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Evaluation of Seismic Behavior in Building Tube Structures System with Respect to Dense Soil-Structure Interaction Effect

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Abstract

The perceiving local site effects on strong ground motion are particularly important for the mitigation of earthquake disasters as well as future earthquake resistant design. The primary objective of this study is to investigate seismic behavior of building tube structure system with respect to dense soil-structure interaction (sand dense and very hard clay soil with a thickness greater than 30 m). For this purpose, the studied building in this paper is placed over two other different modeled soil types and results of seismic behavior of building for three soil types are compared with each other. Through response spectrum analyses, influence of different sub-soils (dense and loose soil) was determined on seismic behavior of 40-storey building reinforced concrete (RC) with tube in tube structure system and performance of each model was assessed in terms of shear lag behavior, overall and critical (maximum) story drifts. Results illustrate that loose soils amplify seismic waves and increase building drifts and shear lag behavior.

Keywords

Response Spectrum Analysis, Earthquake, Compacted Soil, Soil-Structure Interaction

1. Introduction

Recent improvements in seismological source modeling, analysis of travel path effects, and characterization of local site effects on strong vibration have led to significant advances in both code-based and more advanced procedures for evaluating seismic demand for structural design. Seismic wave's propagation through near-surface soil layers can produce ground motions much larger on the soil surface with different characteristics than those recorded at the rock base.

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The combined effect of earthquakes and local site conditions are commonly referred as site effects.

Numerous examples of earthquakes are available where site effects were observed. As an example during Mexico City earthquake [1], site amplification caused substantial damage and collapse of many buildings [1]. Detailed studies on the relationship between building damage and soil conditions were provided by Seed [2]. In addition, there are numerous studies which have shown correlation between damage and local geology and site condition [3]-[5]. Many researchers studied seismic analysis on soil-structure interaction for different types of structures including bridges, minarets, etc. [6]-[9]. Analysis of soil-structure interaction effects during earthquakes is usually made by one of two methods [10]: 1) a complete interaction analysis involving consideration of the variation of motions in the structure and in the adjacent soil, or 2) 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 studies of [11] and [12]. A building framed-tube system is considered one of the most efficient lateral force-resisting systems. This system utilizes closely spaced perimeter columns tied to each other with spandrel beams, often in combination with additional bracing components (e.g., outriggers or belt walls). In general, the lateral force resistance of the framed-tube system is highly promoted by the aid of tube action. The tube action is perceived as the behavior of a system that acts like a cantilever box beam when subjected to overturning moment induced by lateral loading, with a significant contribution by the flange elements (**Figure 1**) [13] [14]. During the tube action, unfavorable shear lag inevitably occurs. The shear lag phenomenon is characterized by non-uniform axial forces or stresses applied in the columns or walls of the peripheral flanges and/or by nonlinear stress distributions in the peripheral webs (**Figure 1**). ETABS (v9.2.0; [15]) program has been used for simulation of the whole project including the local soil and the building structure.

2. Properties of the Simulated Soil

Table 1 describes three soil types that simulated in this paper, type a soil defined as sand dense and very hard clay with a thickness greater than 30 m, type b soil description as soil with average density, clay with average hardness and shattered stone by weathering and soil type c with assumed soft soil with high humidity due to high surface ground water defined specifications. V_s parameter illustrates shear wave velocity in soil layers, in case of lack of V_s parameter could use N1 (60) parameter for aggregate soil and Cu parameter for adhesive soil. N1 (60) parameter marker number of blows modified penetration standard and Cu parameter shows average undrained shear resistance. V_s parameter is shear wave velocity in soil layers that can be used up to 30 m depth, it can be derived from Formula (1), in Formula (1) D_i and V_{si} parameters marker thickness of soil and shear wave velocity in the soil layer, Cu and N1 (60) are calculated similar to V_s parameter.

$$V_s = \frac{\sum D_i}{\sum \left(D_i / V_{si} \right)} \tag{1}$$

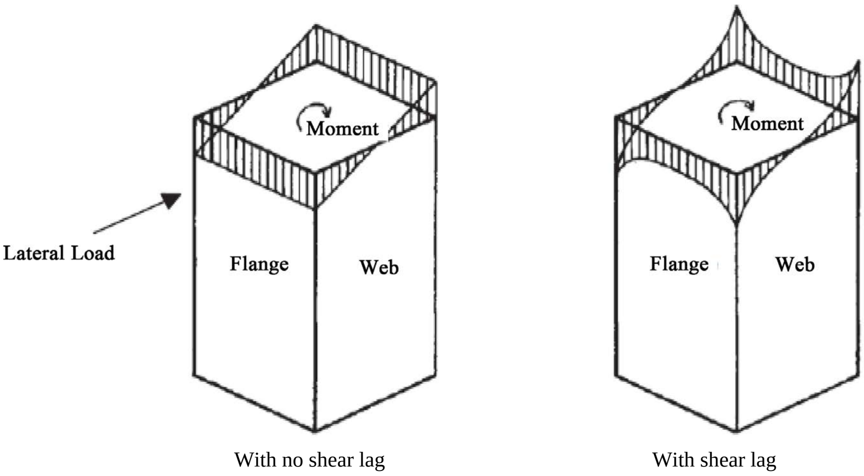

Figure 1. Shear lag occurring during tube action [14].

Table 1. Properties simulated soils.

Type of soil	Description properties soil	Parameters		
		V_s (m/s)	N1 (60)	Cu (kpa)
a	Sand dense and very hard clay with a thickness of more than 30 m	375 - 750	More than 50	More than 250
b	- Soil with average density - Clay with average hardness - Shattered stone by weathering	175 - 375	15 - 50	70 - 250
c	Soft hypothesis with high humidity due to high surface groundwater	Less than 175	Less than 15	Less than 70

3. Structural and Modeling System of the Case Study Building

Figure 2 illustrates 40-storey concrete building plan and ETABS model, the structure is with 148 m height, 21.6 × 21.6 m width and length at the lower, the structural system made entirely of RC, consists of closely columns with 100 × 100 cm dimension, 100 × 80 cm spandrel beam and interior (core) walls with 70 cm thickness surrounding elevator shafts and stair openings. First story height is 4 m and upper floors height is 3.6 m, concrete compressive strengths are considered for all members 350 (kg/cm^2) and the proposed slab thickness is 300 mm for all floors. ETABS building analysis and design software (v9.7.0; Computers and Structures Inc. [15]-[17]) has been used for the modeling and analysis of this study. Several important modeling and analysis approaches used for this study are summarized in the following:

1) Joints between the beams and columns (parts of both the beams and columns belonging to their common regions) are assumed rigid.

2) The contribution of the slab to the beam stiffness (*i.e.*, T-beam action) is ignored.

3) The concrete floors are modeled with rigid diaphragm constraints for lateral force analysis.

4) P-delta effects are taken into account by an approximation method imbedded in ETABS (CSI, 2011).

5) The flexural stiffness of uncracked shear walls is assumed to correspond to 100% of the cross-section properties, while the flexural stiffness of all spandrel beams and coupling beams is taken as 50% based on ACI 318-08, Section 8.8 [18]. It has been verified from the models that the shear walls are expected not to be undergone by cracking at all stories under the lateral forces used for this study. Detailed discussions for the finite element modeling of cracked shear walls can be found elsewhere (Shin *et al.*, 2010).

4. Response Spectrum Analysis

Seismic response of a soil-structure interaction system is affected by many factors during the earthquake including the soil type and parameters (shear modulus, mass density and material damping), structure's height and its materials' properties. Analyses are performed for 40-storey building so as to investigate the effect of building's height and the soil type on acceleration response of the whole system. **Figure 3** shows acceleration for different structure's periods that produced by each simulated soil type, the studied building's period was calculated about 2.12 second. As you can see in **Figure 3**, soil type c gives the most acceleration for a period near to studied building's period and soil type a (sand dense and very hard clay with a thickness greater than 30 m) gives less acceleration for a period near to studied building's period.

5. Storey Drifts

Figure 4 shows story drifts along the building height for three soil types modeled with different properties under the service-level earthquake forces, as you can see building that located over soft hypothesis soil with high humidity due to high surface groundwater shows the most overall story drift and story drift, and building that located over soil type a and b shows significant decrease in overall building drift, overall building drift for building that located over sand dense and very hard clay with a thickness of more than 30 m reduction over 50% proportional to building that is located over the assumed soil with high humidity due to high surface groundwater and building story drift that is located over soil type a reduction as well as over 50% proportional to building that is located over soil type c.

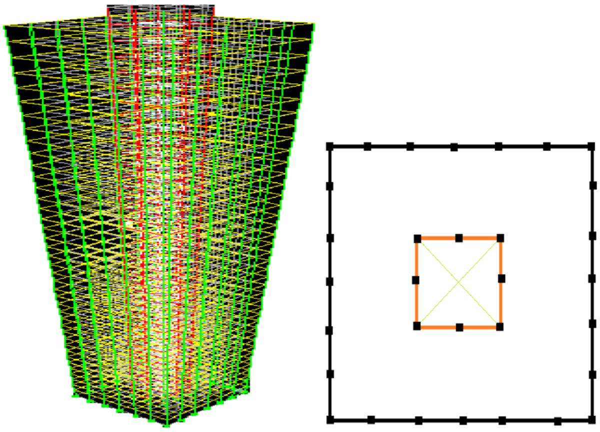

Figure 2. Building plan and Etabs model of the case study building.

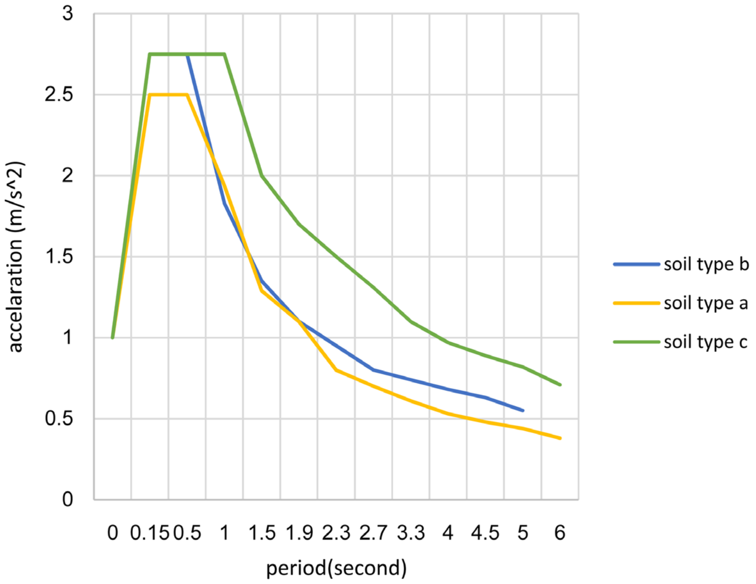

Figure 3. Shows acceleration for different periods.

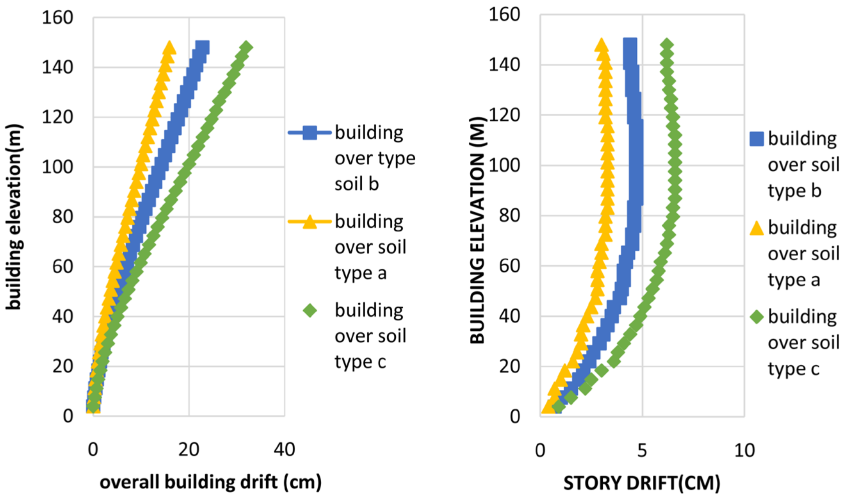

Figure 4. Overall building drift and story drift for building that is located over soil type a, b and c.

6. Distribution of Column Axial Force

During the tube action, unfavorable shear lag occurs inevitably. The shear lag phenomenon is characterized by non-uniform axial forces or stresses applied in the columns or walls of the peripheral flanges and/or by nonlinear stress distributions in the peripheral webs. Two different shear lag modes may exist in building tube systems: 1) positive shear lag and 2) negative shear lag. Positive shear lag is characterized in such a way that corner columns take larger axial forces than middle columns under bending of the building, and vice versa for negative shear lag. **Figure 5** shows columns axial force for first, tenth and twentieth floors for building that is located over soil type a, b and c. As you can see in figure, building that is located over sand dense and very hard clay with a thickness greater than 30 m shows least columns axial force and have situated nearest to the ideal state (linear distribution axial force) as well as building over sand dense and very hard clay with a thickness greater than 30m shows approximately 50% reduction corner column axial force proportional to building over the assumed soft soil with high humidity due to high surface groundwater and 30% reduction corner column axial force proportional to building over soil with average density, clay with average hardness and shattered stone by weathering at the first, tenth and twentieth floors.

7. Conclusions

From **Figures 5-7**, we conclude the following results:

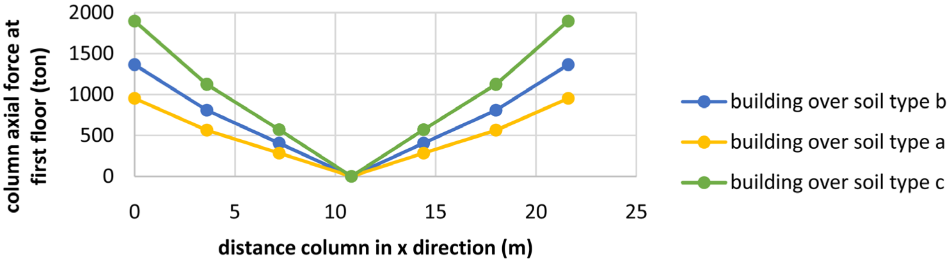

Figure 5. Distribution of column axial force at first floor.

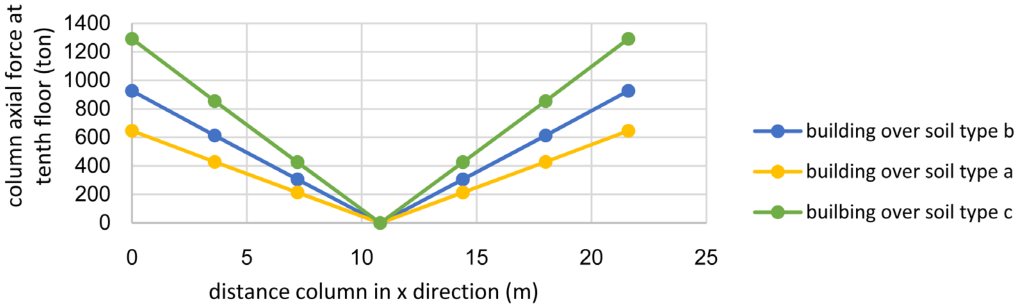

Figure 6. Distribution of column axial force at tenth floor.

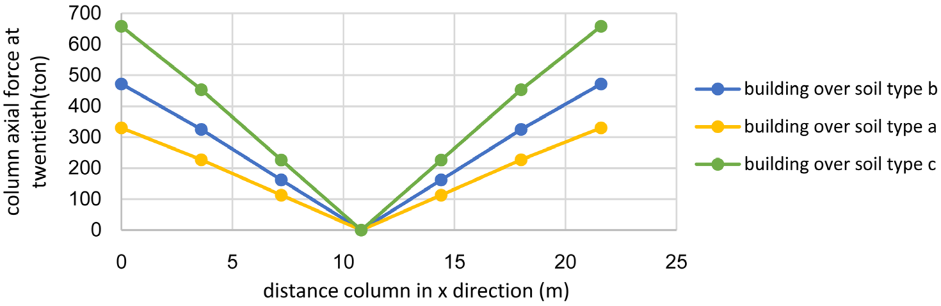

Figure 7. Distribution of column axial force at twentieth floor.

1) Between three soil types, sand dense and very hard clay with a thickness greater than 30 m, soil type a produces least acceleration for case study building, soil with average density, clay with average hardness and shattered stone by weathering (soil type b) and soft hypothesis soil with high humidity due to high surface groundwater (soil type c) in order to produce the maximum acceleration for case study building.

2) For short-period systems, the assumed soft soil is demonstrated with high humidity due to high surface groundwater that shows highest amplification for earthquake waves.

3) In case study building over sand dense and very hard clay with a thickness greater than 30 m, soil type a shows 50 percent decrease less than overall building drift and story drift proportional to case study building over the assumed soft soil with high humidity due to high surface groundwater (soil type c) and 30 percent decrease less than overall building drift and story drift proportional to case study building over soil with average density, clay with average hardness and shattered stone by weathering (soil type b).

4) Distribution of axial column force for case study building that is located over soil type a is situated in nearest position to ideal state; in ideal state distribution of axial column force is similar to linear mode. For case study building over sand dense and very hard clay with a thickness of greater than 30 m, soil type a shows 50 percent decrease less than corner and middle column axial force proportional to case study building over the assumed soft soil with high humidity due to high surface groundwater (soil type c) and 30 percent decrease less than corner and middle column axial force proportional to case study building over soil with average density, clay with average hardness and shattered stone by weathering (soil type b).

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