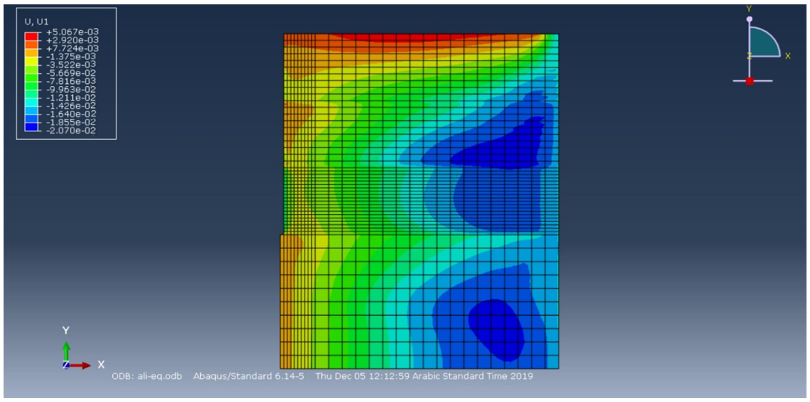

Fig. 6: Horizontal Displacement in Soil

It is found that the maximum relative displacement for El-Centro earthquake dynamic analysis in the horizontal direction at the ground surface point is (-0.01261m) but it is less in the middle point along pile soil system as shown in Fig.7.

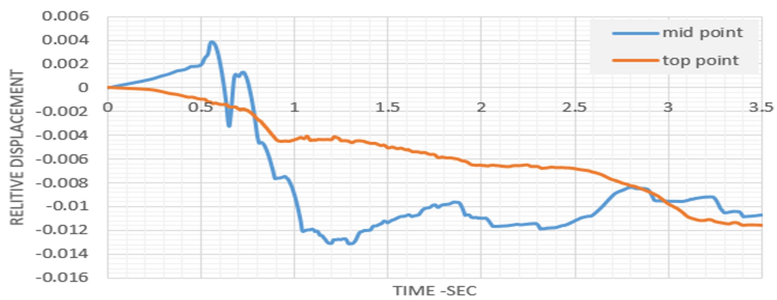

Fig. 7:Reletive Displacement along Pile-Soil System for El-Centro EQ.

Also for Ali-Algharbi and Halabja earthquakes dynamic analysis, same deformation occur but with maximum relative displacement at the top of the system about (-0.00388 m) and (-0.01023 m) respectively as shown in Figures 8 and 9.

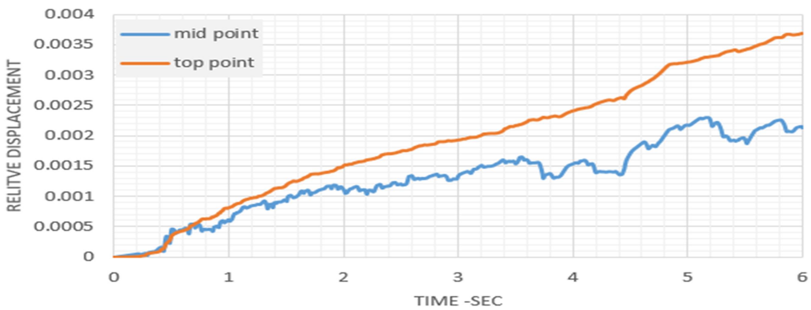

Fig. 8: Reletive Displacement along Pile-Soil System/Ali-Algharbi EQ.

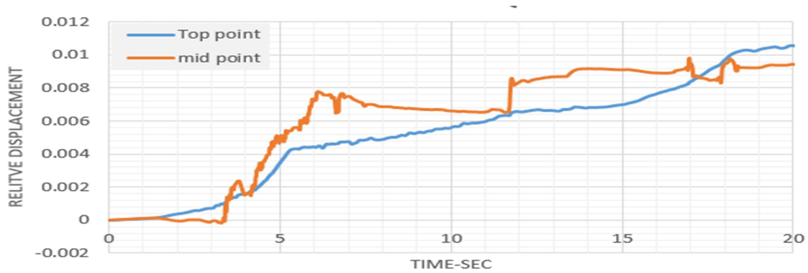

Fig. 9: Reletive Displacement along Pile-Soil System/Halabja

Generally, for the overall response of the system, under the consideration of soil profile properties, the response of pile part soil system varied under each input ground motion and this variation reduced with increase in soil stiffness along the depth of pile. The response of the portion of soil near pile imbedded in the stiffer layer was almost the same as the input ground motion. Additionally, the maximum deflection along pile depth for each earthquake recrds increased due to inertial soil structure interaction effect in the upper part of the pile and its effect decrease with pile depth. It can be noticed that, displacement for the input seismic case of the El-Centro earthquake increased somehow more than the other cases because of that the peak ground acceleration increased as depicted in Figure 10.

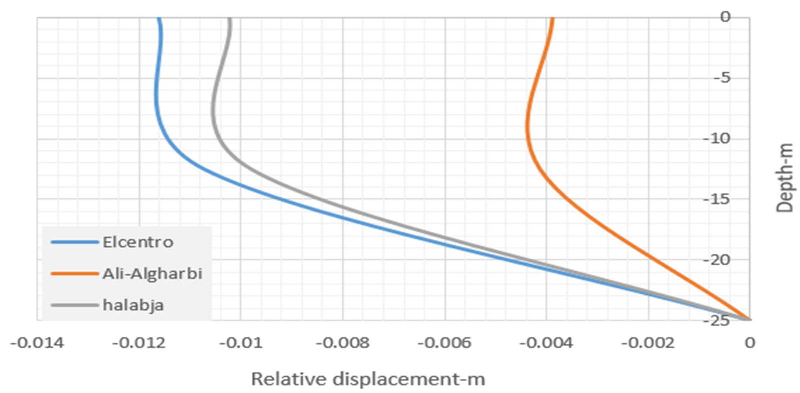

Fig. 10: Reletive Displacements along Pile Depth for Dynamic Analysis the Three Earthquake Records.

V. Conclusion

An axisymmetry 2D finite element analysis was performed to investigate site effects different ground motion. The single pile-system foundation has been successfully modeled using Abaqus program, with actual data from the field investigation report for bridge site in Diyala Governorate/Iraq, the following conclusions have been drawn.

1. There is a large influence of soil-pile interaction system on pile performance during different seismic loadings patternes.
2. Alteration of the deformation and behavior of the soil became obvious and large as stiffness of soil changes with depth, therefore the selection of a sutable soil model and a detailed consideration of the dynamic soil properties playing an important role in estimating the earthquake hazard response for the geotechnical structures and should be to accounted for carefully during the first stage of analysis and design.
3. higher freefield motion for the soil used in the analysis which is due to effect of overlaying layer of soil above the bedrock and hence amplify the bedrock motion.
4. Soil-Pile-Structure Interaction (SPSI) has an important effect in the dynamic analysis and seismic design of massive or heavy structures specially like pile foundations for soil stiffness degraded under earthquake loadings and the amplified response of the soil portion near pile.
5. The overall response of the soil-pile system including the slipping, gapping at the pile soil interface and also the soil plasticity areequivalent to the free field response
6. In this analysis, it was btainedan clear insight into the dynamic-soil-pile-interaction through varying the ground seismic loading and the conclusions are limited to the pile and soil characteristic and the earthquake loading used through this analysis.

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