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Seismic Analysis on Soil-Structure Interaction of Buildings over Sandy Soil

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Abstract

During earthquakes seismic waves propagate from the bedrock through the soil layers and damage structures on the surface. The understanding of local site effects on strong ground motion is of particular importance for the mitigation of earthquake disasters as well as future earthquake resistant design. This paper presents an idealized two dimensional plane strain finite element seismic soil-structure interaction analysis using Abaqus V.6.8 program. The analysis performed by considering three actual ground motion records representing seismic motions with low, intermediate and high frequency content earthquakes. Through these analyses, influence of different subsoils (dense and loose sand), buildings height, in addition to the frequency content of the earthquake have been investigated on amplification, acceleration response and stress propagation on the soil-foundation interface. Results illustrate that both sandy soils amplify seismic waves on the soil-structure interface because of the soil-structure interaction effect.

Keywords: Seismic analysis; Soil-structure interaction; Earthquake; Sandy soil

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1. INTRODUCTION

Seismic waves propagation through near-surface soil layers can produce ground motions much larger and with different characteristics on the soil surface in comparison with those recorded at the rock base. The combined effect of earthquakes and local site conditions are commonly referred to as site effects. Numerous examples of earthquakes where site effects were observed are available. As an example during the 1985 Mexico City earthquake, site amplification caused substantial damage and collapse of many buildings (Romo and Seed 1986). Detailed studies of the relationship between building damage and soil conditions were provided by Seed (Seed 1986). In addition, there are numerous studies which have shown

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correlation between damage and local geology and site condition (Ohsaki 1969, Ghosh and Madabhushi 2003). Many researchers studied seismic analysis of soil-structure interaction for different types of structures including bridges, minarets and etc (Htwe, 2005; Dogangun et al 2007; Mwafy et al, 2008).

Analysis of soil-structure interaction effects during earthquakes are usually made by one of two methods (Rahgozar 1993): (a) a complete interaction analysis involving consideration of the variation of motions in the structure and in the adjacent soil, or (b) an internal analysis in which the motions in the adjacent soil are assumed to be the same at all points above foundation depth. Different aspects of seismic soil-structure interaction analysis are investigated by different researchers which are also available in the literature including Gazetas (2006) and Kolekova et al (2006).

In this paper finite element method has been used for seismic analysis of soil-structure interaction. Two different sandy soils (dense and loose sand) has been considered as the hypothetical site soil in order to investigate the effect of sandy soil properties on the seismic response of the soil-structure system. ABAQUS v. 6.8 program has been used for two dimensional finite element simulation of the whole project including the local soil and the building structure. The simulated buildings are two dimensional 5 and 20 storey buildings with moment resisting frames representing low and high rise buildings. The earthquakes are selected from three actual ground motion records representing seismic motions with low, intermediate and high magnitudes of a/v (pick ground acceleration in g to pick ground velocity in m/s) so as to investigate the effect of frequency content on soil-structure interaction. Investigating the acceleration response of the soil-structure system in the soil profile and stress propagation on the soil-structure interface in each soil subjected to these three actual earthquakes are the main objectives of the current project.

2. GENERAL PROPERTIES OF THE SIMULATED MODEL

2.1. Creating finite element model for the soil-structure system

The simulated soil medium was considered to be rectangular shaped with 600m width and 50m depth. Simulated buildings are two dimensional 5 and 20 storey one-bay moment resistant frames representing low and high rise buildings in order to investigate the effect of structures height on acceleration response of the soil-structure system and stress propagation on soil-structure interface. Effect of sandy soil properties are also investigated by consideration of two types of sandy soils: dense and loose sand. Soil-structure interaction analysis are performed by considering the amplification of seismic waves on the soil-structure interface and maximum principle stresses on the soil-structure interface for both modelled soils and buildings.

Previous studies illustrate that the frame structures base shear force for the motion at the surface exceeded the values computed for wall structures, especially in the low and intermediate frequency contents (Hiedebrecht et al, 1990, Rahgozar 1993). Based on foregoing, the moment-resisting frames are expected to represent the extreme of the dynamic response of regular multi-storey buildings so concrete moment-resisting frames are considered as structural systems in the current study.

The response of symmetrical one-bay frame is considered satisfactory approximation to the response of actual multi-bay frames subjected to dynamic or static loads (Council on Tall Buildings and Urban Habitant 1979) so it is appropriate to adopt one-bay frame models in this study. The spans of these frames are assumed to be 10m for both buildings. The storey height is taken as 3.2m. The cross sections of columns were chosen identical for every two-sequential storeys and the dimensions of the column's cross sections reduced 5cm in every two storey from bottom to the top. The 20 storey building was modelled with 100x100cm columns for the first two storeys and 55x55 storeys for the 19th and 20th (Rahgozar 1993) while the 5 storey building was modelled with 75x75cm columns for the first two storyes and 55x55 for the last one. The beam length is 10m and its cross section is assumed to be 100x50cm in all floors for both structural models. Foundations are assumed to be concrete mat with 1m thickness and extended 2.5 meters from the axes of columns (Rahgozar 1993).

Sandy soil in each state (dense or loose) and the concrete body of the structure are both modelled using visco-elastic constitutive model with consideration of Rayleigh damping coefficients of the materials. The simulation of the model is done in two dimensional plane strain system with finite element mesh generation consist of quadrilateral elements used for soil media and foundation concrete body in addition to line elements used for column and beam elements. In order to prevent reflection of the seismic waves from lateral boundaries of the model through the soil medium, and consideration of the infinite lateral boundary conditions, lateral boundaries are modelled using spring/dashpot system so as to absorb seismic waves as a viscous boundary (Wolf 1997). Calculating the dashpot coefficient and springs stiffness were done using Whitman and Richard proposed method (Whiteman and Richard 1967). In order to simulate the soil-structure interaction correctly, the soil-foundation interface has to be modelled in two separate surfaces with consideration of the friction between them (Concrete and Soil). The friction between these two surfaces are defined by considering two components: normal friction which is perpendicular to the soil-structure interface and shear friction component which is the tangential component. Columb theory for obtaining friction coefficient has been used in this project for determination of friction coefficients between two surfaces ($\mu = \delta$ tangφ ≈ 0.6 tangφ). Figure 1 illustrates the finite element mesh of the whole model as simulated through the ABAQUES v.6.8.

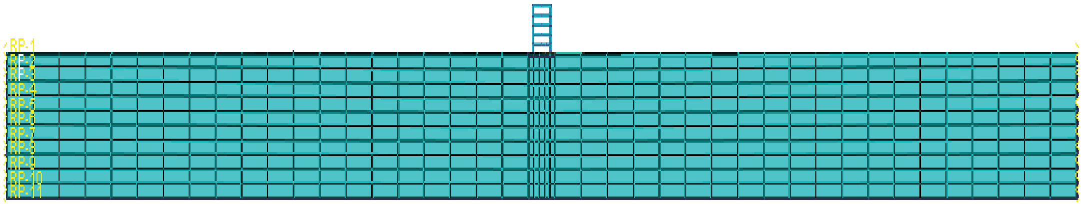


Figure.1. Two dimensional finite element mesh of the soil-structure system (5storey building)

2.2. Properties of the simulated soil, concrete and earthquakes

The simulated soil is sand in two different states: loose and dense, in order to investigate the effect of sandy soil properties on seismic soil-structure response and interaction. Sandy soils and concrete body of the structure (foundation, beams and columns) are modelled using visco-elastic constitutive model. Different parameters of the simulated soils and concrete are presented in table 1. Rayleigh damping coefficients has also been considered and defined as damping parameters of the soils and concrete which has been extracted through frequency analysis.

All of the models are subjected to three different natural ground motion records with different frequency contents with high, intermediate and low magnitude of a/v (pick ground acceleration in g to pick ground velocity in m/s) classified as Hav, Iav and Lav respectively. The earthquakes' properties are presented in table 2 including their magnitude, maximum acceleration, velocity and classification.

Table.1. Simulated sandy soils and concrete properties

Soil type	Density (Kg/m^3)	Elastic Modulus (Pa)	Damping ratio α	Damping ratio β	Poisson's ratio ν	ξ
Dense sand	1840	1.0E8	0.566351	0.0014813	0.3	0.05
Loose sand	1470	2.5E7	0.268412	0.00312554	0.3	0.05
Concrete (5storey)	2400	2.5E10	0.38832	0.00424	0.2	0.05
Concrete (20storey)	2400	2.5E10	0.11817	0.01335	0.2	0.05

Table.2. Earthquakes properties

Classification	Classification criteria	Location	Date	Magnitude	Maximum Acceleration (g)	Maximum Velocity (m/s^2)	a/v
Hav	a/v > 1.2	Lytle Greek	Sep12.1970	5.4	0.198	0.096	2.03
Iav	0.8< a/v <1.2	Japan	Nov16.1974	6.1	0.07	0.072	0.97
Lav	a/v < 0.8	California	Feb9.1971	6.4	0.101	0.193	0.52

3. SEISMIC RESPONSE OF THE SITE TO POPAGATED WAVES

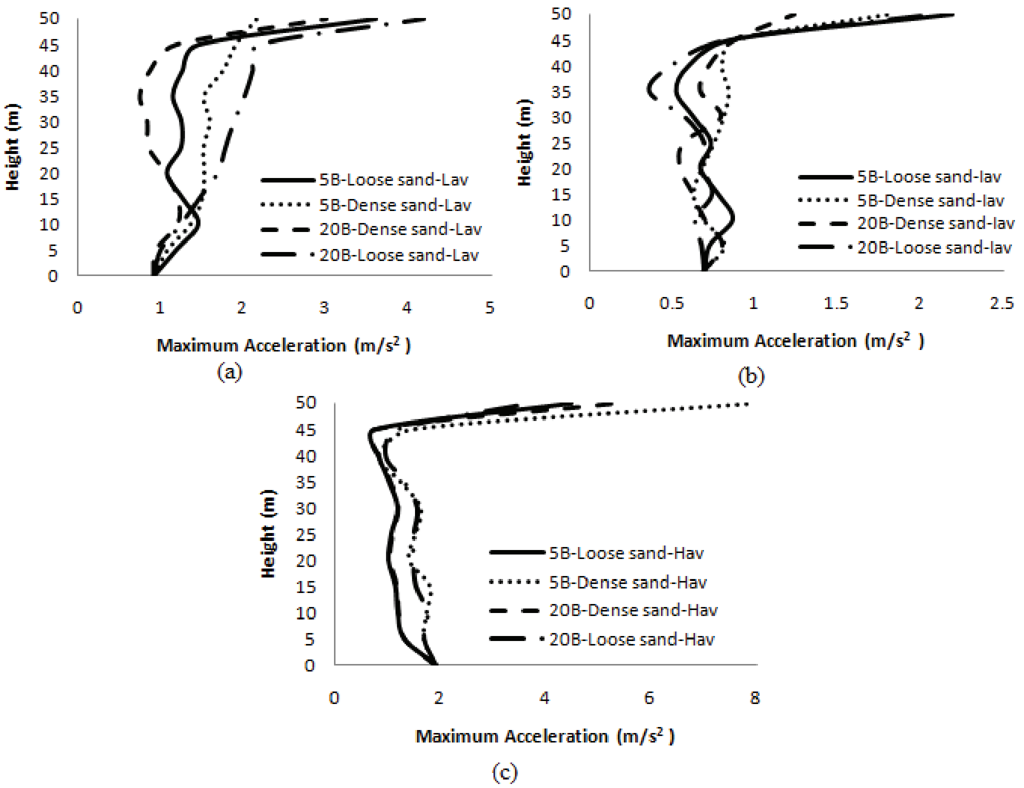
Seismic response of a soil-structure system during the earthquake is affected by many factors including the soil type and parameters (Shear modulus, mass density and material damping), structure's height and its materials' properties, in addition to the frequency content of the earthquake and soil-structure interaction. In order to consider the effect of sandy soil type and parameters, two different sandy soils has been modeled as dense and loose sand. On the other hand influence of earthquake's frequency content has been investigated on seismic response of the soil-structure system by considering forenamed actual ground motion records. Analysis are performed for 5 and 20 storey building so as to investigate the effect of building's height and the soil-structure interaction on acceleration response of the whole system. Maximum spatial acceleration is the selected parameter used to illustrate the seismic response and amplification of seismic waves during their propagation from the bedrock to the soil-foundation interface.

Figure 2 presents the effect of sandy soil type in each frequency content for 5 and 20 storey building on maximum acceleration of the soil-structure system during the earthquake. These graphs illustrate maximum spatial accelerations on each node of the soil medium from the bedrock to the soil-foundation interface during the earthquakes.

According to these graphs both soil types in all earthquakes amplified the bedrock motion on the soil-foundation interface for both modeled buildings because of the effect of soil-structure interaction. Figure 2(a) illustrates that in Lav earthquake 20 storey building over loose sand has the highest acceleration on the soil-foundation interface. This can be rationalized by considering the fact that high rise building over soft soil (loose sand) has the longest period among others so it would amplify the low frequency content earthquake more than other cases. The lowest amplification in Lav earthquake is occurred for 5 storey building over dense sand because it has the shortest period among all. The graph also illustrates that 5 storey building on loose sand presented higher acceleration on soil-foundation interface in comparison with 20 storey building on dense sand so it can be concluded that in this case soil type plays the major role on amplification in comparison with building's height.

Figure 2(b) considers the seismic response of all models for Iav earthquake. It is demonstrates that all models amplified the seismic waves on the soil-foundation interface. Although all of the values of maximum acceleration are too close on the interface, but the highest acceleration is for 5 storey building over loose sand.

Seismic response of soil-structure systems for high frequency content earthquake is presented in figure 2(c). The highest amplification on this earthquake is occurred for 5 storey building over dense sand which has the shortest period close to the Hav earthquake period. The least amount of amplification in this case is for 20 storey building over loose sand which has the longest period.



(a)

(b)

(c)

Figure 2. Effect of sand's dry density on seismic response of the site in different frequency contents: (a) Low, (b) intermediate and (c) High frequency content

4. SEISMIC RESPONSE OF THE SOIL-STRUCTURE SYSTEM BY CONSIDERATION OF THE SOIL-STRUCTURE INTERACTION

Investigation of the seismic waves propagation from the bedrock to the soil-foundation interface illustrated considerable amplification on the soil-foundation interface for both soils and buildings in each earthquake. This amplification increases the destructive potential of the earthquake on the soil-foundation interface. In order to investigate soil-structure interaction and possible hazard of the earthquake on the overlying structure (due to the fact that the highest amplification on soil profile occurred on the soil-foundation interface) inspection of propagated stress during the earthquake on the soil-structure interface is the next purpose of the current study. Figure 3 illustrates the maximum principle stress on the soil-foundation interface for both buildings and both modeled soils with consideration of three earthquakes.

This figure consists of three parts demonstrating maximum principle stress along the soil-tunnel interface for Lav, Iav and Hav earthquakes (Figure.3-a, b and c respectively). The horizontal axis is the soil-foundation interface length which starts from the left corner of the foundation (represents 0 on the axis) and extends to 15 meters. As can be seen from the graphs maximum stress in all cases is propagated beneath the columns of the structure and the minimum is occurred in the middle of the foundation (each column is 2.5 meter away from each corner as mentioned before because of the extension of the foundation in lateral directions). It can generally be seen from all these graphs that in each frequency content and each soil the 20 storey building has higher stress in its foundation's interface in comparison with 5 storey building while this difference might not be considerable. On the other hand Lav earthquake cause the highest magnitude of stress in both buildings and all soils in comparison with other earthquakes. In Iav earthquakes all graphs are too close to each other and for Hav earthquake 20 storey building over dense sand illustrated the highest magnitude of propagated stress on its soil-foundation interface.

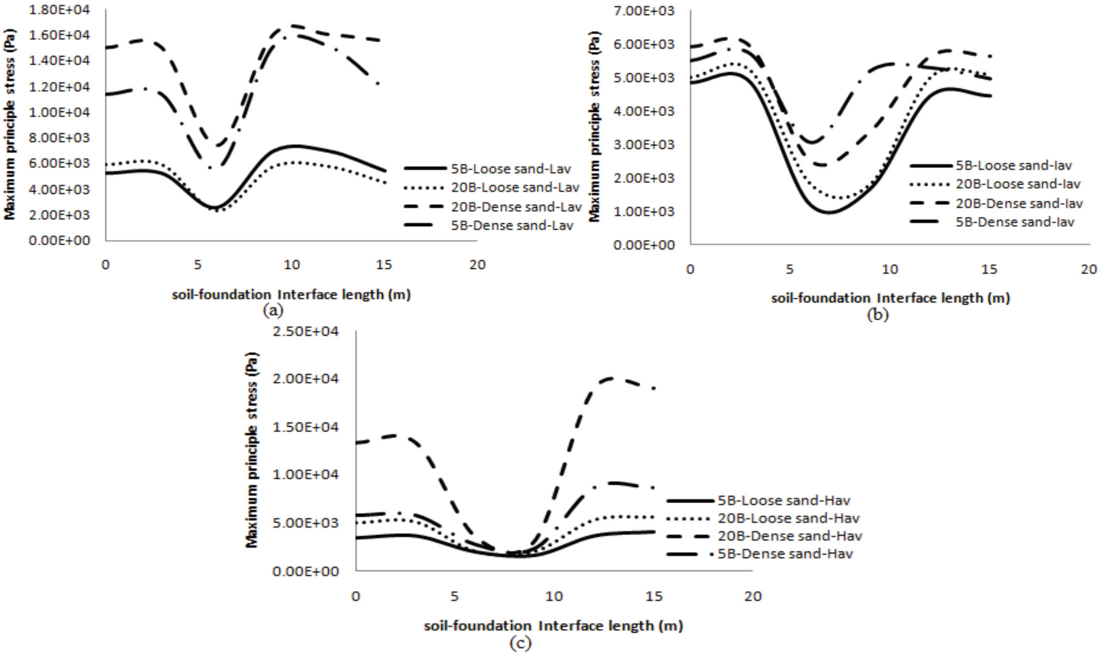


Figure.3 Maximum principle stress on the soil-tunnel interface for Lav (a), Iav (b) and Hav (c)

5. CONCLUSIONS

1. All soil types amplify bedrock motions in the soil-structure interface but with different degrees. The amount of amplification is affected by many factors including the soil type and properties, earthquake frequency content and the properties of the overlying building.
2. Those combinations of soil condition, structural models and seismic excitations that lead to lower effective damping, will amplify the bedrock motion most significantly.

3. soil-structure models including dense sand has shorter period in comparison with loose sand and high rise buildings have longer period in comparison with low-rise buildings. The combination of these two can assess the amount of amplification of each earthquake.
4. Shorter period soil-structure systems (5 storey building over dense sand) demonstrated the highest amplification for Hav earthquake and lowest maximum acceleration (on the soil-structure interface) on Lav earthquake.
5. Longer period soil-structure system (20 storey building over loose sand) presented the highest amplification in Lav earthquake and lowest in Hav earthquake.
6. Maximum principle stress on the soil-foundation interface in all models occurred beneath the columns while the lowest stress was in the middle of foundation.
7. 20 storey buildings generated higher principle stresses during the earthquake in the soil-structure interfaces in each earthquake for both soils.

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