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SEISMIC SOIL-STRUCTURE INTERACTION EFFECTS ON A HIGH RISE RC BUILDING

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Abstract

Soil-structure interaction (SSI) is for sure one of the most neglected effects in seismic structural design practice. However, many researchers showed that it might notably affect seismic performance results. In fact, the state-of-the-art seismic codes are encouraging including SSI for structures with considerable p-Δ effects and mid to high-rise buildings. In the current research, seismic soil-structure interaction analysis is made for a selected mid-rise reinforced concrete building with several different SSI techniques (models). In order to quantify the effect of SSI on the overall response of the selected structure, the global seismic response within a frame of force-displacement relationship for different earthquake intensities, different SSI mathematical models and different soil categories is presented. Comparing the outcome of the performed analysis it was observed that the structural performance was affected significantly by the foundation system and contributes considerably to the overall structural performance of the selected structure in specific soil conditions. As the results indicate, more code-based recommendations are required for the improvement of the SSI structural seismic design, especially in soft soil cases, where the soil-structure interaction might significantly affect the seismic response of buildings.

Keywords: Soil-structure interaction (SSI), Reinforced concrete buildings, Seismic performance

1. Introduction

The constitutive modeling of soil media has been an important topic in the field of soil-structure interaction. In the past decades, many attempts have been performed to develop constitutive models for modeling of soil media. Two major classes are available in the literature: linear elastic models and nonlinear elastic model in which stress-strain relations deviate from linearity. It is of special attention to deal also with failure envelope where its description plays a crucial role in soil simulation. The aim of this study is to present the newly implemented material models in finite element software ANSYS for simulation of soil medium in soil-structure interaction problems. Although in numerical calculations constitutive models are the most difficult and tricky part of the problem, there are some elementary features of the soil behavior which should be taken into consideration in most cases. The constitutive models are usually classified with respect to their mathematical parameters. For a more detailed explanation the reader can refer to the following publications [1, 2]. Although the classification of the material models is useful for scientists it is still confusing for the wider professional public. In the end, the engineers are the users of the constitutive models for modeling properly the particular tasks. Therefore, model evaluation appears more useful for users of constitutive models in geotechnical engineering. Laboratory experiments of soil specimens are used for testing constitutive models and checking for some basic soil features such as nonlinearity, irreversibility, failure criteria, deformation history etc.

As given in the work of Herle [3] it is quite impossible to consider all features by using only single material model. In the work of Chi and Kuchwaha [4] a nonlinear finite element model has been

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developed to study the soil failure by using the hyperbolic stress strain model. Experiments conducted by Rowe and Peaker [5] show that both deformation mode and magnitude affect the distribution of earth pressure. Building upon the pioneering works of Drucker-- and Prager [6] on soil plasticity the trend has been to develop more precise and correct elastoplastic models for simulation of real materials. In the work of Loret and Prevost [7] different parameters are considered in solutions for the Drucker-- Prager elasto plastic material models. On the other hand development of von Mises [8] elastic plastic equations has enabled considerable improvement in simulation of soil materials. Moreover, the dynamic non-linear characteristics of soil media are taken into account in the work of other authors [9-10].

2. Numerical modelling of soil

In the finite element context of integration of material models, the constitutive equations are carried out at integration points. The incremental analysis is done and the solution is assumed to be known at the start of the increments. Knowing the strain increment $\Delta\varepsilon$ it is possible to calculate the stress at the end of the increment. In general the integration of the elasto-plastic models presents a challenging numerical problem since the plastic strain is defined as a rate after the material behavior has changed at the yield point. In this work in numerical modeling the soil in the soil structure interaction problem is modeled as a non linear medium using the Drucker-Prager and Bilinear Isotropic (BISO) material models. In order to complete the investigation, an elastic model of soil is also simulated for completeness of the comparison. The frame structure is exposed to earthquake acceleration and the results compared accordingly. Then the non linear material models are compared with elastic soil medium and the results are discussed consequently. For more detailed explanation of the material models the reader is referred to [7, 11]. The calibration of the non linear material models for Bilinear and Drucker- Prager material laws is done according to the work of Kodama and Komiyo [12]. The Biliniear Isotropic material model (BISO) uses the von Mises yield criteria coupled with an isotropic work hardening assumption. The material behavior is described by a “bilinear” stress-strain curve starting at the origin with positive stress and strain values. The initial slope of the curve is taken as the elastic modulus of the material. At the specified yield stress the curve continues along the second slope defined by the tangent modulus. The tangent modulus cannot be less than zero nor greater than the elastic modulus [13]. The constitutive models are shown in the Fig.1 below:

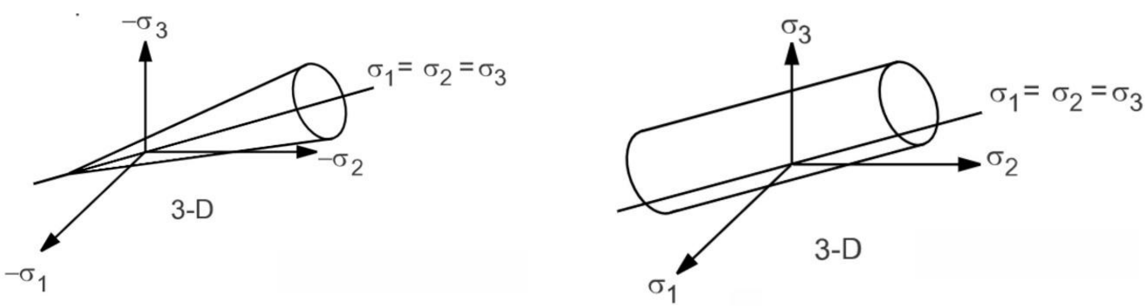

Figure 1. Graphical 3D representation of constitutive models, DP on the left and BISO on the right side

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On the other hand the Drucker-Prager model uses the outer cone approximation to the Mohr-Coulomb law. The amount of dilatancy can be controlled with the dilatancy angle. If the dilatancy angle is equal to the friction angle, the flow rule is associative [13]. The soil medium is presented as a two dimensional model composed of four layers resting on bedrock. In Table 1 the soil layers properties are tabulated in a way that the bottom layers are characterized with better soil characteristics..

Table 1. Material parameters in finite element analysis

Soil medium	Layer number	Thickness (m)	Density (kg/m^3)	Elastic Modulus (kPa)	Friction angle (deg)	Uniaxial yield stress (kPa)
Elastic	1	3	1.1	2000		
	2	7	1.3	2200		
	3	6	1.5	2400		
	4	14	2	2600		
Drucker--Prager	1	3	1.1	2000	35	
	2	7	1.3	2200	35	
	3	6	1.5	2400	35	
	4	14	2	2600	35	
Von Mises	1	3	1.1	2000		0.1
	2	7	1.3	2200		0.1
	3	6	1.5	2400		0.1
	4	14	2	2600		0.1

The soil is discretized using eight nodded plane strain elements PLANE82. The dynamic analysis is performed by transient analysis using the step by step method. The proportional viscous damping matrix is taken to be proportional to mass and stiffness matrix (Rayleigh damping). The Rayleigh damping factors, alpha and beta are calculated such that the critical damping is 5% for first two modes. The bottom boundary of the soil model is fixed while side boundaries are simulated as viscous boundaries. The earthquake input is El Centro N-S, USA, 1940, with magnitude M=6.7 which is presented in Figure 2 below.

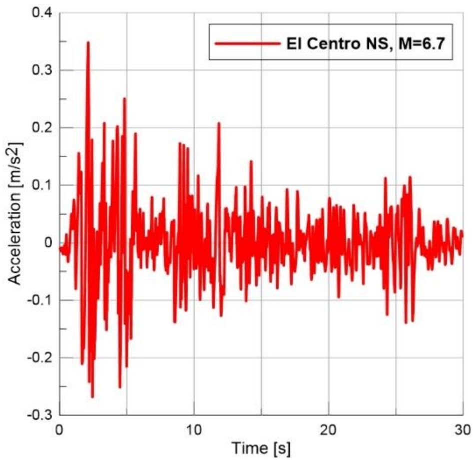

Figure 2 Selected acceleration history of El Centro N-S

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3. SOIL STRUCTURE INTERACTION SYSTEM

In order to show the influence of the soil material modelling to the structural response a comparison of three different cases has been performed. First the soil medium is simulated as an elastic material model. Then the same soil medium is simulated as nonlinear by considering the Drucker-- Prager and BISO material models. In order to have a bigger range of results the frame is considered as one, three and five storey frames. The frame structural elements are idealized as two dimensional elastic beam elements BEAM3 having three degrees of freedom at each node, translations in the nodal x and y directions and rotation about the nodal z axis. The behaviour of the frame structure is supposed as elastic and is modelled using two parameters, the modulus of elasticity E=3.15x107 kPa and Poisson's ration n=0.2. The bay length of the frame is taken to be 4.0 m and storey height of 3.0 m. Section of beams is 40 x 50 cm while the column section is 50 x 50cm. A mass of 11 tons is assigned on each node to simulate the real structural behaviour (total 44 tons per floor). For all RC frames the beam and column sections, floor masses and number of bays are kept constant in all cases. The only parameter that is altered is the storey number.

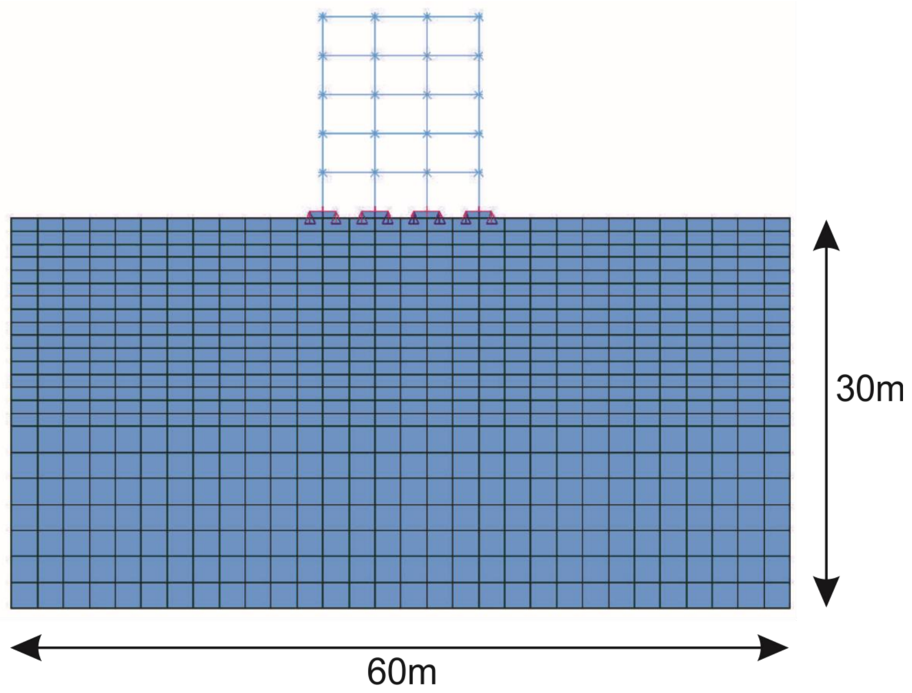

Figure 3. Coupled Soil structure system of a mid-rise building

Finite element modelling of the coupled soil-structure system is performed by the software ANSYS [13] as shown in Figure 3. The effect of soil-structure interaction is carried out with the acceleration time history of the El Centro earthquake with a scaled peak ground acceleration of 0.25g. The foundation where the structure is supported is taken to be 8 nodded plane element having two degrees of freedom in each node, translations in the nodal x and y directions. The moment transfer capability between the column and the footing is created by using a constraint equation where the rotation of the beam is transferred as force couples to the plane element. In Table 2 below the difference in the structural response is given.

Table 2. Structural values from the analysis of the frame structures

No. of Storey	Soil Medium	Max. acceleration at top of Str. (m/s^2)	Max. displacement at top of Str. (mm)	Max. moment at top of Str. (kNm)

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1	Elastic	2.54	9.44	28.5
	Drucker-Prager	2.77	9.33	25.6
	BISO	2.79	9.39	31.7
3	Elastic	2.60	4.89	2.02
	Drucker-Prager	2.60	4.08	4.03
	BISO	2.68	4.66	4.40
5	Elastic	2.55	5.67	2.75
	Drucker-Prager	2.60	5.57	5.49
	BISO	2.61	6.87	5.79

According to the acceleration values of the Table 2 the maximum displacement at the top of structure is considerably big when using linear elastic material model in a single and three storey frames. In the case of five storey frame the biggest displacement is obtained using the BISO model.

This illustrates that in soil medium analysis usage of material models for soil simulations should be considered carefully. On the other hand, in using Drucker-Prager material model the maximum structural moment at top of structure has smaller values when compared with elastic material model. This can be elaborated as nonlinearity taking place in the columns which prevent increase of structural moments. In moment comparison the usage of BISO model has similar values with the Drucker-Prager model although small deviation of the results is observed. In comparing of maximum acceleration values at the top of structures it can be concluded that the elastic material model has the smallest values while the usage of Drucker-Prager and BISO models vary accordingly. Thus it can be stated that in simulation of soil medium by nonlinear material models the calibration of the parameters with experimental results has to be performed previously.

4. Conclusions

It is to be stated that in the literature there are many examples where behavior of real geotechnical structures are compared. Eventhough, relatively little attention has been given to effects of material modeling on the results from analysis. The major advantage of the proposed model including simulation of both structure and soil is that the description of the soil model is both linear and non-linear which allows basic mechanical responses to be predicted accurately. Moreover, all parameters

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used in the model have explicit physical meanings and can be calibrated through laboratory tests. On the other hand the main limitations of the model is that due to linear effects the predictability using linear material model can cause over prediction of the critical strength at high deformation values. The best algorithm of soil modeling is the one that combines computational efficiency with acceptable accuracy. Since analytical solution is not always available all elastoplastic models are implemented with some negligible error.

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