STUDY OF STRUCTURE-SOIL-STRUCTURE INTERACTION EFFECTS FOR TWO ADJACENT BUILDINGS – A REVIEW

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ABSTRACT: Soil-structure interaction effects are generally ignored in the design of high rise structures. However in the high rise structures such as tall buildings these effects are required to be considered. These effects can be carried to the adjacent building if it is located on the similar foundation soil, resulting in the structure-soil-structure interaction. This paper attempts to introduce the concept of structure-soil-structure interaction and a literature review is conducted in this area of study. Case history on dynamic structure-soil-structure interaction analysis that considers adjacent tall buildings modeled by computer programs is conducted to provide as a reference in this area of study for researchers.

KEYWORDS: Structure-Soil-Structure interaction, tall buildings, base shear.

1 INTRODUCTION

In some situations, tall buildings are located in soils which are geotechnically unsuitable. As their height to width ratio is high, there is a danger of uplift of the structure and during earthquake; there is also risk of overturning of structure. Hence, there is a need to study the soil-structure interaction effects due to seismic behaviour of a structure. These soil structure interaction effects can also be considered to the adjacent building located on the similar foundation soil, resulting in the structure-soil-structure interaction. Soil-structure interaction is a process in which structural motion is influenced by the response of the soil and the response of the soil is influenced by structural motion. The total interaction response in dynamic structure-soil-structure interaction analysis is a combination of kinematic and inertial interaction. When a seismic wave travels through a mass of soil, it vibrates and is displaced on account of distortion and dilation of waves through soil mass. Such type of phenomenon is known as kinematic interaction. When an excited seismic wave passing through a mass of soil reaches at the base of a structure, it results in a vibration of a structure. This type of phenomenon is called inertial interaction.

In seismic excitation, the analysis of soil-structure interaction consists of calculating the free field response at the site, seismic motion and the actual interaction. The problem of structure-soil-structure interaction is analyzed by two methods such as substructure method and direct method. In substructure method, analysis of soil structure interaction is divided into various steps and the total response of the system is obtained by calculating the response of individual step. In direct method, the kinematic and inertial interaction is calculated by modeling the soil-structure system together.

2 LITERATURE REVIEW

Numbers of studies have been carried out by various researchers on the effects of soil structure interaction of adjacent tall buildings. Studies have also been carried out on type of foundations that can be provided for tall buildings. Behnamfar and Sugimura (1999) conducted a study on the system of adjacent 1,2,10 and 20 story adjacent tall structures due to dynamic response. They observed that the amplification frequency increases as the structures are closer and it is also found that structural response also increases in some cases. Hosseizadeh and Nateghi (2004) evaluated the effects of single and adjacent tall buildings due to dynamic response. For experimental testing ground model specimen of soft soil and steel building models consisting of 5, 10, 15 and 20 stories were used. Two real earthquake records were used and generated by shaking table. From the results it was observed that main cause of soil-structure interaction in low rise structures were the rocking and horizontal motion of foundations. It was also observed that compared to different adjacent buildings, adjacent buildings which were similar showed greater effect on each other. Rolf Katzenbach and Alexander Schmitt (2004) studied soil-structure interaction of deep foundations of tall buildings in Germany. In the study Deutsche Bank adjacent towers constructed on shallow foundations were considered and the settlement obtained was
studied. Another high-rise building in Frankfurt was considered for study which was constructed on combined pile-raft foundation. It was observed that combined pile-raft foundation reduces differential settlement compared to pile foundation. Fatahi et al. (2014) conducted a study on the soil structure interaction on soft soil versus the site effects of tall buildings considering seismic design. The local site effect was considered neglecting soil structure interaction effects. Three structural models were considered including 5, 10 and 15 story buildings with two soil types and application of four different earthquake ground motions. The results in terms of structural response and base shear were obtained. It was observed that considering local site effects neglecting soil structure interaction does not adequately guarantee the safety of structures on soft soils. Pallavi Badry and Neelima Satyam (2014) studied different types of foundation failures that result from earthquake and it was found that during analysis and design of foundation the effect of interaction between soil and foundation must be considered. A literature review was carried out on asymmetrical building supported on pile foundation that is in contact with greater mass of soil as compared to other type of foundation. It was observed that very few studies are carried out on asymmetrical buildings on pile foundations.

3 CASE STUDIES

3.1 Case study 1: Soil-structure interaction of adjacent tall buildings in Iran by Rahgozar and Ghandil (2011)

To study the effects of soil-structure interaction assumed building site is in Iran and three dimensional models of 15 story and 30 story buildings are analysed under several earthquake records. The combinations of adjacent buildings used are of three types (i) one 15-story and one 30-story (ii) Two 15 stories (iii) Two 30 stories. In plan the model structures consisted of 4 bays of 5 meters in each direction. The height of each storey is considered as 3 m. An earthquake acceleration of 0.35g is used. The structural system is assumed as special moment resisting frame and the design is carried out as per ASCE 7-2010 code using ETABS software package. Two types of foundation soils such as clay and sand are considered in the analysis. The behaviour of foundation soil is assumed as equivalent linear. Direct method is used to study the structure-soil-structure interaction analysis. The foundation provided for both type of structures are pile group. For the 15 story and 30-story structures, pile group consists of 16 piles and 25 piles respectively. The length of each pile consists of 20 meters with one meter thick pile cap. In the study two building sites are taken into consideration. Site 1 comprise of sandy soil up to a depth of 20 m in two layers and site 2 includes clayey soil in three layers 45 m in depth.

In the analysis at least seven records should be considered as per ASCE 7-2010 code to carry out seismic analysis and structural design. SAP2000 software is used to perform time history analyses of seismic responses of structure-soil-structure interaction. These analyses are carried out for three different combinations on structures on two sites as (i) Two adjacent buildings placed on pile group (ii) One single structure (15-story or 30-story) placed on rigid support (iii) One single structure placed on pile group considered on (Site 1 or 2). The dimensions of site used are 40 x 160 m for all cases of seismic analysis. In order to evaluate the critical distance between two adjacent buildings, single 30 storey building and two adjacent 30 storey buildings are considered on site 2 and the distance between them is varied as 0.125a to 3a, where ‘a’ represents the lateral dimension of building in plan (i.e. 20 m). It is observed that highest responses take place where distances between adjacent buildings vary from 0.125a to 0.25a. It was seen that pounding does not occur at a distance of 0.125a i.e. 2.5 m, therefore distances 0.125a to 0.25a are used in adjacency study. Fig. 1 shows base shears in two-adjacent 30-story structures.

![Base shears in adjacency cases of all 30-story structures](image)

Figure 1 Base shears in adjacency cases of all 30-story structures (Rahgozar and Ghandil, 2011)

Results obtained due to structure-soil-structure interaction effect shows that taller building increases the response of a shorter building adjacent to it. Results obtained due to these effects on structural base shear shows that base shear in tall buildings is higher compared to shorter building when placed adjacent to each other.

3.2 Case Study 2: Dynamic soil-structure interaction of adjacent 32-story buildings in Iran by Yahyai et al. (2008)

The research aimed to analyze the effects of soil-structure interaction of two adjacent 32-story buildings
in Iran on account of seismic behaviour. The effects due to interaction are investigated by varying the distances between the two adjacent buildings by considering different types of soil i.e. sandy gravel, compacted sandy gravel and soft clay. Steel moment frame is considered for structural system. The total height of building is 100m. The soil type considered is type II. The shear strength parameters considered were 'c' (cohesion) and 'φ' (Angle of internal friction of soil) as 0.2 kg/m² and 35° respectively. Three types of soil are chosen for analysis of model as per Iranian code. ANSYS5.4 software is used to model 2 dimensional frame of building. ETABS software is used to model a single building where soil-structure interaction effects are not considered. Different distances used between adjacent structures in the model analysis are d/a = 0.5, 1.0, 2.0, 3.0 and 4.0 where 'd' is the distance between two adjacent structures and foundation width is ‘2a’. Dynamic analysis is used to compare single building response with that of two adjacent buildings. The earthquake records such as El Centro, Naghan and Tabas are applied at the soil bottom. The base shear and displacements in single building (SSI) to that of two adjacent buildings are calculated. Fig. 2 and Fig. 3 shows lateral response due to dynamic response and base shear of single structure to adjacent structure respectively.

3.3 Case Study 3: Soil-structure interaction of adjacent 15-story and 30-story structures in Iran by Nateghi A and Rezaei-Tabrizi (2011)

The main aim of the study is to analyze the effects due to structure-soil-structure on the nonlinear dynamic behaviour of tall buildings in Iran. In order to study these effects, two models of steel structures consisting of 15-story and 30-story are used. Finite element method is used to model the complete system.

The buildings are located on two different types of soil i.e. soft soil and hard soil. The appropriate dimensions such as height of structure and width of foundation are chosen as the first step in the structure-soil-structure interaction analysis. The heights of two buildings considered are 45 m and 90 m respectively and the plan dimensions considered are 20 m x 20 m. The building with a height of 45 m and 90 m consists of 15 stories and 30 stories respectively. In each direction the two buildings consist of four 5-m bays. The horizontal loads considered are 800 kg/m². The type of structure assumed for both the buildings is special moment resisting frame. Soil type is assumed in accordance with the Iranian seismic code. Seismic loading is another important parameter considered in the study. Analysis is carried out in the form of modal analysis, and the base shears are obtained from the analysis.

Finite Element modeling of the two adjacent buildings is carried out using ANSYS software. To model the structural elements, a two dimensional or three dimensional elements are used. In the analysis, the earthquake records such as Loma Prieta, El Centro and Tabas are used. The period of the earthquake records which are dominant are scaled to Peak Ground Acceleration (PGA). Shear wave velocity of the soil layers is taken into consideration. According to the faults which are active in the region of Tehran, the period which is dominant of the bedrock of a particular earthquake with a magnitude and distance are calculated. Then the PGA or the particular return period is assumed based on calculations. Using the records which are normalized i.e. PGA and the return period, the acceleration response spectra is generated using software program. Using the finite element program, various boundary conditions, element dimensions are applied in the analysis. While performing structure-soil-structure interaction,
important input parameter i.e. the distance between the two adjacent tall buildings is used. Therefore, to study the effects of adjacency, the buildings are separated by distances of 2.5 m and 5 m which correspond to 1/4 and 1/3 of the foundation width respectively and the results are obtained. Fig. 4 and Fig. 5 shows nonlinear story displacements for Soil No. 1 and Soil No. 2 in adjacent buildings.

![Figure 4 Non-linear story displacement for Soil No.1 (Nateghi and Tabrizi, 2011)](image1)

![Figure 5 Non-linear story displacement for Soil No. 2 (Nateghi and Tabrizi, 2011)](image2)

It was observed that when the soil and structure periods were almost near to each other, increase in nonlinear responses resulted in the interaction of adjacent structures to be noticeable.

### 4 CONCLUSIONS

The Structure-Soil Structure interaction of adjacent buildings was studied in detail by considering the work carried out by different researchers as a reference. The taller building increased the response of a shorter building adjacent to it and a shorter building decreased the response of a taller adjacent building when the distance between the adjacent buildings are varied. The study showed that base shear in tall buildings is higher compared to shorter adjacent building.

The effects of structure-soil-structure increases time period, base shear and displacement when the distances between adjacent buildings are varied. Considering effects of SSSI, base shear and lateral displacement changes up to two and three times respectively.

When the soil and structure periods are almost near to each other, increase in nonlinear responses results in the interaction of adjacent buildings to be noticeable.

### References


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