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Original Article

Analysis of Dynamic Response of a Single Concrete Pile Subjected to Static Vertical Load and Ground Acceleration Simultaneously

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Abstract *- In so many cases, the Pile Foundations have largely been integrated, and it's nearly impossible to imagine the stability of the systems without its application. Pile foundation is used at places where it's difficult to find desired strength of soil at shallow depth like transmission towers, high rise buildings, offshore structures, highways and railways. Pile is designed to bear the vertical load of the superstructure, and in some cases, horizontal loads are generally static in nature. Pile is also subjected to dynamic loads like wave action, wind action, earthquake and vibrations due to heavy machinery. Dynamic analysis is required to study the approximate behaviour of such loads. During an earthquake, i.e., in the case of dynamic lateral loading on the pile, the pile is considered to be a laterally loaded beam, and its bending is governed by the strength of the pile material. The PLAXIS 2D finite element software package was used to observe the pile's reaction. In addition, piles in the homogeneous medium have been extensively researched, but there is no systematic analysis of the behaviour of piles in the layered deposits that are typically found at the site. The goal of this study is to fill that void. Damping characteristics and local soil properties based on lab results have been incorporated. In particular, the deformation characteristics of the piles under lateral dynamic, as well as the axial loading, have been considered.*

Keywords *- Stiffness, Dynamic response, Ground acceleration, Foundation analysis, Damping.*

1. Introduction

The nature of soil generally varies in both directions are towards depth as well as lateral directions due to stratification, water table location, the geology of the location, etc. The strength of soil varies accordingly due to these internal characteristics too.

The variation of soil strength parameters and external forces influence the need for different types of foundations. Concerning the soil strength relation to depth, shallow and pile foundations are generally provided. As the name suggests, the shallow foundation is for shallow depth of foundation, and the pile foundation is for deep foundations due to the availability of sufficient strength at shallow and deep depth, respectively.

As a structural member, a pile foundation is actually a slender column or long cylinder made of concrete or steel to transfer the load from the superstructure at the desired depth either by end-bearing or by skin fiction. In general, large structures are employed in conditions when the soil at shallow depth is not capable of resisting settlement, uplift, etc. The load is generally passed to a hard rocky stratum through the pile for resisting the load finally.

Concerning forces resisted by pile foundation, it encounters both dynamic and static forces. The static parameters are generally sufficient to govern the stability of the pile foundation under static conditions. For the maximum possible safety of the foundation towards dynamic load, like that of an earthquake, vibrations, etc., dynamic analysis of pile foundation is needed. The dynamic study and analysis done throughout the thesis work are based on the PLAXIS 2D dynamic module, which can analyse the effect of vibrations on the soil.

Vibrations are either man-made or natural such as pile driving, movement of vehicles, machines, earthquakes, etc. The most important and concerning source is an earthquake, predominantly horizontal waves or surface waves. Travelling through the crust of the earth, surface waves are of low frequency than the body waves and thus are distinguished on a seismogram result. Surface waves are almost entirely responsible for the damage and destruction associated with the earthquake. The surface waves propagate side to side and in rolling action introducing horizontal and vertical (up and down) motion, respectively. In Plaxis 2d, the prescribed displacements feature is used to simulate such conditions and waves actions.

The situations where the frequency of vibrations is in order of the natural frequency, the chances of resonance is there. Such situations can also be analysed by the plaxis dynamic module by using the dynamic load feature. Under the dynamic analysis on plaxis 2d, the analysis is limited to axisymmetric and plane strain conditions.

Many research theories have been developed for the dynamic analysis of the pile foundation system. In the pioneering work, researchers such as Hayashi (1965) and Prakash and Sharma (1969); Barkan (1962) considered the theory of modulus of subgrade reaction and idealized the soil as a massless equivalent cantilever. The lumped mass-spring-dashpot model was used in the analysis of the pile system by) and Maxwell (1969). In the continuation of research on dynamic characteristics of soil, few researchers like Novak, Novak and El Sharnouby, El Naggar and Novak (1996) developed a number of solutions for the dynamic analysis of the pile foundation assuming the soil behaviour as linearly elastic or viscoelastic in nature and that the soil is fully bonded to the pile. Jadi and Prakash (2002) suggested reduction factors to the shear modulus of the soil and considered radiation damping to improve the theoretical predictions. They gave approximate solutions that helped understand the basic mechanism of the dynamic soil pile interaction.

Plaxis is a FEM (finite element method) software that analyses the behaviour of structures under various initial conditions and loadings. FEM acts reliably as a powerful computational tool for the analysis of the nonlinear dynamic response of soil pile systems.

The FEM (finite element method) model has been created for isolated pile and pile in the group (3*3) in PLAXIS 2D. To analyse the effect of the earthquake, ENCINO, CA(California) Earthquake accelerograms data is used as input in all cases under consideration. The earthquake accelerograms data is stored in. SMC (strong-motion time series data) and made available by USGS (United States geological survey)

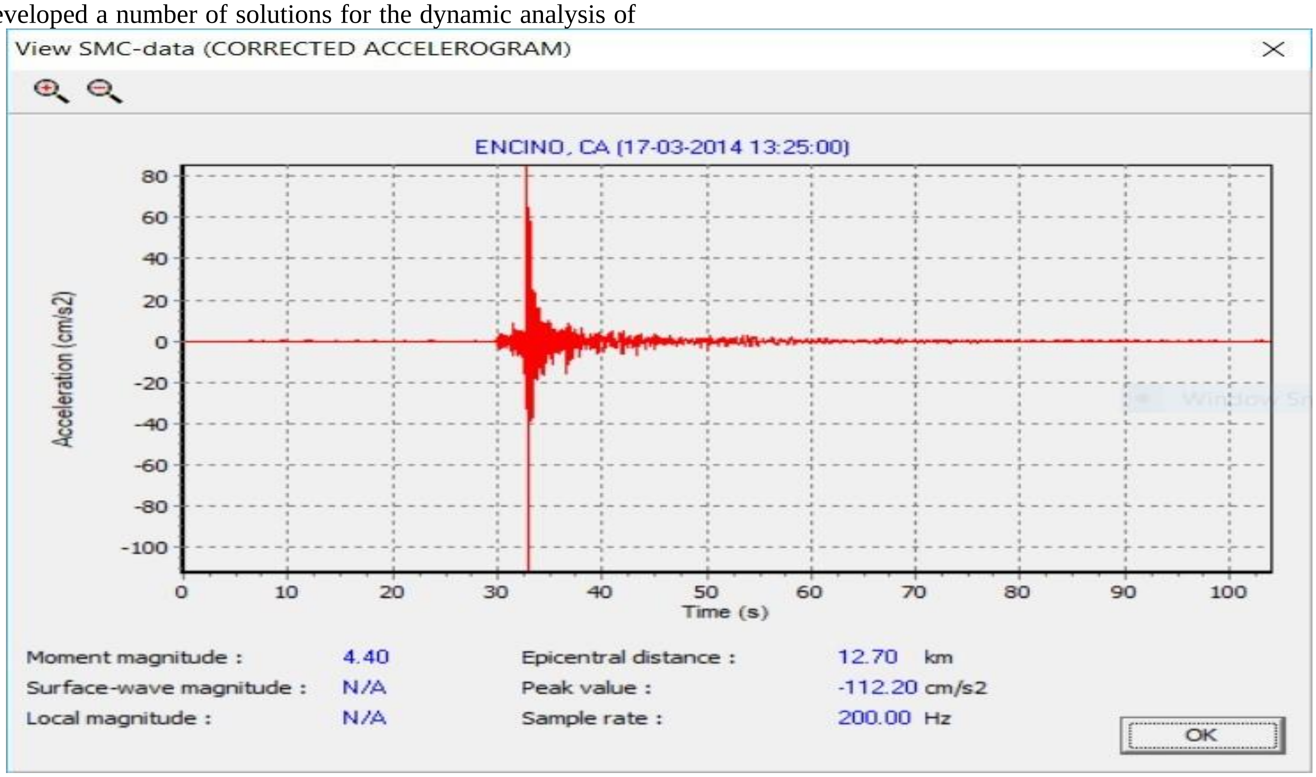


Fig. 1 Accelogram data

The .smc format is supported by PLAXIS 2d software as an input for generating earthquake simulation. The stratification of soil consists of clay and sand with defined properties, clay at the top layer and sand in the bottom layer. Moh-Coulomb model is used for modelling clay for effectively capturing the behaviour of clay. Sand is modelled using HS (Hardening Soil) model to account for the nonlinearity of dynamic load input. The pile is a model made of linear elastic nonporous material input.

2. Material Properties

Isolated concrete pile with 0.4m diameter and 12m length is located in CL clay underlay by SP soil subjected to static vertical load as well as ground acceleration simultaneously with and without damping. For comparison purposes, single layer CL soil is also being considered to connect the research trend. Material properties are as under:

Table 1. Material properties

Material model	Model	Mohr-Coulomb (CL soil)	Hardening soil (SP soil)	Linear elastic	unit
Type of behaviour	**type**	**undrained**	**undrained**	**nonporous**	
Unit weight below the water table	γ_{unsat}	17.5	17	25	kN/m^3
Unit weight above the water table	γ_{sat}	20	20	-	kN/m^3
Young's modulus	E_{ref}	1600	4600	3x10^7	kN/m^3
cohesion	C	20	0	-	kN/m^3
Friction angle	Φ	17	17.5	-	degree
Interface strength reduction factor	R_{inter}	0.5	0.67	-	--

3. Finite Element Method

The finite element method, sometimes referred to as finite element analysis (FEA), is a computational technique to solve boundary value problems through approximate solutions in the field of engineering. The whole continuum is divided into various geometric shapes known as finite elements. The material properties and the governing equations are considered in over these elements, and these are expressed in terms of unknown values at the element corners. An assembly process duly considering the loading and constraints result in a set of equations. It is the solutions of these equations which gives the approximate behaviour over the continuum.

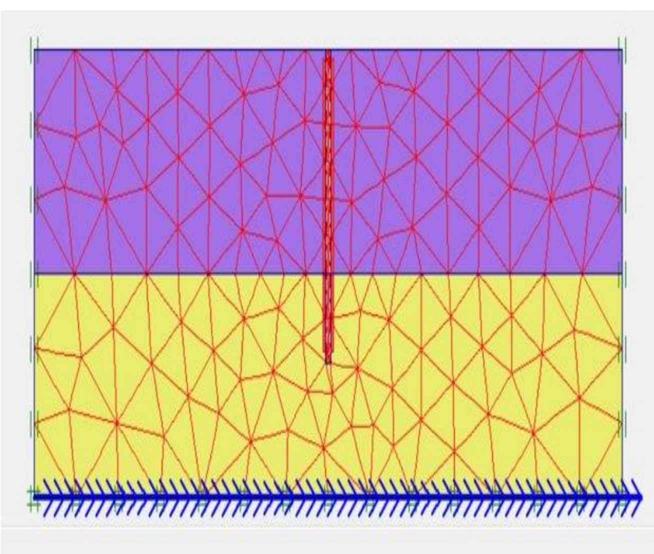


Fig. 2 Globally refined generated mesh

PLAXIS offers the choice between 6-noded and 15-noded triangles, but in this study throughout, 15 noded elements have been chosen for accuracy and results that are more agreeable. Out of axisymmetric and plane strain model representation, the axisymmetric model has been chosen owing to the symmetry in the pile and the soil system. To model the pile-soil interaction, proper interface elements have been used around the pile system along with proper strength reduction factors.

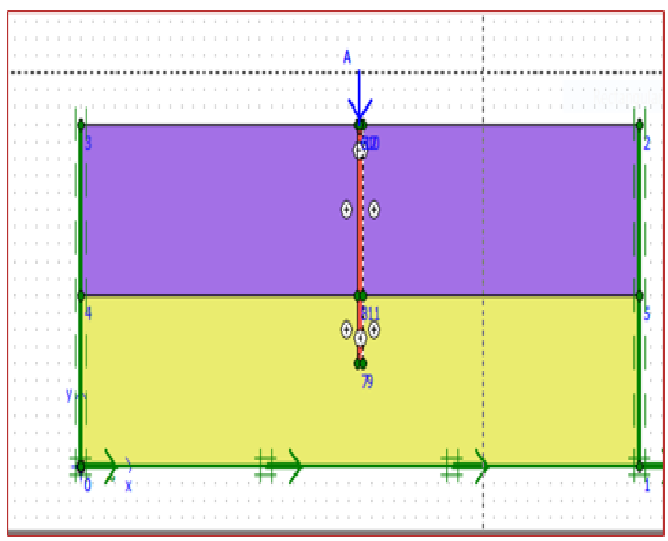


Fig. 3 Isolated pile model

To simulate the superstructure loading point, the load of magnitude 700 kN has been taken in input. Also, for the dynamic loading input, earthquake data for the 2014 Encino, CA earthquake. has been taken. PLAXIS takes the dynamic data in the smc (strong-motion CD-ROM) format. The earthquake is modelled by imposing the prescribed displacement at the bottom of the boundary. In the double-layered soil system, the top clay layer has been modelled with the Mohr-Coulomb Model and the sandy bottom layer with Hardening Soil Model so as to model the nonlinear deformations around the tip of the pile. The effect of the water table has been ignored, and by default, it is placed at the bottom of the boundary.

Classical Rayleigh damping is applied to the soil system.

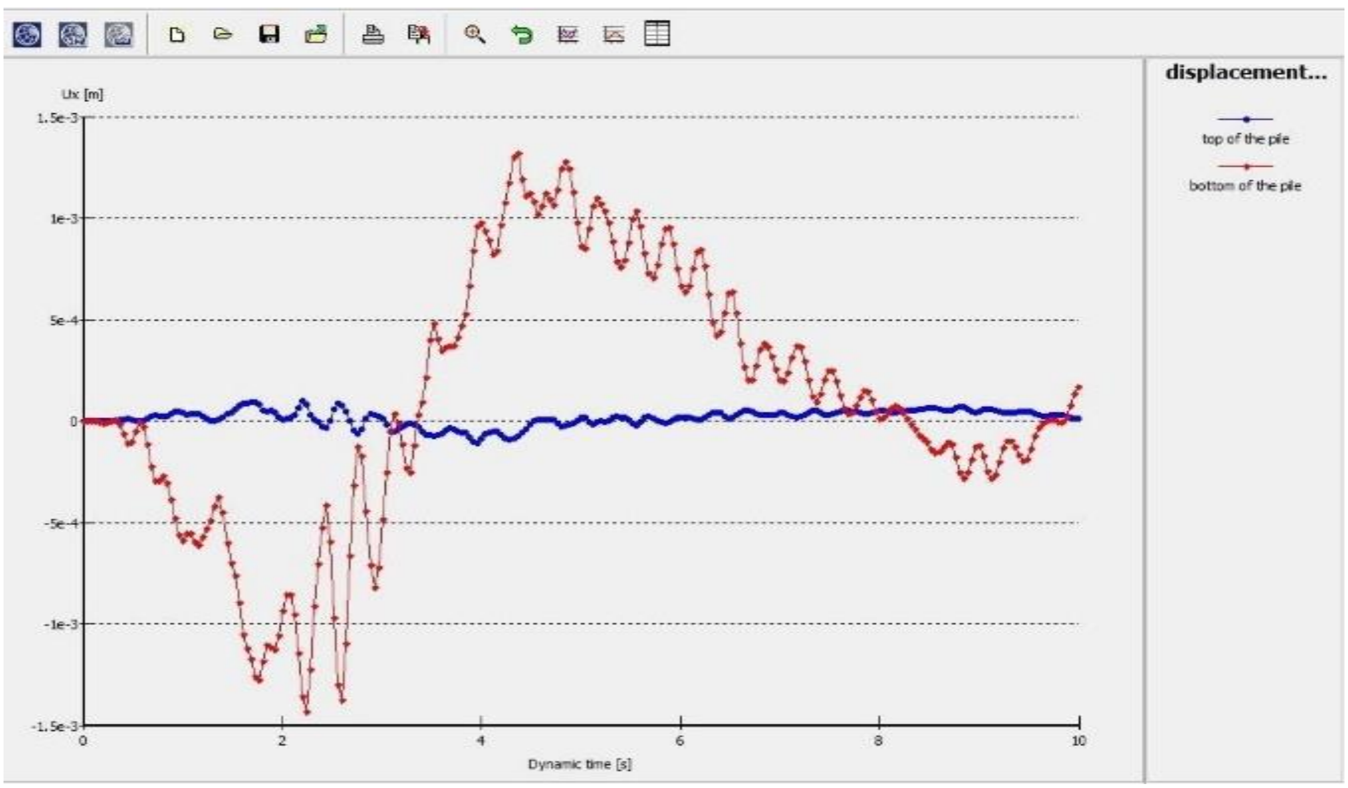
$$C = \alpha M + \beta K$$

where M and K are the mass and stiffness matrix, respectively, and α and β are the constants of proportionality. The values of α and β can be conveniently varied in the PLAXIS software, thus inducing damping effects in the soil. Rayleigh damping factors are activated with α= 0.001 and β = 0.01 as default values otherwise set to zero for the undamped case.

4. Results and Discussions

Pile deformation characteristics using the predefined key points in the geometry at the top and bottom of the pile are studied and analysed.
Comparisons are categorised into 3 sections:
Case 1: Undamped single-layer soil system
Case 2: Undamped & layered soil system
Case 3: Damped & layered soil system

The top and bottom key points are analysed for acceleration and displacement characteristics with respect to time and are displayed below in the form of curves and shadings, as shown in figure 4.



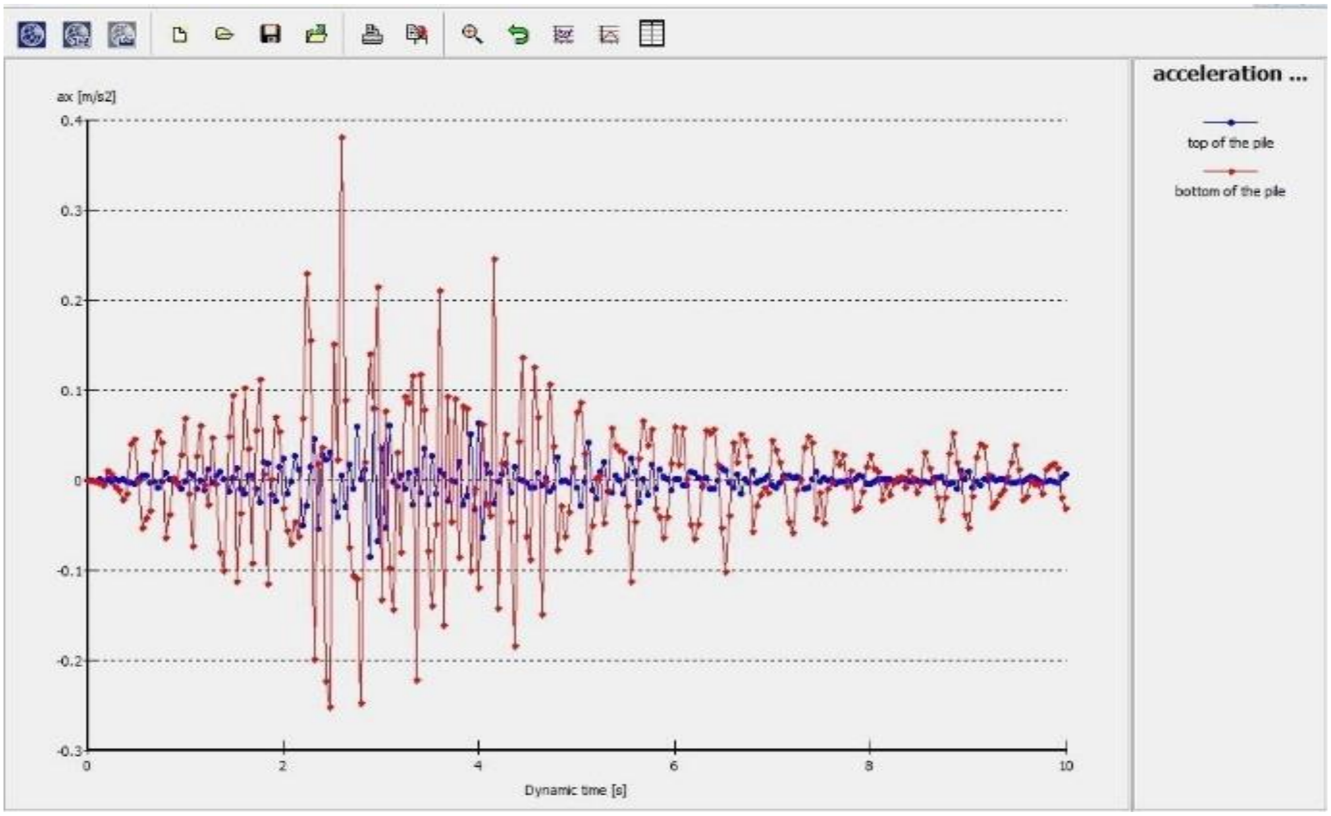
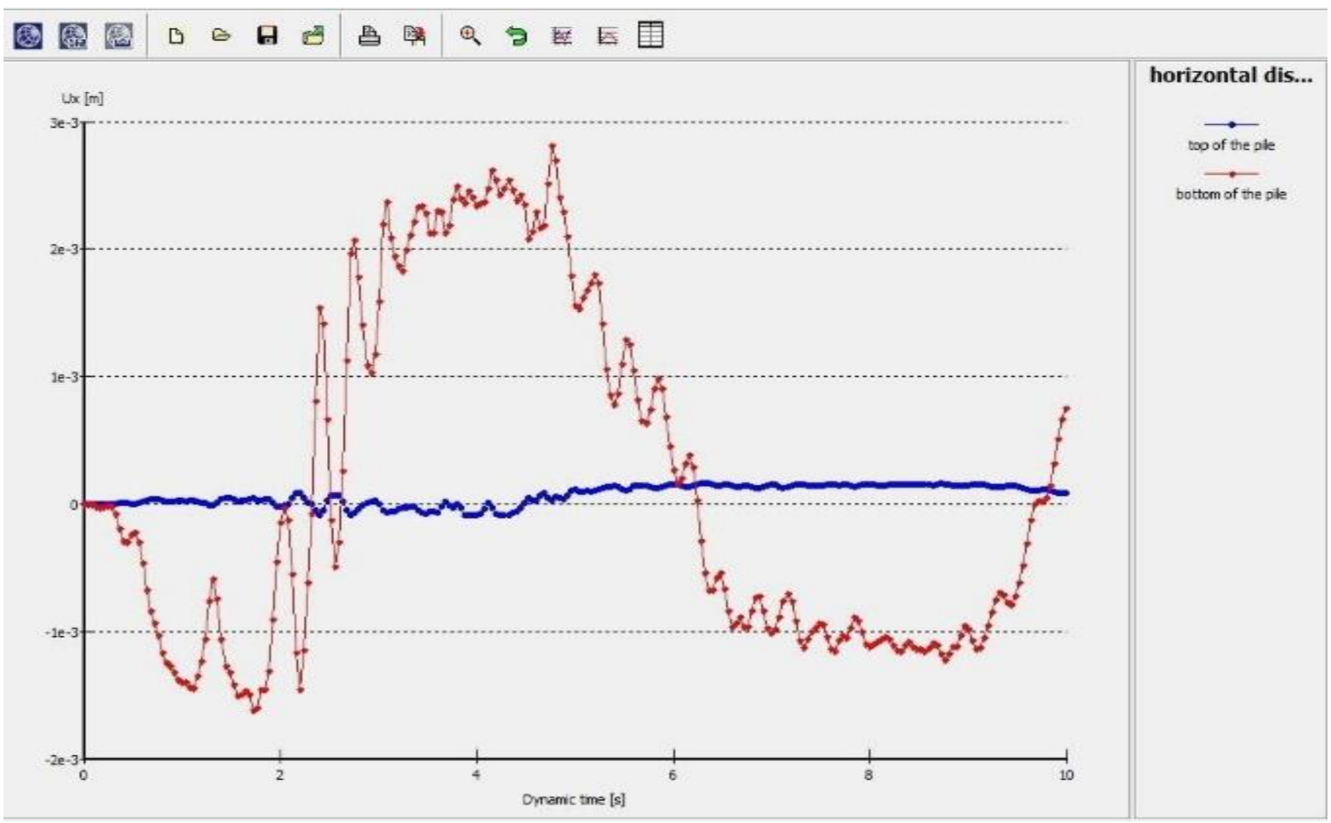


Fig. 4 Displacement and acceleration values of top and bottom key points (case 1)



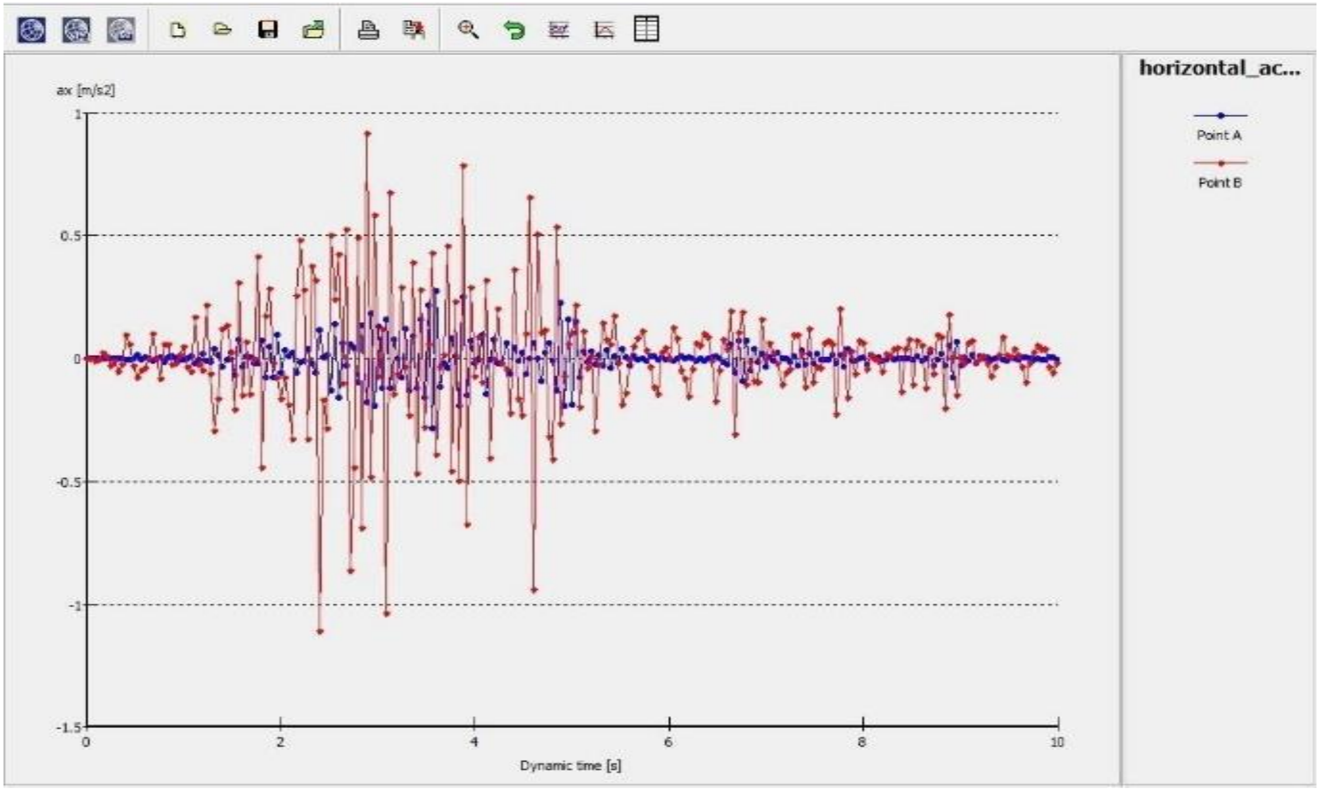
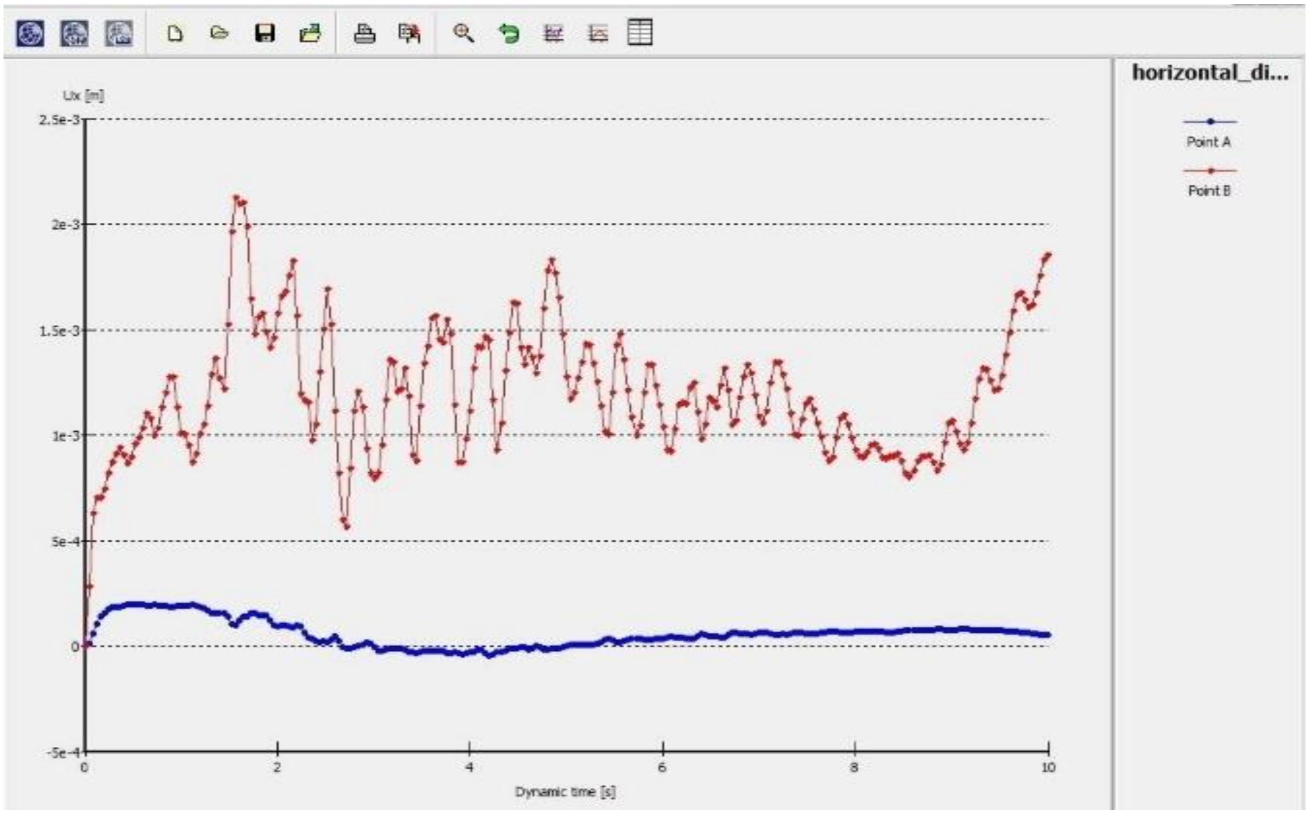


Fig. 5 Acceleration and displacement values of top and bottom tip of the pile (case 2)



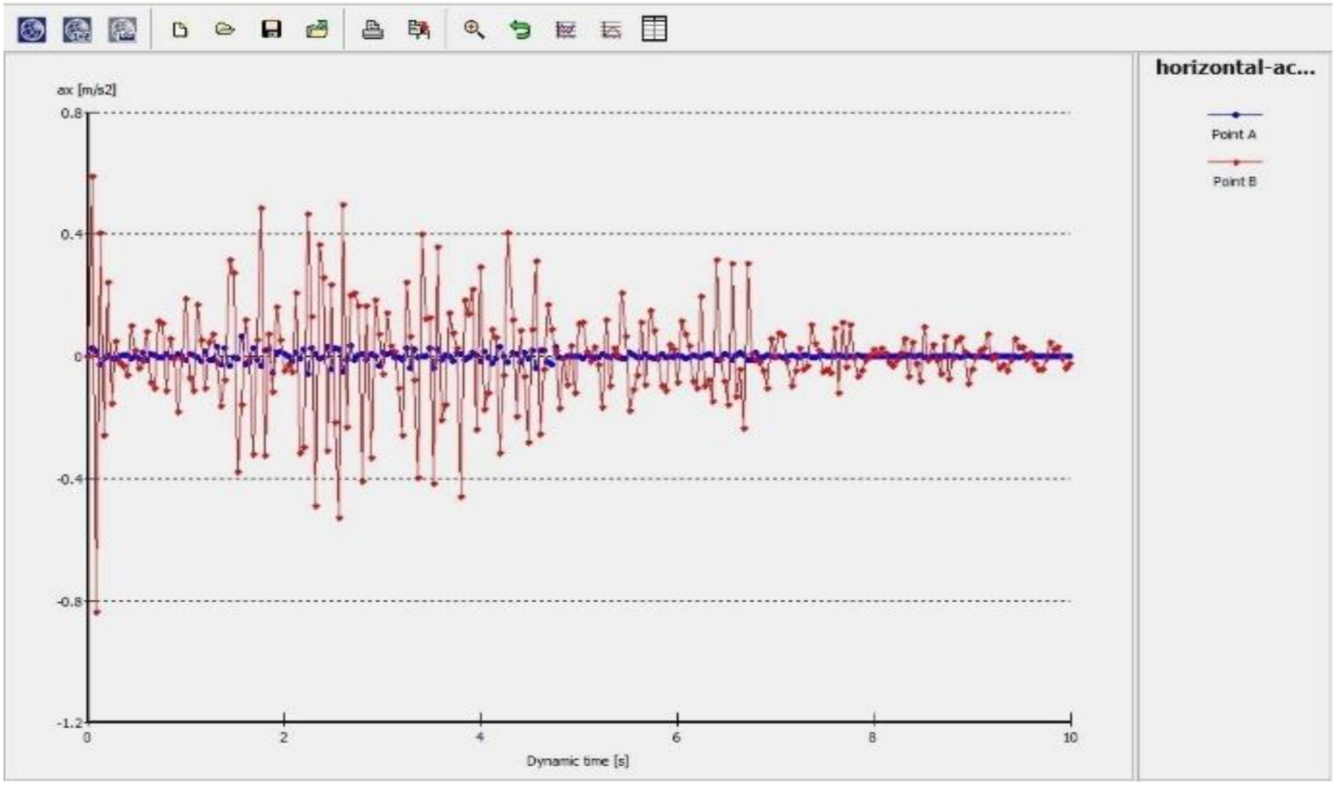


Fig. 6 Acceleration and Displacement values of top and bottom of the pile (case 3)

Table 2. Peak acceleration and displacement values

Case	Point	Displacement (m)	Time (s)	Acceleration (m/s^2)	Time (s)
1	A (top)	-1.071×10^{-4}	3.96	-0.085	2.88
2		1.613×10^{-4}	6.28	0.275	3.6
3		1.534×10^{-4}	0.48	0.065	1.56
1	B (bottom)	-1.432×10^{-3}	2.24	0.381	2.6
2		2.808×10^{-3}	4.76	-1.105	2.4
3		2.12×10^{-3}	1.56	-0.835	0.08

The comparison of peak values of cases 1 and 2 states that the criticality of layered soil system comes out to be more than single layer soil system. Thus, the layered soil system needs more careful analysis.

By analysing peak results of cases 2 and 3, it can be clearly observed that the bottom key points of the pile undergo greater displacement and acceleration values than the top key point of the pile.

5. Conclusion

In this paper, the results of dynamic response of a single concrete pile located in CL clay as well as underlay by SP soil subjected to static vertical load as well as ground acceleration simultaneously was presented.

It can be concluded that,

- The bottom key point of the pile reaches the maximum value earlier than the top key point of the pile.
- Soil stratification has a significant effect on the dynamic response of the pile, with the stratified soil case being more critical than the homogeneous one. Thus more emphasis should be put on that.
- Also, due to stratification, the maximum values of displacement and acceleration are reached later than the homogeneous case.
- Due to damping, a considerable difference in the acceleration and displacement values along with damping values are significantly less than the undamped case. The maximum values are also reached earlier in the dumping case.

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