Analyzing the Seismic Response with Consideration to Soil-Structure Interaction in Reinforced Concrete Multistory Buildings Located in Halabja City.

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ABSTRACT

Response of structures to seismic loads measures the degree of safety of the structures. In order for buildings to be under a more realistic circumstance, it is essential to consider the effect of Soil – Structure – Interaction (SSI) in the analysis of the building subjected to seismic loads. In this study, three samples of typical buildings with six, eight and ten stories are chosen with and without the effect of SSI using both equivalent static method and dynamic response spectrum analysis. For each method, the five different soil categories (SA, SB, SC, SD, SE) are examined to illustrate the effect of the foundation soil on the buildings subjected to a seismic load. The results show that no modifications can be observed in rock foundations with or without the consideration of SSI. On the contrary, the effect on SSI can increase the displacement in low stiffness soils particularly soil type (SE). Similarly the natural time period of the buildings increase significantly with decreasing the soil stiffness.

Key words: Soil types, Soil structure interaction, Multistory building, Equivalent static method, Dynamic response spectrum analysis, seismic analysis

1. INTRODUCTION

To design and retrofit of structures, it is very crucial to estimate the earthquake motions at the site of structures. The nature of excitation, type of structures and the properties of the foundation soil are indispensable to evaluate the effect of the soil on structures experiencing the seismic load Samali et al. (2011). The difference between structures located on different types of soils and rocks has been an ongoing topic for many researches. In some researches, it is assumed that the structure is fixed on the ground Faraj Rabar, H (2018) meanwhile; flexible-base structures are modelled to include the effect of the soil on structures in other researches. In traditional studies, it is assumed that the motion at the foundation level equals to the ground free field motion. Although this might be true for a structure located on hard rocks, the effect of the soil on structures is not considered so that more realistic results can be obtained. The motion of foundation may differ from free field motion for the structures resting on soft soils Tabatabaiefar and Massumi (2010). The response of the soil to an earthquake can remarkably modify the motion of the structure; the response of the structure for the same earthquake also affects the motion of the soil. This process is referred to as Soil Structure Interaction (SSI).

In some design codes, the contribution of SSI is ignored; this is apparently due to false observation that SSI can decrease the overall seismic response of a structure. Hence, unconservative results are obtained Patil et al. (2016). Considering SSI system in evaluating the effect of seismic loads on structures can play a significant role in representing more realistic inertial force and displacements. For the structures resting on soft soil, through wave radiation and hysteresis procedures a significant amount of the input energy will be absorbed and dissipated. This is because of the damping of soil materials Samali et al. (2011). However, this dissipation of energy is ignored in the structures resting on hard rocks in traditional studies Tabatabaiefar and Massumi (2010).

The earthquakes occurred in some cities which caused remarkable damages such as those in (Mexico City 1985, Fukushima 2011 and Christchurch 2011) and other recent earthquakes presents the fact that the local soil properties can play a substantial role in quantifying the earthquake response of the structures. These also indicated that the rock motions can be intensified at the base of the structure Tabatabaiefar and Massumi (2010). Therefore, it is very important to determine a realistic site-dependent free-field surface motion at the base of the structures to design earthquake resistant structures properly. In this regard, several researchers (Tabatabaiefar *et al*. (2012); Abdel Raheem *et al*. (2015); Patil *et al*. (2016); Samali et al. (2011); Tabatabaiefar and Massumi (2010); Kabtamu *et al.* (2018) and etc.) have studied the influence of SSI on the structures for seismic loads.

Rabar Faraj (2018) studied the influence of different soil types on the seismic response of reinforced concrete intermediate rise regular building in halabja city using equivalent static method without considering SSI. He observed that for residential typical eight story building the maximum story displacement is only 34 mm for soil type SA (Hard Rock). However, this value was dramatically increased to 92 mm for soil type SE (Soft Soil). He also observed that the base shear and base moment of the building analyzed on soil type SE were three times greater than the same building analyzed on Soil type SA. Tabatabaiefar *et al.* (2012) investigated the effect of various soil types on the response of moment resisting frames. They concluded that the effects of the SSI for elastic and inelastic seismic design of moment-resisting buildings founded on Soil Class C was negligible, while the performance level of the model resting on Soil Classes D and E substantially increased (especially for Soil Class E) from life safe to near collapse. Generally, the decrement of the dynamic properties of the subsoil, such as the shear-wave velocity and shear modulus, the base shear ratios decrease while the inter-story drifts of the moment-resisting building frames increase relatively.

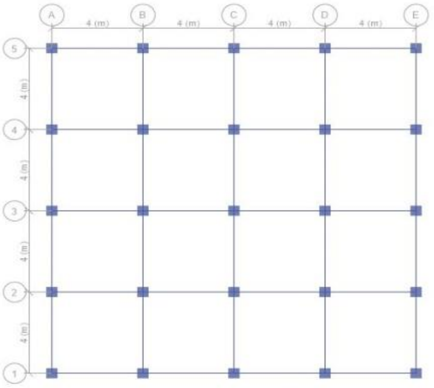
Galal and Naimi (2008) showed that for moment resisting building frames up to 20 stories, considering the effect of SSI on seismic behavior is only essential for the structures resting on soft soil deposits with shear wave velocity less than 180 m/sec. However, Tabatabaiefar and Massumi (2010) concluded that SSI effect is not required to be considered for seismic design of RC-MRF buildings founded on a soil (375 < Vs < 750 m/s) meanwhile it is considered for a RC-MRF buildings higher than 7 stories on soil (175 < Vs < 375 m/s). They also claimed that, for a RC-MRF buildings higher than 3 stories founded on a soil (Vs > 175 m/s), the effect of SSI is essential to be taken into account.

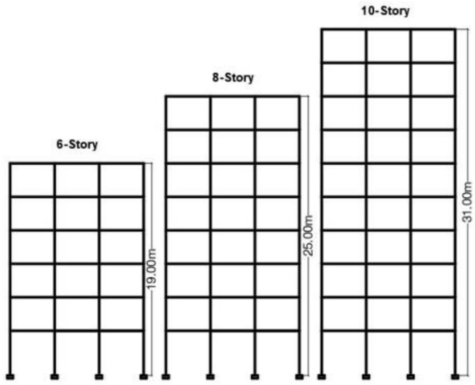
The aim of this research is to investigate the effect of different soil types on the R.C multistory buildings in Halabja-city excited by a seismic load. Seismic site classifications are included and three different building stories (6- stories, 8- stories and 10-stories) are examined using both equivalent static method (ESM) and dynamic response spectrum method (RSM). For each case, both SSI and Non-SSI (NSSI) are considered to identify whether the SSI can modify the response building and to what extent changing soil types can impact the response in terms of maximum story displacements and building time periods.

2. STRUCTURAL AND GEOTECHNICAL CHARACTERISTICS OF MODELS

2.1 Characteristics of structural models

For comparative analysis of flexible and fixed base buildings, three samples of typical buildings with six, eight and ten stories are chosen for this study as shown in Fig. 2. Building's layout has essentially regular plans of four equal bays with a typical bay width of 4 *m* in both directions, to avoid secondary effects due to irregularity. The models represent the conventional types of buildings in current practice in Halabja city located in Kurdistan region of Iraq, which recently shocked by different earthquake intensities and the most intensive one was hit the city on 12 November 2017 with the magnitude of 7.2 by Richter scale according to (USGS). The 3D model buildings here after denoted as S6, S8 and S10 for 6, 8 and 10-stories respectively. The building structural members have been first designed according to ACI318-14, ASCE 7-16 (2016) under static loads assuming an un-cracked section for beam and slabs in the analysis. Fig. 1 shows typical plan for S6, S8, and S10 story with first story height 4 m and other typical Story heights of 3 m as a normal height for residential buildings in the city.





Figurer 1. Typical buildings floor plan Figurer 2. Typical elevations for different building models

The materials were selected for the buildings based on their availability in the area market. The ultimate compressive strength of concrete f_c' = 25MPa; the reinforcement yield strength fy = 420MPa, and a modulus of elasticity of 200GPa.

The gravity dead loads assigned to the all building models were the self-weights of the structural elements including the reinforced concrete columns, slabs and beams. The weights of the nonstructural elements (e.g. tiling, partitions, finishing, etc.) were assigned as a superimposed uniform dead load equal to 4kN/m^2. A uniform live load of 2kN/m^2 was used for all residential areas based on the ASCE 7-16 (2016) load requirement criteria. The minimum safe column cross sections under static and dynamic loads, to satisfy the code requirements are is 0.6 x 0.6 m for S10 building, 0.5 x 0.5 m for S8 building and 0.4 x 0.4 m for S6 buildings. The beams were 0.5m in depth and 0.4m in width with the floor slab thickness of 0.15m.

2.2 Geotechnical Characteristics of the Subsoil Model

To investigate the effect of different soil profile types on the seismic performance of selected buildings, the site soil classes were considered in this analysis are: soil class A corresponding to 'Hard rock', soil class B corresponding to 'Rock', soil class C corresponding to 'Very dense soil and soft rock', soil class D corresponding to 'Stiff soil' and soil class E corresponding to 'Soft clay soil', in regard with ASCE 7-16 (2016). All buildings were analyzed on the five different soil classes considering both SSI and Non-SSI circumstances. Characteristics of the utilized soil profiles are shown in Table. 1 and have been obtained from ASCE7-16 (2016) and (Bowles, 1992).

Table 1. Geotechnical characteristics of utilized soils.

Soil Type	Shear Wave Velocity V_S (m/s)	Shear modulus G (kn/m^2)	Density ρ (Kn/m^3)	Poisson's ratio
SA	1500 (≥1500)	60750000	27	0.1
SB	760 (760-1500)	11552000	20	0.2

SC	360 (360-760)	2462400	19	0.25
SD	180 (180-360)	550800	17	0.3
SE	100 (≤180)	150000	15	0.4

3. SEISMIC ANALYSIS AND SOIL–STRUCTURE INTERACTION SYSTEM

3.1 Raft foundation and soil conditions

For understanding the influence of SSI on the seismic response of selected buildings, this study focuses on evaluating the seismic behavior of reinforced concrete buildings on raft foundation with thickness of 0.6 m for S6, 0.8 m for S8 and 1.0 m for S10 building. The underneath soil is modeled by Winkler spring approach with equivalent static stiffness for 6 degree of freedom (DOF) based on soil elastic modulus (Kraus, I. and Džakić, D. 2013, Raheem *et al*. 2015). The soil spring stiffness for all 6 DOF can be calculated using ASCE41-17 expressions shown in Eq. (1) to (6). It is worth to mention that, these equations will determine the stiffness's at the surface. However in this study it was assumed that the foundations were below the ground surface level by 1.5 m. Therefore, the correction factors for embedment depth (β) for all building models were considered according to ASCE41-17.

Translation a long x-axis $$K_{x,sur} = \frac{GB}{2-\nu}\left[3.4\left[\frac{L}{B}\right]^{0.65} + 1.2\right]$$ (1)

Translation a long y-axis $$K_{y,sur} = \frac{GB}{2-\nu}\left[3.4\left[\frac{L}{B}\right]^{0.65} + 0.4\frac{L}{B} + 0.8\right]$$ (2)

Translation a long z-axis $$K_{z,sur} = \frac{GB}{1-\nu}\left[1.55\left[\frac{L}{B}\right]^{0.75} + 0.8\right]$$ (3)

Rocking about x-axis $$K_{xx,sur} = \frac{GB^3}{1-\nu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$$ (4)

Rocking about y-axis $$K_{YY,sur} = \frac{GB^3}{1-\nu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$$ (5)

Torsion about z-axis $$K_{zz,sur} = GB^3 \left[0.53 \left(\frac{L}{B}\right)^{2.45} + 0.51\right]$$ (6)

$$G=\rho * V_S^2$$ (7)

Where G is shear modulus of soil, ρ is the density of soil; v is the Poisson's ratio of soil. L and B are the length and width of foundation, respectively.

3.2 Equivalent Static Lateral Force Method

As one of the most popular methods to analyze regular residential buildings, the equivalent static lateral force procedure (ESM) was used along with response spectrum analysis to analyze the selected buildings and calculate the seismic parameters according to ASCE7-16 (2016). All seismic coefficients and parameters which are required for analysis have been taken from ASCE7-16 and Iraqi seismic code 2014 (ISC) for Halabja city as shown in Tab. 2.

Table 2. Seismic Coefficients

Parameter	value
S_s: mapped MCE, 5 percent damped, spectral response acceleration parameter at short periods. (for Halabja city)	2.16 (g)
S_1: mapped MCE, 5 percent damped, spectral response acceleration parameter at a period of 1 s. (for Halabja city)	0.86 (g)
R = response modification coefficient (SMRF)	8
W = effective seismic weight of the building	Dead Loads+ %25 live load
Cd = deflection amplification factor	5.5
Ω_0 = System over strength factor	3
Ie = the importance factor (residential Buildings)	1
Ta = approximate fundamental period of the Building	Varies for different models
T_L = Long-Period Transition Period (s)	6 seconds
Risk Category	II

3.3 Dynamic Response Spectrum Method

The response spectrum analysis (RSA) is applicable for all types of buildings. This method requires sufficient number of modes of vibration to capture the participation of at least 90 % of the structure's mass in each of the two orthogonal directions ASCE7-16 (2016). To compare the effects of SSI base models with fixed base models, all buildings were also analyzed by this method considering the both circumstances. Fig. 3 shows equivalent seismic design response spectrum used in this analysis which constructed for Halabja city considering all different soil types.

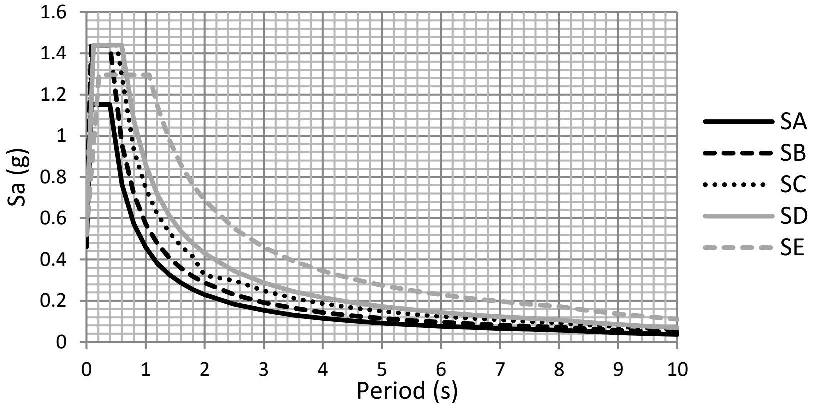


Figure 3. Design response spectrum for all soil profile types of Halabja city according to ISC 2014.

The buildings were modeled as 3D frame structure using frame elements for columns, longitudinal and transverse beams, shell element for slabs and raft foundation, spring element for soil. All structures were modeled and analyzed in this paper using the computer program ETABS 2016 (CSI, 2016).

4. RESULTS AND DISCUSSIONS

4.1 Displacements

In this paper, S6, S8 and S10 buildings are examined using both ESM and RSA. Each building is analyzed under fix base (NSSI) and flexible base (SSI) conditions.

Fig. 4 shows the maximum story displacements obtained from ESM for S6 building. It can be observed that for both types of soil SA and SB the displacements are exactly the same in both conditions. However, for types of SC and SD the displacements vary. In SSI, the displacements are increased by approximately (15%) and (25%) for types SC and SD respectively. A substantial change in displacement can be seen in type SE soil. The displacements are increased approximately by 50% when considering SSI. This is reasonable because the dynamic properties of the SE such as; shear wave velocity and shear modulus much smaller than aforementioned types.

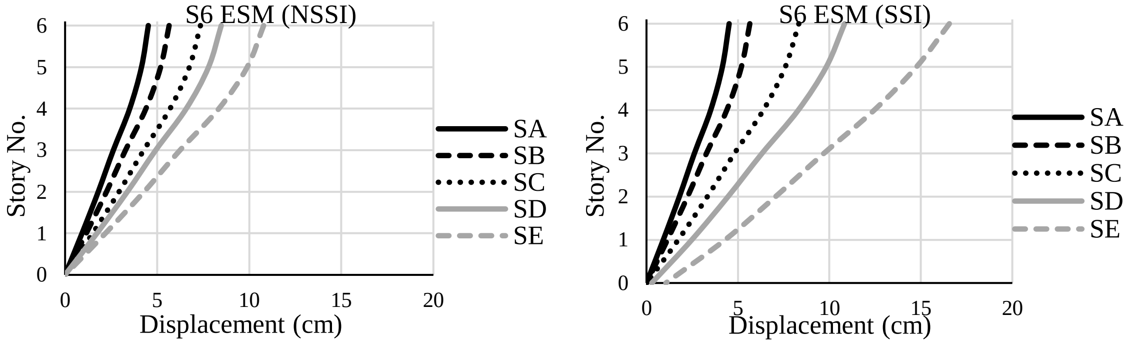


Figure 4. Max Story displacements for S6 building by Equivalent Static Method

Fig. 5 depicts the displacements obtained in RSA. It can be obviously seen that no considerable changes are achieved in the different types of soil but type SE under both circumstances. Opposed to the other types, soil type SE provides remarkable change when considering SSI. Meaning, considering SSI rises displacements by 45% almost in each story.

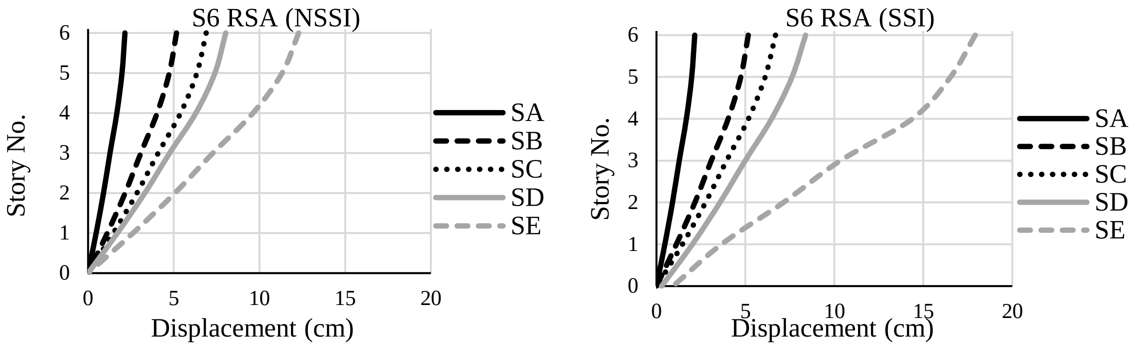


Figure 5. Max Story displacements for S6 building by dynamic response spectrum method

Fig. 6 and 7 demonstrate the analysis of S8 building under both NSSI and SSI conditions. Fig. 6 illustrates ESM analysis. As shown, the response of the building is the same on soil types SA and SB in both circumstances. Further, the response in soil type SD is also increased by nearly 15% in SSI. Nevertheless, the response in soil type SE is by far increased and shifted away from NSSI – SE. As observed, the amount of displacements is grown by nearly 115% in almost all stories. This means that the response of the S8 building is considerably affected by considering SSI.

In RSA, it is also evident that soil type SE depicts considerable change in response when considering SSI, as shown in Fig. 7. Similar to ESM S8, soil types SC and SD show minor change, with no change in soil type SA and SB.

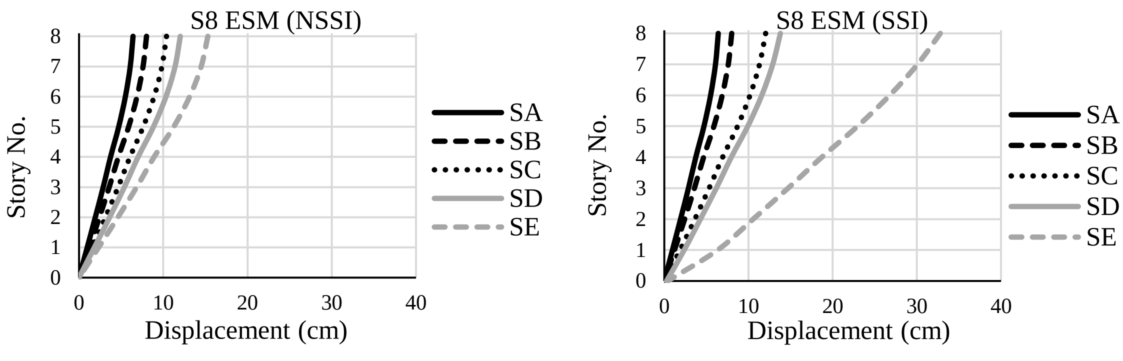


Figure 6. Max Story displacements for S8 building by Equivalent Static Method

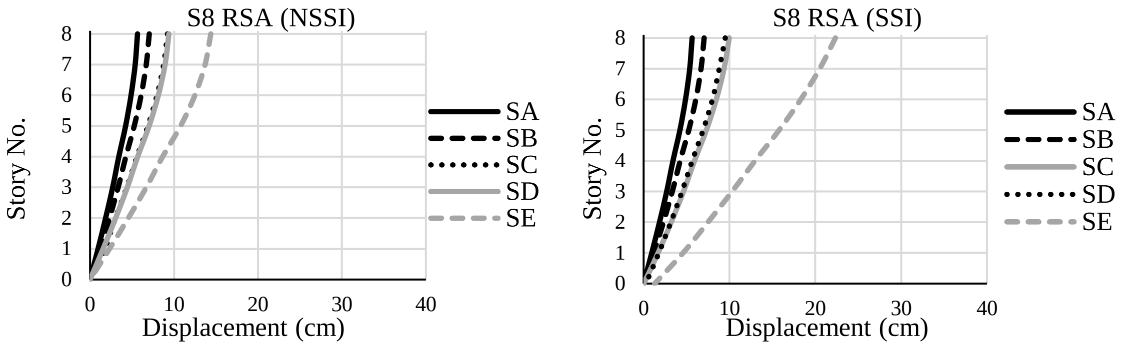


Figure 7. Max Story displacements for S8 building by dynamic response spectrum method

Fig. 8 represents the response of S10 building under both conditions using ESM. Similar to S8, remarkable change in displacements can be noted. Although the response soil types SA and SB remained constant under both conditions, substantial modifications in soil types SC, SD and SE are obvious, particularly in type SE when the effect of SSI is included. The rates of increments are approximately (18%) and (35%) for type SC and SD respectively. This is by far greater in soil type SE as it is nearly (130%).

In RSA, SSI has small effect on soil type SC and SD as it is noticeable in Fig. 9. In contrast, significant change in displacement is observed in soil type SE. The rate of the increase in the displacement is approximately (60%). It presents that the soil type SE is very vulnerable to a seismic load compared to the other types and needed to be considered when designing a S10 moment resisting frame building. It can be noticeably seen that the soil type SE shows remarkable change in modification in the displacement when the effect of SSI is considered in all the three types of the buildings. This is also declared by Tabatabaiefar et al. (2012).

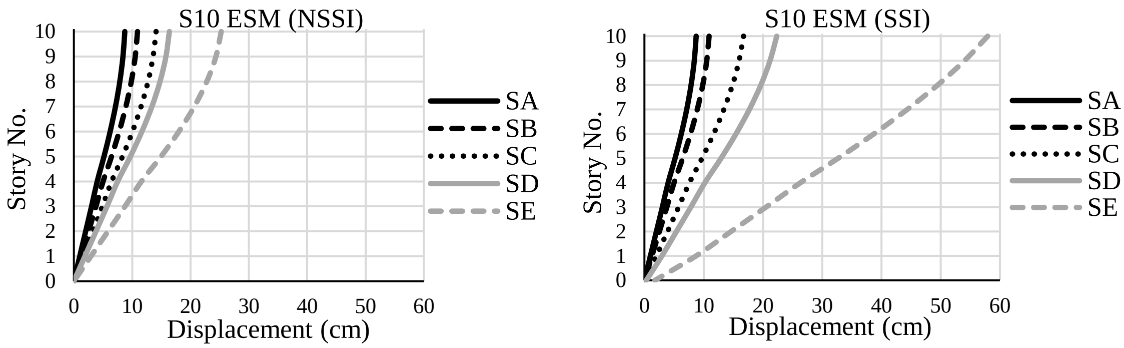


Figure 8. Max Story displacements for S10 building by Equivalent Static Method

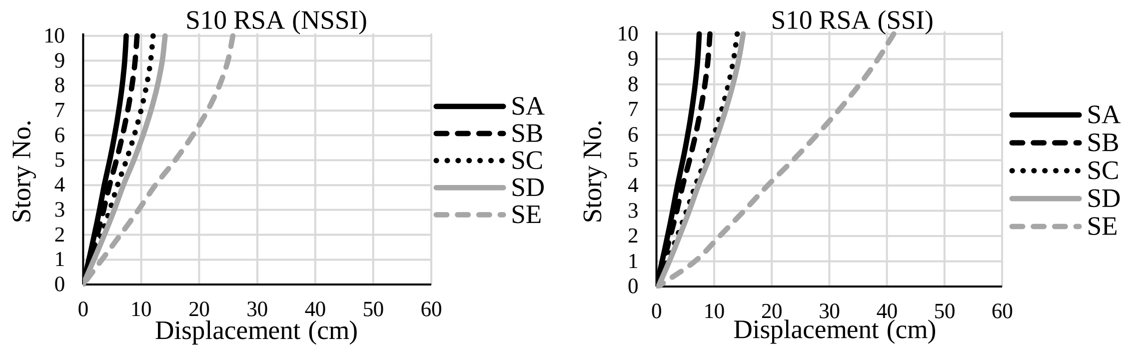
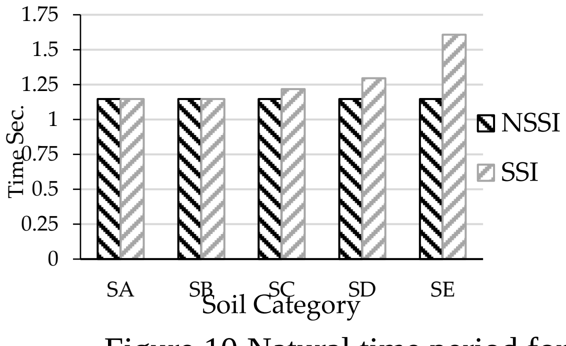


Figure 9. Max Story displacements for S10 building by dynamic response spectrum method

4.2 Natural Time Period

The Natural time periods for the buildings are examined and both cases are also considered for the different soil types. Fig. 10 shows the time period for the S6 building, it can be seen that in NSSI building the time period does not change regardless of soil types. In considering SSI, soil types SA and SB do not demonstrate any change in the period while there is a slight change in soil types SC and SD. However, this change is very remarkable in soil type SE as the flexibility of this soil is greater than the others. This is due to the fact that the dynamic properties (shear wave velocity and shear modulus) decline remarkably compared to other soil types. Therefore, the more flexibility provides the greater time period. In the Fig. 11 and 12, the same changes can be observed with the great time period as it is increased with the increment of the number of stories.



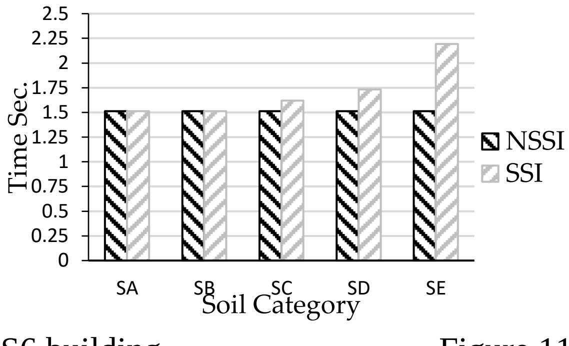


Figure 10 Natural time period for S6 building Figure 11 Natural time period for S8 building

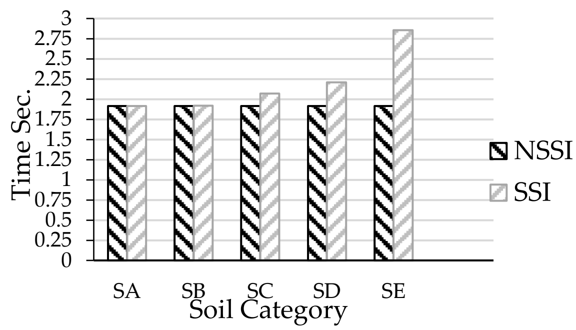


Figure 12 Natural time period for S10 building

5. CONCLUSION

This research concludes that considering SSI does not have any effect of maximum story displacement and natural time period on both soil type SA and SB regardless of the number of stories. Further, in S6 building, the effect of SSI can also be ignored for soil type SC while, in S8 and more, soil types SC and SD show remarkable changes particularly in ESM. Nonetheless, soil type SE is very vulnerable for seismic loads and the effect of SSI is required to be considered in both methods. The degree of the change in the response is directly proportional with the number of stories, as it can be noted that the change in S10 is greater than others. Therefore, it can be concluded that by decreasing the dynamic properties of the subsoil, such as the shear-wave velocity (Vs) and shear modulus (G), the maximum story displacements of the moment resisting frame buildings increased substantially.

With regard to the natural time period, the type of the soil does not have any impact on the time period in fix base buildings while in flexible base it has a significant contribution. Natural time period increases with increasing soil flexibility as soil type SE represents a substantial increase in time period whereas soil types SA and SB depict no change. This is also because of the decrement of the dynamic properties of the soil.

As far as the method of analysis is concerned, it is crucial to note that the effect of SSI, in terms of maximum story displacement and time period, is more obvious in ESM than in RSA. Meaning that soil types SC and SD might not have remarkable contribution in response of some buildings when RSA is used while they can cause some change in the response of the same buildings in ESM analysis.

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