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A numerical investigation on soil-concrete foundation interaction

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Abstract

The soil-concrete foundation interaction is one of the complicate job in civil engineering. The theoretical concept and numerical analysis are well supportive in understanding soil-concrete foundation interaction. In this paper, the seismic response of group concrete foundations are evaluated for understanding nonlinear soil behavior. The main objective is, to understand effect of a real earthquake acceleration on morphology of differential settlement of soil at the base of concrete foundation and the overall of the soil foundation. The ABAQUS has been used in numerical simulation, in order to simulate differential settlement of soil due to nonlinear soil-concrete foundation interaction. The models were subjected to similar seismic loading. The seismic data are reported at literature, used in numerical simulation. The results indicated that the differential settlement of soil depends on soil-concrete foundation interaction.

Keywords: FEM; seismic force; differential settlement; failure mode.

1. Introduction

The nonlinear soil-concrete foundation interaction may occurs during a strong earthquake. The nonlinear deformations of soil is an important factor in structural stability. From other hand, in most of seismic response of concrete foundation investigation, the foundation is usually considered alone. However, this situation rarely happens in an urban area. The dynamic response single and group foundation are not same. Due to this issue, in this investigation group foundation have been selected for numerical analysis.

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There are several investigation on soil dynamic behavior, safe bearing capacity and economical developing construction materials including soil (Namdar, 2016; Namdar and Feng 2015; Namdar and Feng 2014). It has been reported that, the nonlinear dynamic response of 10 buildings on two different soft soils, and soil-structure interaction as well. It has been found total plastic hinge rotation decreases in a building due to soil-structure interaction (SSI) (Behnamfar and Banizadeh, 2016). The SSI significantly effect on structure stability. According to Frost et al. (2002), a summary of recent research on the coupled effect of surface roughness and hardness on interface shear behavior and strength have been presented. The work is applicable in soil-concrete, soil-steel, soil-geomembranes interaction quality, and also is applicable in geotechnical engineering. And also several application of numerical simulation in different engineering field for nonlinear analysis and materials interactions have been reported by Namdar et al. (2016) and Martínez-Casas et al. (2013).

To predict dynamic soil-structure interaction and dynamic wave propagation, the numerical simulation is considering as a non-destructive and economic effective technique. Therefore, many research topics on dynamic soil-structure interaction still left and need to by investigate. In this paper, to understand soil-concrete foundation interaction problem and benefit from developing numerical simulation, the FEM is employed. It is assumed a rigid concrete foundation rested on soil, and the nonlinear soil-concrete foundation interaction has numerically been simulated. The effect of the acceleration on differential settlement of soil is also investigated. To analysis failure mechanism of concrete foundation, the differential settlement of soil foundation studied, and effect of nonlinear soil-concrete foundation interaction on two group of concrete foundation were analysed.

Nomenclature

Δ_1	Vertical motion
Δ_2	Horizontal motion
θ	Rotational motion
$\hat{R}1$	Resultant reaction forces in x_1 direction
$\hat{R}2$	Resultant reaction forces in x_2 direction
$\hat{M}$	Moment
$\hat{\theta}$	Rotation angle

2. Theoretical concept

A rigid foundation in a plane-strain has three degrees of freedom-namely, the vertical, horizontal, and rotational motions, respectively denoted here by Δ_1, Δ_2 and θ. The displacement-reaction relationships in the frequency domain can be described by a dimensionless impedance matrix, as in

$$\begin{bmatrix} \hat{R}_2 \\ \hat{R}_1 \\ \hat{M}/_b \end{bmatrix} = \pi\mu \begin{bmatrix} \hat{K}_v & 0 & 0 \\ 0 & \hat{K}_{HH} & \hat{K}_{HM} \\ 0 & \hat{K}_{MH} & \hat{K}_{MM} \end{bmatrix} \begin{bmatrix} \hat{\Delta}_2 \\ \hat{\Delta}_1 \\ b\hat{\theta} \end{bmatrix}$$

Where $\hat{R}1$ and $\hat{R}2$ are resultant reaction forces in x_1 and x_2 directions, respectively. The characteristic length b is used for normalizing $\hat{M}$ and $\hat{\theta}$, which denote, respectively, the moment and the rotation angle with respect to the centroid of the foundation boundary (x_{1c}, x_{2c}) (Figure 1) (Seylabi et al. 2016) . This theoretical concept has been applied in numerical simulation.

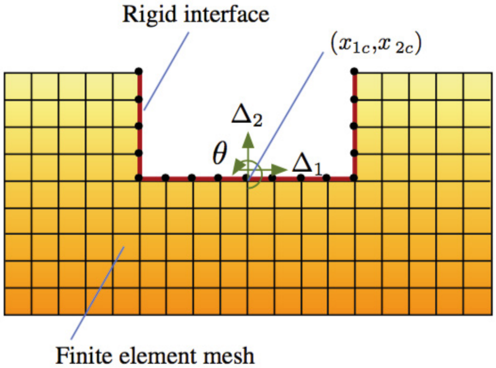

Fig. 1. Rigid foundation kinematics: the grids indicate the finite element meshes, and the dots indicate the nodes along the soil-structure interface (Seylabi et al. 2016).

3. Numerical simulation and materials

It assumed a rigid base under the soil. And a flexible and deformable soil rests between concrete foundations and rigid based. The soil acts as an energy sink and controlling damping of the whole system. In numerical simulation, the concrete foundation is assumed to be rigid, but the soil subjects to nonlinear deformations. To simulate deformation of soil, the nonlinear strain-stress were applied to the soil. The concept of nonlinear theory of elasticity was implemented in finite element method analysis. The dynamic system was subjected to ground acceleration in the X and Y directions. It is aimed to numerically simulate effect of seismic loading on soil-concrete foundation interaction and differential settlement of soil.

The acceleration time history corresponds to the earthquake depicts in figure 2. This earthquake information has been applied in numerical simulation for simulate nonlinear soil-concrete foundation interaction analysis. Near-fault ground motions are different from far-field ground motions, in this work, seismic data recorded at far-field ground motions has been applied in numerical analysis. The concrete foundation rest on soil, has been modelled in figure 3. Two models have numerically been analysed. The model one is with two concrete foundations and model two is with three concrete foundations.

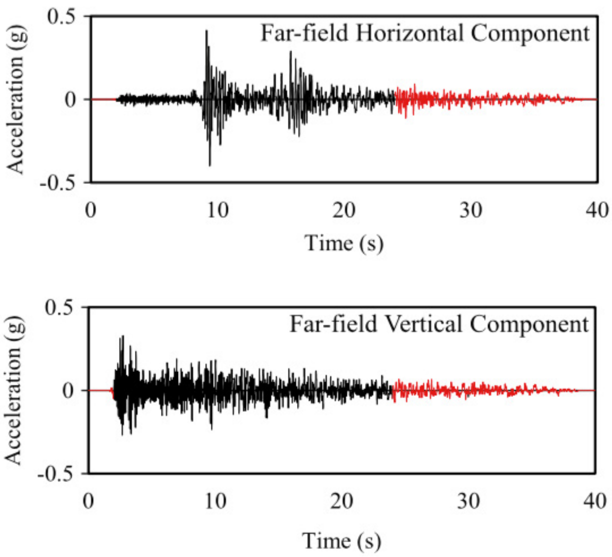

Fig. 2. Ground acceleration time series used in analyses (Hariri-Ardebili et al. 2016).

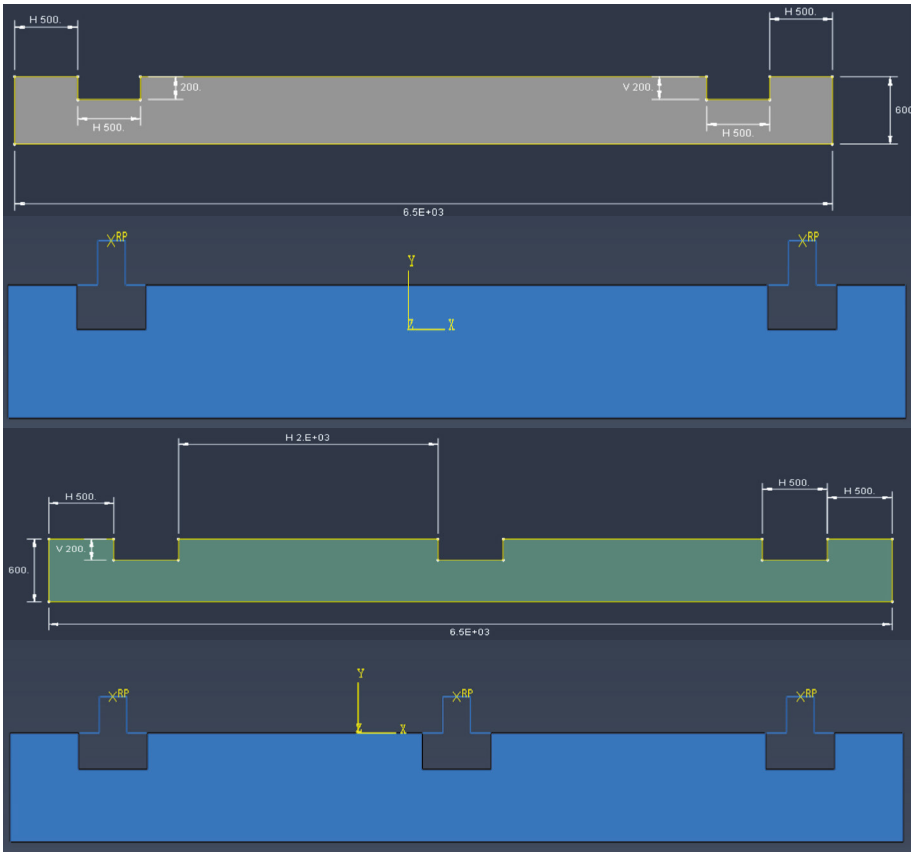

Fig. 3. Soil foundation model subjected to the seismic loading, all dimensions in (mm)

The table 1, present soil mechanical property. These data have been used in numerical simulation. The coefficient of soil-concrete interaction has been assumed to be 0.7.

Table 1. Mechanical property of soil foundation (Armin et al. 2014).

Mechanical property	level
Cohesion (KPa)	20
Soil internal friction angle (degree)	35
Dilatancy angle (degree)	20
Moisture (%)	7
Modulus of elasticity (MPa)	5
Poisson's ratio	0.36
Density (kg/m^3)	1220

4. Results and discussion

Soil-concrete foundation interaction is an important issue in both static and dynamic stability of structure. There are many practical works available to predict effect of future earthquake on seismic stability of structure. The present paper, illustrates a practical methodology for using recorded seismic data to apply in soil foundation seismic design.

The theoretical concept and numerical analysis have been simulated, to simplify two models of soil-concrete foundation interaction. A two dimension (2-D) finite element (FE) model was developed to predict soil-concrete foundation interaction, and understanding displacement behavior of soil foundation, subjected to the seismic loading.

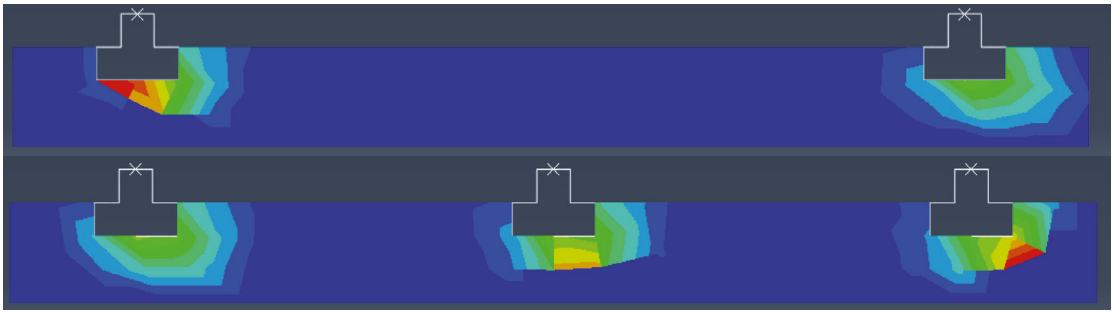

Fig. 4. Stress at different models in occurrence of maximum displacement

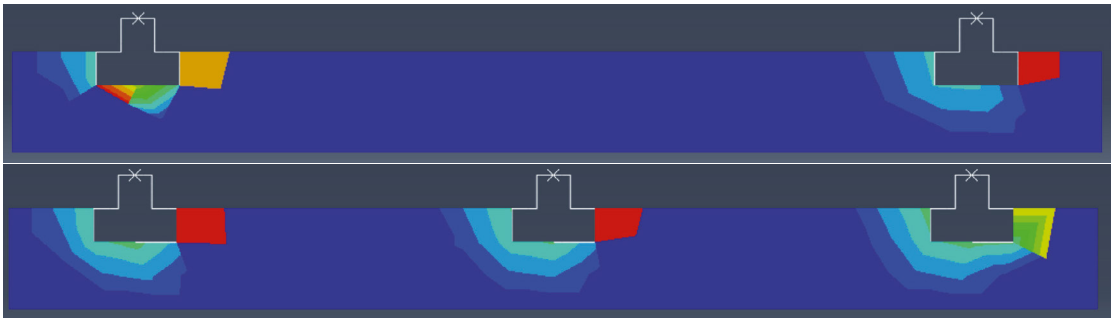

Fig. 5. Strain at different models in occurrence of maximum displacement

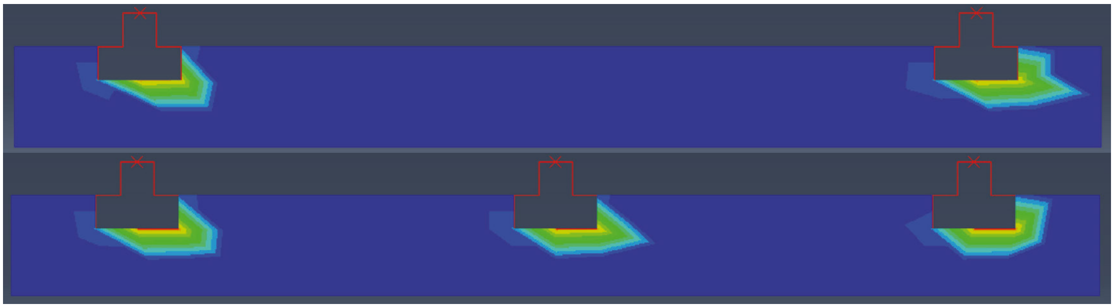

Fig. 6. Maximum displacement at different models

Figures 4 and 5 show, stress and strain distribution at soil foundation, during soil foundation reach to maximum displacement. The maximum displacement of soil is depicted in figure 6. Results show non-uniform ground deformation. The seismic waves arrive to various points of the soil foundation with specific arrival time, it leads to different propagation stress, strain and displacement at soil foundation. In models 1 and 2, the displacement across the soil foundation, at the level of concrete foundation base, depicted in figure 7. Increase number of concrete foundation rested on soil foundation, results higher level of differential settlement of soil in base level of concrete foundation. But from other hand, figure 8 indicates, the overall magnitude of differential settlement in soil foundation in models 1 and 2 are same, while the fluctuation of force in model 2 is decreased compare to model 1. The morphology of differential settlement depends on number concrete foundation rested on soil. The increase number of concrete foundation, leads to occurrence minimum fluctuation of differential settlement of soil foundation. Acceleration of soil foundation is vary with respect to depth of soil, while input are same, subsequently differential settlement is change with associate to seismic force propagation. The morphology of maximum acceleration in soil foundation, at any point is depend to number of concrete foundation, and soil-concrete foundation interaction. The maximum reaction force at any step of numerical analysis depend on soil-concrete foundation interaction.

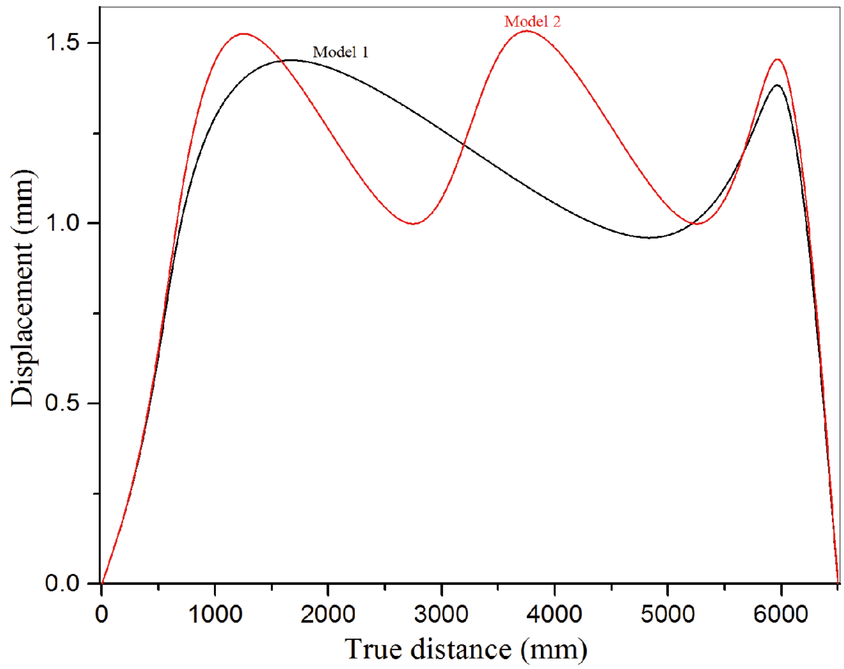

Fig. 7. Displacement (mm) Vs true distance (mm) in models 1and 2

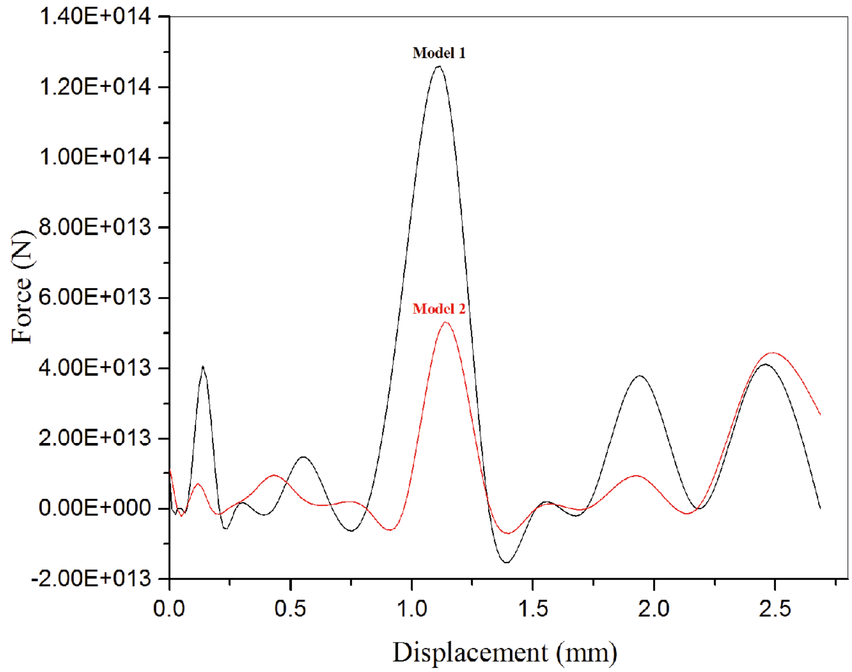

Fig. 8. Force (N) Vs maximum displacement (mm) in numerical analysis

The seismic ground motion is the response of the earthquake on the soil foundation, and results overall nonlinear stress distribution on soil, and its effect to structure seismic stability. The figure 9, shows different cracks developed on a soil subjected to seismic force. This kind of crack, produced after horizontal and vertical differential settlement of soil. The structural elements and joints deform and may cracked after differential settlement of soil, and caused collapse of structure. It need to keep in mind that the seismic stability of structure is depend on soil-concrete foundation interaction and morphology of displacement soil foundation.

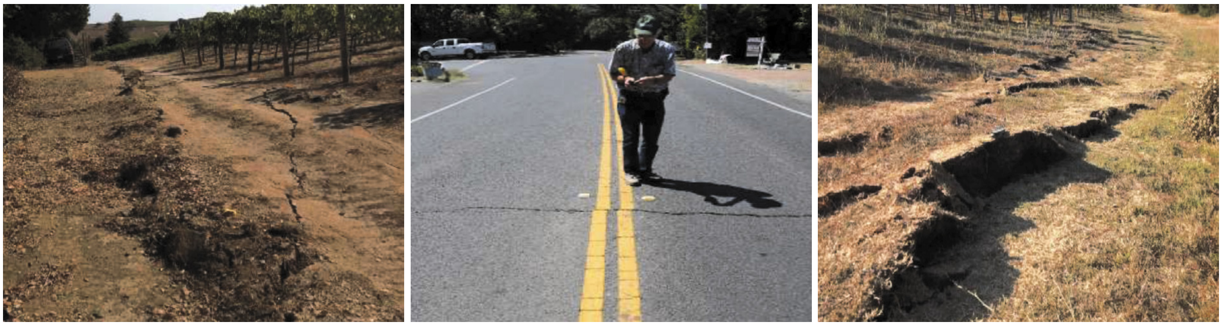

Fig. 9. Different types of shear crack due to seismic [Saylabi et al. (2016)].

5. Conclusion

The theoretical concepts along with numerical simulation indicate the important effect of soil-structure interaction. The model with good accuracy has been developed. Numerical simulation is shown that the model can predict the dynamic characteristics and seismic response of the soil-concrete foundation interaction. It has been found that, the increased number of concrete foundation rested on soil, increases differential settlement at base level of the concrete foundation, while overall magnitude of differential settlement in whole soil foundation at both models are same, even with fluctuation of seismic force. The morphology of differential settlement depends on soil-concrete foundation interaction.

References

Armin, A., Fotouhi, R., Szyszkowski, W., 2014. On the FE modeling of soil–blade interaction in tillage operations. Finite Elements in Analysis and Design 92, 1–11.

Behnamfar, F., Banizadeh, M., 2016. Effects of soil–structure interaction on distribution of seismic vulnerability in RC structures. Soil Dynamics and Earthquake Engineering 80, 73–86.

Frost, J.D., DeJong, J.T., Recalde, M., 2002. Shear failure behavior of granular–continuum interfaces. Engineering Fracture Mechanics 69, 2029-2048.

Hariri-Ardebili, M.A., Seyed-Kolbadi, S.M., Kianoush, M.R., 2016. FEM-based parametric analysis of a typical gravity dam considering input excitation mechanism. Soil Dynamics and Earthquake Engineering 84, 22–43.

http://gallery.usgs.gov/sets/2014_South_Napa_CA.

Martínez-Casas, J., Mazzola, L., Baeza, L., Bruni, S., 2013. Numerical estimation of stresses in railway axles using a train–track interaction model. International Journal of Fatigue 47, 18-30.

Namdar, A., 2016. Liquefaction zone and differential settlement of cohesionless soil subjected to dynamic loading. Electronic Journal of Geotechnical Engineering 21, 593-605.

Namdar, A., Feng, X., 2014. Evaluation of safe bearing capacity of soil foundation by using numerical analysis method. Frattura ed Integrità Strutturale 30, 138-144.

Namdar, A., Feng, X., 2015. Economical considerations in the development of construction materials – a review. Engineering Review 35, 291-297.

Namdar, N., Darvishi, E., Feng, X., Zakaria, I., Yahaya, F.M., 2016. Effect of flexural crack on plain concrete beam failure mechanism - A numerical simulation. Frattura ed Integrità Strutturale, 36, 168-181.

Seylabi, E.E., Jeong, C., Taciroglu, E., 2016. On numerical computation of impedance functions for rigid soil-structure interfaces embedded in heterogeneous half-spaces. Computers and Geotechnics 72, 15-27.