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EFFECT OF SOIL CHARACTERISTICS ON THE ROCKING OF FOUDATIONS

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Rocking of shallow foundations is a consequence of soil-structure interaction, in which the base of the foundations subjected to strong vibration may separate from the underneath soil by rotating about the longitudinal axis. In this rotational mode, plastic hinge spreads in the underlying soil instead of the main elements of the structure such as columns, therefore prevents a catastrophic collapse of the structures during strong vibrations, however, resulting in residual deformation in the soil and permanent displacement of the foundation. Rocking of shallow foundation is an intricate phenomenon and its results including displacement time history of the foundation, amount of mobilized moment and dissipated energy, are dependent on several factors such as specifications of the underlying ground, properties of the foundation and the superstructure and characteristics of inducing vibration.

In this investigation, the effects of soil behavior including nonlinearity, plasticity and the soil mechanical properties such as stiffness or shear modulus and frictional angle, on the response of rocking of shallow foundations of high-rise buildings subjected to dynamic loading, is studied by simulation of the problem using ABAQUS software. Four scenarios namely linear, nonlinear (elastic and elastoplastic) were considered for modeling of the soil. For efficiency modeling and applying nonlinearity behavior in the soil, subroutine USDFLD coded in FORTRAN was deployed . The soil-structure interaction is modeled completely in which the whole structure and the affected soil are modeled altogether. The structure in this study is modeled as a rectangular block which is integrated with its foundation. The earthquake propagates in the soil layer from the bedrock. The bedrock and the lateral boundaries of the soil were considered to be five times of the foundation width away from the boundary of the foundation to avoid reflecting seismic waves inside the model. Predominant frequency of the imposed dynamic loading is considered to be 1/758 Hz and the duration of this loading is considered to be 8/75 seconds. The studied soil is sand with a maximum shear modulus, obtaining from Equation 1. This equation is proposed by Seed and Idriss (1970).

$$G_{\max} = 218.816 \times K_{2\max} \times \left(\sigma_m\right)^{0.5} \tag{1}$$

In Equation 1, σ_m is the effective confining stress, and the magnitudes of $K_{2\max}$ vary from 35 to 70 for sandy soils as a function of relative density of the soil. There is a consensus among researchers that shear modulus of the soils, particularly the granular soils, varies with both shear strain levels and confining pressure (Kramer, 1996) Shear modulus inhomogeneity as a function of depth was deployed for all soil models. Mohr-Columb model was deployed for yield surface, and therefore, nonlinear elastic-perfect plastic model could be used in the modeling of the soil.

The rocking of foundations on soil may be evaluated as a contact problem, therefore, the definition of properties of the interface between soil and foundation is important in this modeling. The normal behavior of the interface is considered as Hard contact in which surfaces are in contact, any contact pressure can be transmitted between them, and if the surfaces separate, the contact pressure reduces to zero. Penalty friction is defined as tangential behavior of the interface. For more realistic results, Rayleigh viscous damping for expressing elastic energy dissipation has been determined in this study, and the amount of damping ratio is taken %5 for both structure and foundation and %8 for underlying soil. For calculating Rayleigh coefficients alfa and beta, natural frequencies of the system were extracted by step frequency in linear perturbation solver of ABAQUS. To calculate accurately mobilized moment, induced acceleration of all nodes on different levels of structure were used instead of only multiplying structure center gravity acceleration by its perpendicular distance to the pivot point.

For validation of these numerical modeling, a centrifuge test namely SSG04-9b provided by Gajan et al. (2006), containing a pair of aluminum shear walls conjunct to a shallow foundation placed on Nevada sand with %80 relative density, has been simulated. The obtained results were in good agreement with experimental results.

The results of this investigation revealed that the soil model can affect the response of soil-structure system. According to Figure 1, which is demonstrating the rotation-moment of one cycle of rocking of a structure with a height of 30 m and a width of 20 m, the rotation-moment relationship of plastic soil is more linear than the curve of elastic soil. Besides, in this figure, the hysteresis curve obtained for nonlinear elastic-perfect plastic soil, encloses large area in comparison to the other curves, i.e. in nonlinear elastic-perfect plastic soil more energy was dissipated.

Even though linear models for soil presents valuable information such as capacity moment, rotation of footing and even damping ratio, they are not useful for determination of residual rotation and settlement.

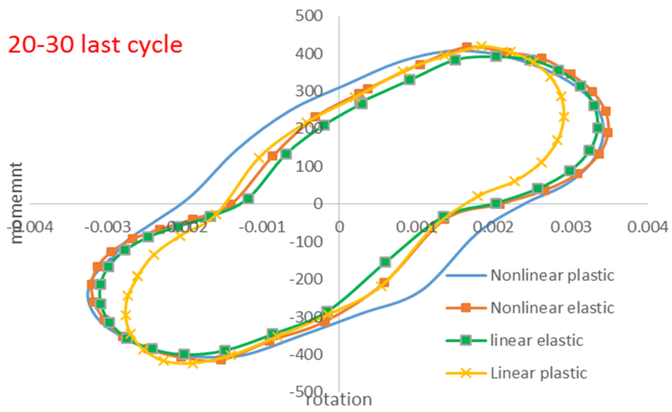

Figure 1. Moment (MN.m)–rotation(rad) for one structure placed on the four soil models (Amiri, 2019)

To study the stiffness of underlying soil, K_{2max} has been taken as the representative of stiffness. Figure 2 is a sample of results of this investigation which indicates that the rotation of foundation decreases and mobilized moment increases as the stiffness of the soil increases. In nonlinear elastic behavior, dissipation of energy increases in looser soils; however, in linear elastoplastic soil the obtained results are different, because the amount of friction angle and cohesion of the soils are kept constant.

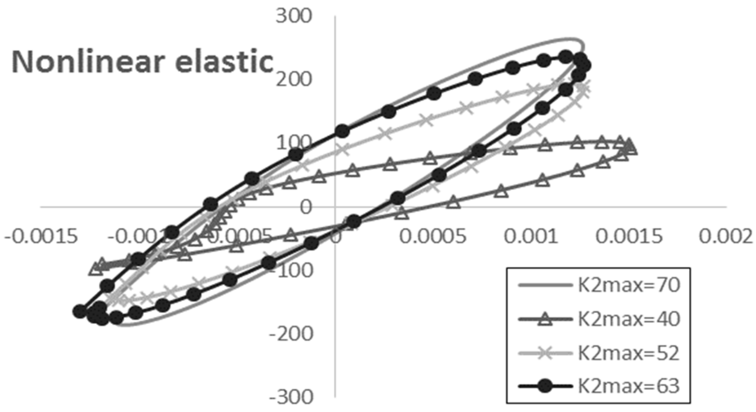

Figure 2. Moment (MN.m)– rotation(rad) for one structure on diffrenent soil stiffness (Amiri, 2019)

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