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by

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DSSI FOR PILE SUPPORTED ASYMETRICAL BUILDINGS IN A STRATIFIED SOIL

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Abstract. In order to get the exact response of the structure under the earthquake loading, it is necessary to include the interaction effect in the analysis. It is a very challenging task to include the interaction effect in the analysis as it is very complex and governed by the many factors including impedance, wave propagation, resonance, damping etc [10]. In the present study, the 3-story asymmetrical building supported by pile foundation is considered for the analysis. Dynamic analysis is carried out in time domain by applying a Bhuj (2001,0.31g) ground motion and the response of the superstructure is predicted in the form of displacements and stresses. The elastic half space is considered as supporting local soil which included the horizontal stratification with four soil layers. The parametric study has been carried out for a different stratification order with the Mohr-Coulomb material model. For each analysis case the displacement of the superstructure and piles have been estimated using finite element software. The response is compared with the equivalent homogeneous soil strata which shows the average engineering properties of the stratified soil considered in the present study. It has been observed that the response varies with the stratification sequence and more for the granular soil overlaid on the clay. The response with the equivalent homogenous soil strata is found to be greater that other analysis cases and thus study concluded that the stratification plays an important role in the response of the superstructure.

Keywords: DSSI, Soil pile interaction, Asymmetrical building, Soil stratification

Introduction

Dynamic Soil Structure interaction (DSSI) is a very complex phenomenon to implement in real design practice for a structure as it governed by several parameters including attenuation of waves through soil, nonlinear soil behaviour under dynamic loading, impedance of the soil strata and superstructure inertia [10,13]. In most of the design practices the superstructure is assumed to be founded on the rigid bed rock which dilutes the reality of soil as a supporting media for the foundation, which predicts the incorrect response of the system under dynamic transient loads like Earthquakes. To understand the soil structure interaction and analyze the system nearer to the actual one, many researchers made an attempt to consider soil strata in a foundation system. Considering a soil as a homogenous under the foundation again it violates the reality that soil medium is highly heterogeneous which give rise to the impedance and the attenuation for the dynamic loading [14]. Thus to estimate the structural behaviour against the dynamic loading supported on a deep foundation system with soil heterogeneity is very challenging.

Theory and Background of DSSI

In 1980 wolf has given a understandable shape by introducing elastic half space theory for the soil structure interaction [13]. Ground motions that are not influenced by the presence of structure are referred as free field motions. Structures founded on rock are considered as fixed base structures. When a structure founded on solid rock is subjected to an earthquake, the extremely high stiffness of the rock constrains the rock motion to be very close to the free field motion and can be considered as a free field motions and fixed base structures.Dynamic analysis of SSI can be done either using direct method or Substructure Method. Direct approach is one in which the soil and structure are modeled together in a single step accounting for both inertial and kinematic interaction. Substructure method is one in which the analysis is broken down into several steps that is the principal of superposition is used to isolate the two primary causes of SSI [13]. If the structure is supported on soft soil deposit, the inability of the foundation to confirm to the deformations of the free field motion would cause the motion of the base of the structure to deviate from the free field motion. Also the dynamic response of the structure itself would induce deformation of the supporting soil. This process, in which the response of the soil influences the motion of the structure and the response of the structure influences the motion of the soil, is studied under the interaction effects and termed as the Dynamic Soil Structure Interaction (DSSI), as shown in Fig. 1.

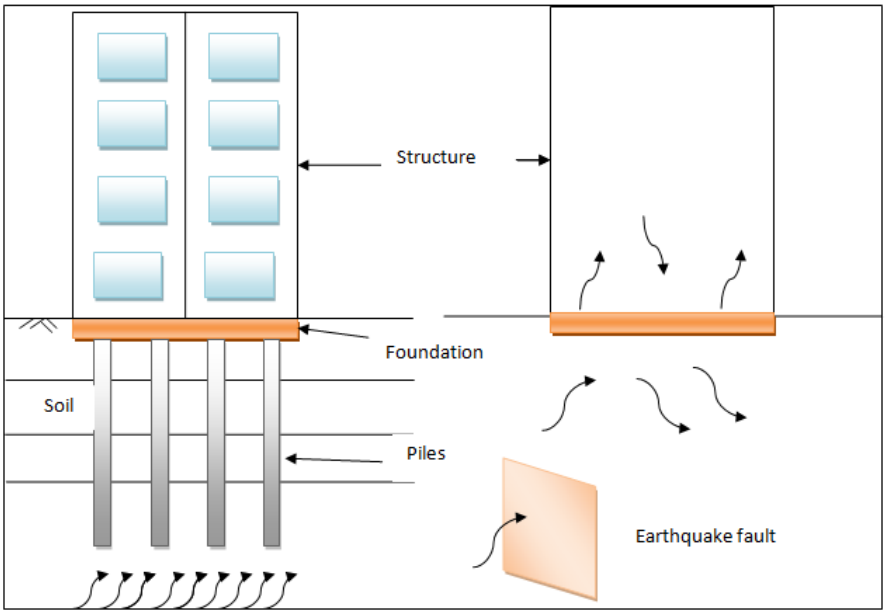


Figure 1. General scenario of consideration of soil structure interaction effect and wave propagation [13]

These effects are more significant for stiff and/ or heavy structures supported on relatively soft soils. For soft and /or light structures founded on stiff soil these effects are generally small. It is also significant for closely spaced structure that may subject to pounding, when the relative displacement is large [10].

Scope of present study

In this research paper the effect of stratification and soil heterogeneity on the superstructure response is studied by developing a Finite Element model using Plaxis 2D [12].

Soil details

To capture the real time scenario of an analysis the soil heterogeneity is considered including the four horizontal stratified zones including medium dense (S1), dense (S2), medium stiff (C1) and stiff (C2). The details of the each soil layers each type of soil is described in Fig. 2.

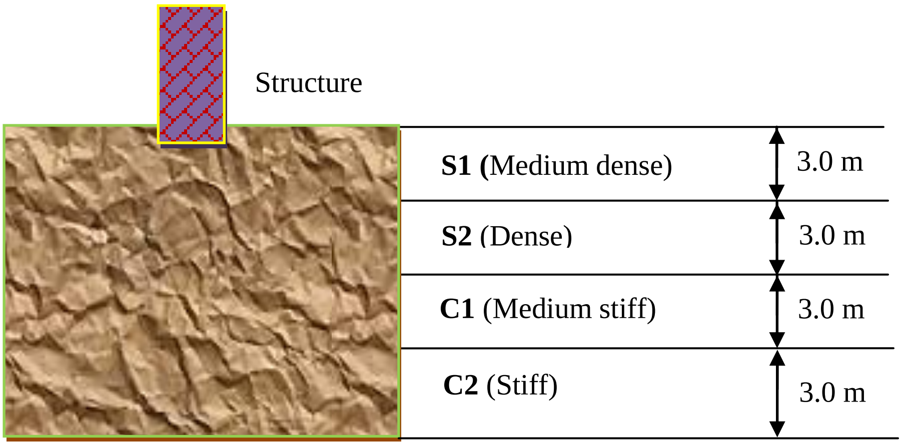


Figure 2. Details of soil layers considered in present study

The engineering properties of the soils zones is detailed in the Table 1.The parametric study is carried out altering these layers and the interaction response against the dynamic load is studied.

Table 1. Engineering properties of the soil layer considered in the present study [11]

Soil Type	Unit Wt. (γ_{sat}) (kN/m^3)	Cohesion, C_u, (kN/m^2)	Friction angle, ϕ' (^{0})	Poisson's Ratio	E_{ref} (kN/m^2)
S1	20	0	32	0.47	6000
S2	21	0	38	0.38	12000
C1	19	40	0	0.4	4500
C2	20	80	0	0.45	9000
Eqv	20	60	35	0.42	7900

Structure and foundation details

A 3 storey structure with pile foundation is considered in the present analysis. The details of the structure model are given in Table 2 as below.

Table 2. Details of superstructure and foundation

Parameter	Discriptions
Asymmetry Type	Loading
Height	9 m
Asymmetrical Ht.	3 m
Base Dimension	6 x 6 m
Beam and column	0.25 x 0.25 m , 3m Length/Height
Pile configuration	0.25 m dia x 6 m at 3 m c/c
Grade of concrete	M_{30}

Finite element modeling

Superstructure and foundation system:
In present study structural elements like beam and column and pile foundation is modeled with plate element. Plates in the 2D finite element model are composed of plate elements (line elements) with three degrees of freedom per node viz two translational degrees of freedom (ux,uy) and one rotational degrees of freedom (rotation in the x-y and @ plane z). The plate elements are based on Mindlin's plate theory [9]. This theory allows for plate deflections due to shearing as well as bending. In addition, the element can change length when an axial force is applied. Plate elements can become plastic if prescribed maximum bending moment or maximum axial force is reached. Soil is modeled with 15 node plate element.

Interfaces:
Interfaces or joint elements need to model adjacent to plates element to allow for a proper modeling of soil-structure interaction. In present study soil pile interaction is achieved by modeling interface element at soil and pile element at both side of the pile. The contact between different soil strata is also model by proper size of interface element. The roughness of the interaction is included by choosing a suitable value for the strength reduction factor which is governed by the friction theory of the different and same type of material [8].
Each interface has assigned to it a virtual thickness which is an imaginary dimension used to define the material properties of the interface. The higher the virtual thickness is the more elastic deformations are generated. In general, interface elements are supposed to generate very little elastic deformations and therefore the virtual thickness should be small. On the other hand, if the virtual thickness is too small, numerical ill-conditioning may occur [8,12]. Thus the proper understanding is required to model the interface element thickness and can be implemented in modeling by virtual thickness factor which calculated as the virtual thickness factor times the global element size (size of the element at the time of mesh generation).

Viscous Boundary:
In dynamic soil structure interaction problem the far filed is modeled by the viscous boundary conditions in order to avoid the reflection of the waves during the earthquake. It is always preferred to model far field with viscous boundaries than the standard fixities in order to absorb waves that reach the model boundaries and that would result in spurious reflections otherwise [3,6]. A viscous boundary is aimed to absorb the increments of stresses on the boundaries caused by dynamic loading, which would be reflected inside the soil body.

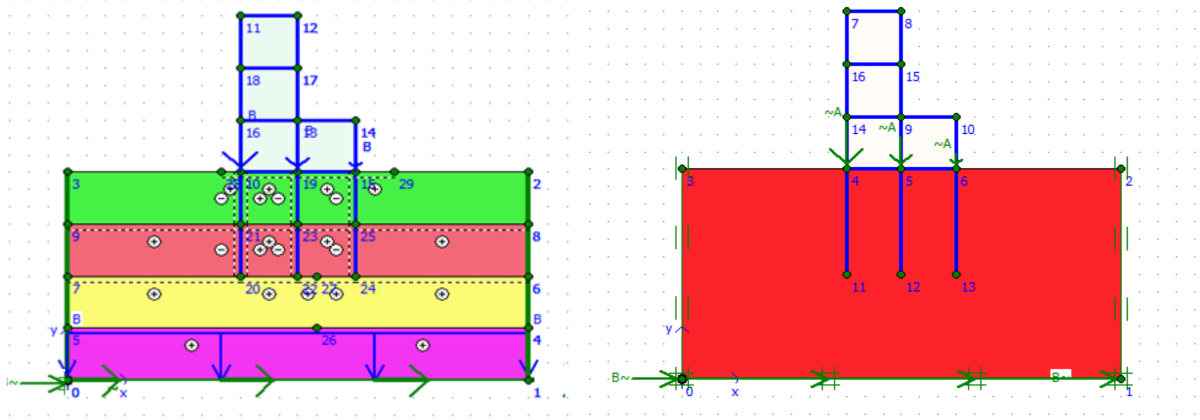
Dynamic loading:
The structure and foundation system is subjected to the Bhuj ground motion (2001, 0.31g). The dynamic loading is applied at the bottom of the soil domain and the response of the structure at each storey level and pile levels are estimated.

Analysis:
The finite element model for pile supported 3-storey asymmetrical building including soil stratification is developed using Palxis a finite element geotechnical tool for different stratification arrangements mentioned in Table 3. Fig. 3a. and 3b. explains the details of the finite element modeling including soil stratification and equivalent homogenous soil strata respectively. The response of the structure has been estimated against the dynamic loading at

each storey for all analysis cases including Case1, Case2, Case3 and Case4 and results are compared with the response obtained for equivalent homogenous soil strata.

Table 3 Details of parametric study

Analysis cases	**Soil layers (ordered from surface)**
Case 1	S1,S2,C1,C2
Case 2	S2,S1,C1,C2
Case 3	C1,S1,S2,C2
Case 4	C2,S1,S2,C1



(a) (b)

Figure 3. Finite Element model for DSSI (a). Soil stratification with appropriate interfaces and (b). Equivalent homogenous soil

Result and Discussion

The 3 storey pile supported R.C.C frame is analyzed for the Bhuj ground motions applied at the bottom of the finite soil domain and response of the structure at each storey and at different foundation levels including different cases of stratification arrangement has been estimated in time domain. The time domain displacement history for analysis Case 1 for different location points shown in Fig. 4 along the height of the model is shown in Fig. 5.

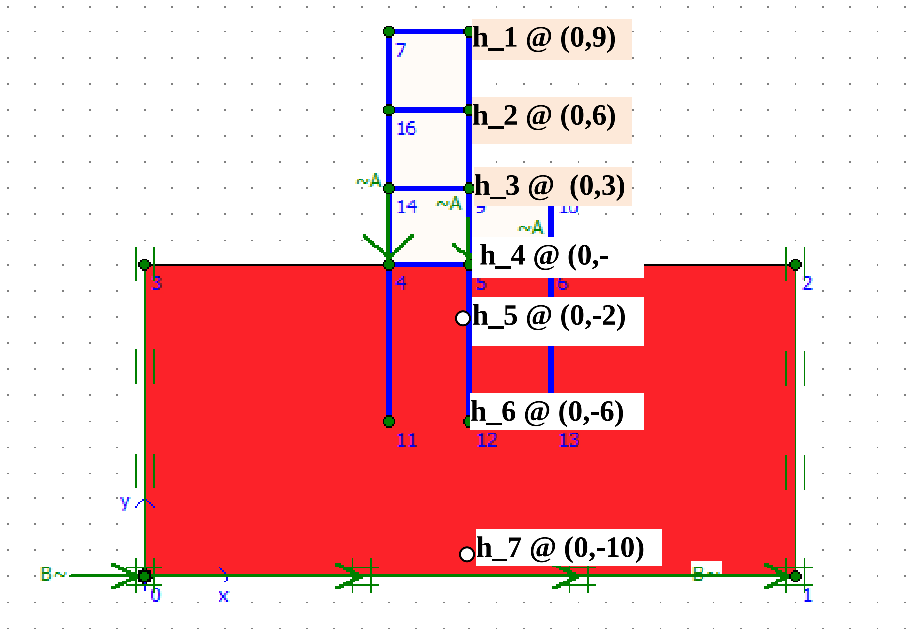


Figure 4. Locations of the response

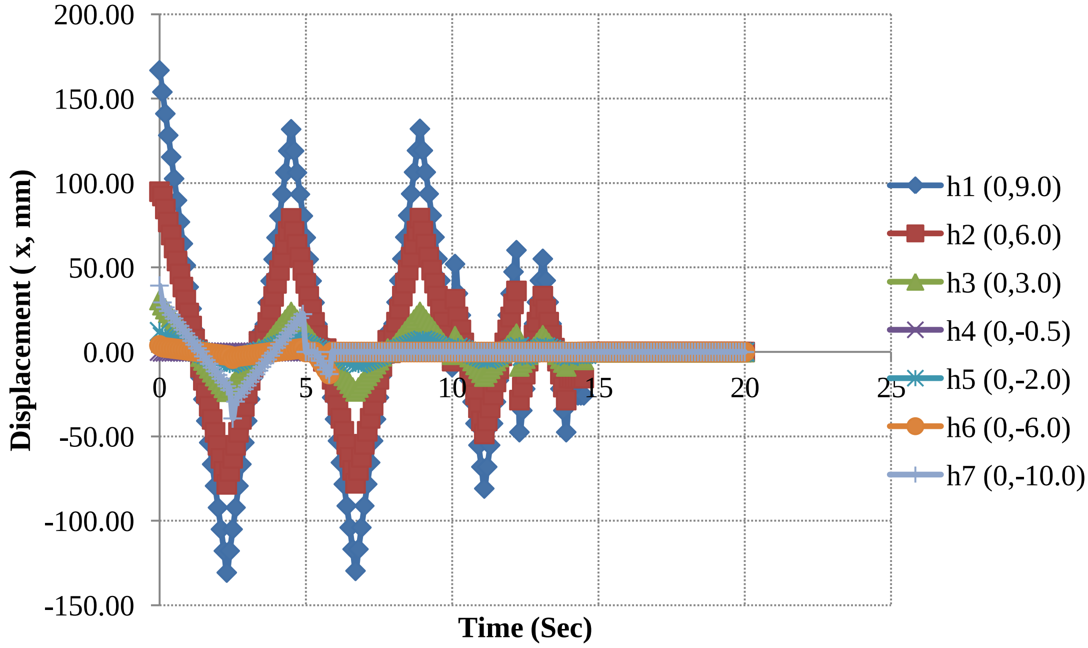


Figure 5. Displacement history at different locations along elevation of the model

Fig. 6a and 6b shows the time history displacement for structures and foundation system respectively.

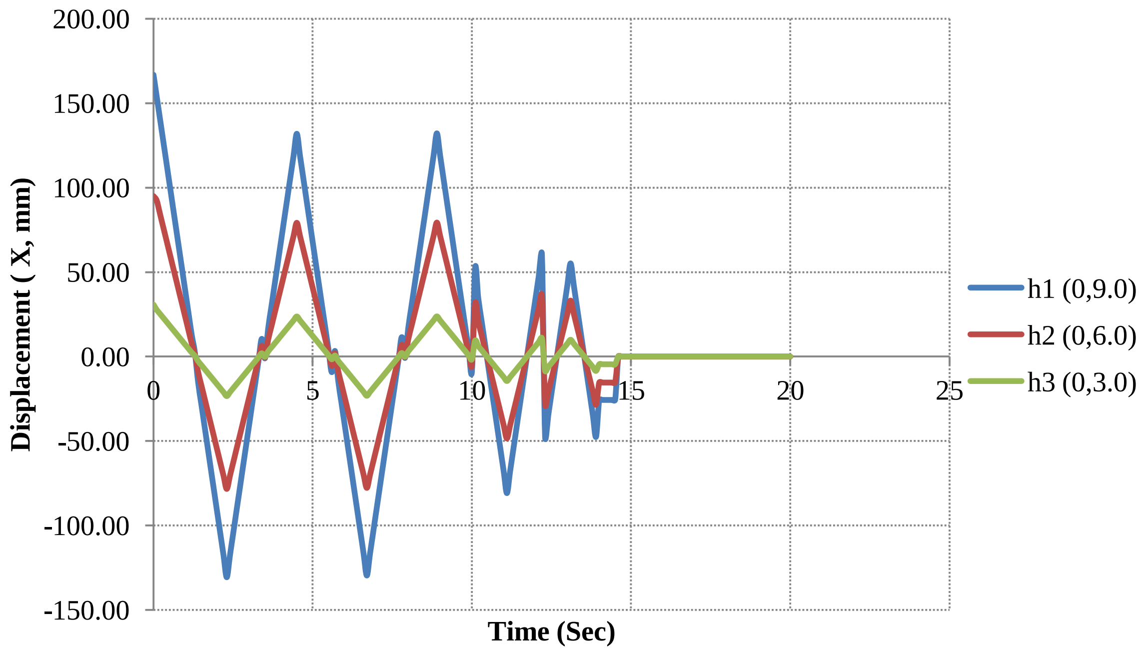


Figure 6a. Time history displacement of superstructure at each storey

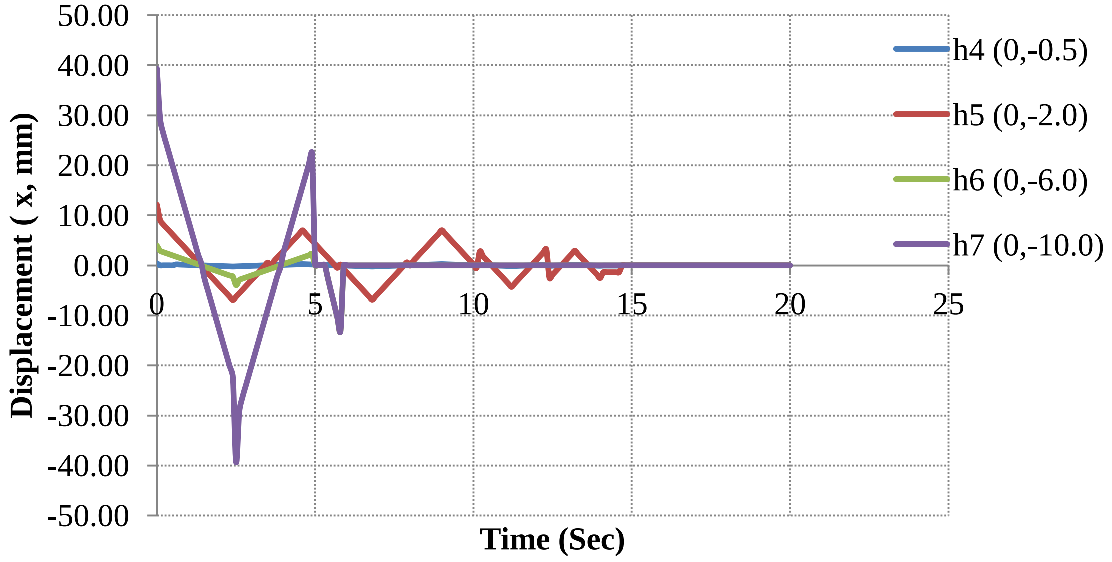


Figure 6b. Time history displacement of foundation system

The analysis has been carried out for homogenous soil strata which are having an engineering properties equivalent to the all four soil strata. The response in terms of the peak displacement during the transient loading for superstructure and foundation system is compared with the response of the equivalent soil condition. Fig.7 shows the comparative summary of all analysis cases and homogenous equivalent soil condition.

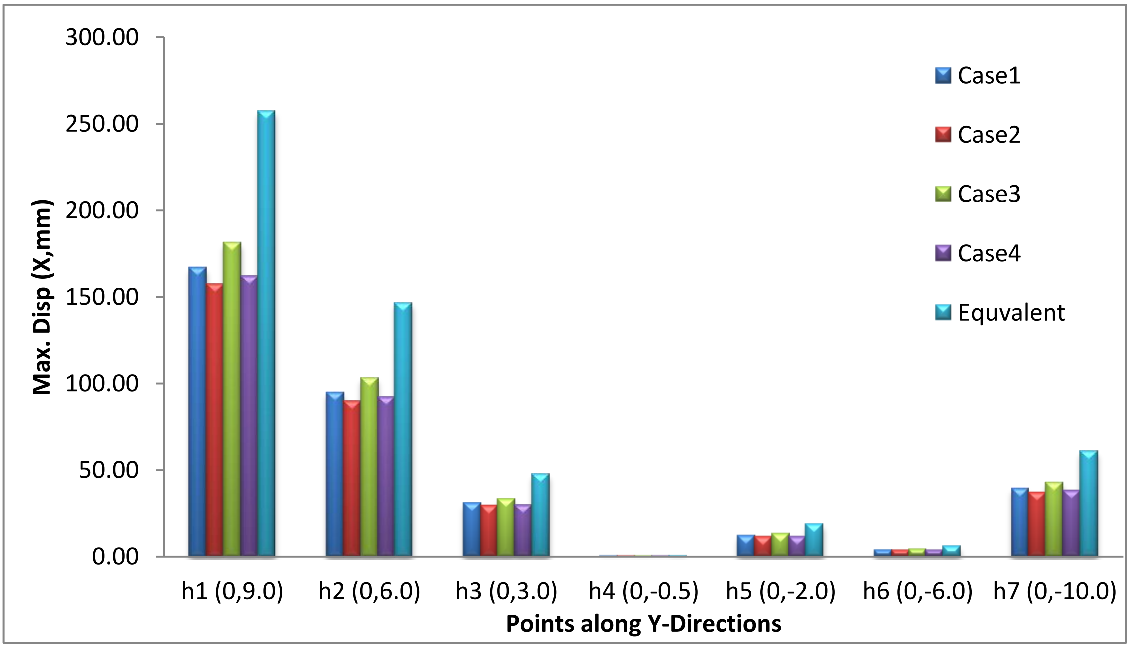


Figure 6 Comparison for peak displacement values for each case

Conclusions

The dynamic analysis for pile supported three storey building has been carried out using Geotechnical Finite Element tool, Plaxis 2D [12].The response analyzed for the soil heterogeneity to meet the actual scenario including the four horizontal stratified zones including medium dense (S1), dense (S2), medium stiff (C1) and stiff (C2) for soil structure interaction effect. Following are few conclusions drawn from the present study.

- All stories of the superstructure follows the same displacement profile with different peak displacemnt value.The pile cap and centre of the pile also follows the same displacement pattern and attains the full damping condition at in an average 15 sec for all analysis cases.
- Displacement at the bottom of the pile follows very mild curve and attains the full damping condition at very early stage of the i.e in average 5 sec for all cases.
- The displacement of the soil is comparively more than the displacement at the pile bottom but system dessipates in a short time than the above ponts.
- The maximum displacement is found in the superstructure than the foundation system and the peak displacement is more for analyss case 3 which includes the prfile with the cohesionless soil overlaid by the cohesive soil thus granular soil gives and transfers more displacement than the cohesive soil.
- The displcement for equivalent homogenous strata is found to be more by 35% as campred to the other analysis cases including soil stratification thus considering a homogenous strata for an anlysis is prooved to be conservative approach for DSSI analysis.
- It has been observed that the soil damps more quickly than the superstructure during the time of loading.

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