A case study: Effect of Soil-flexibility on the Seismic Response of Reinforced Concrete Intermediate-rise Regular Buildings in Halabja City

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ABSTRACT

On November ٢٠١٧ an earthquake hit the city of Halabja which is located at Iraq-Iran border with the magnitude of ٧,٣ according to Richter scale. However, the damages still can be considered not that huge comparing to the intensity of the earthquake shake. Therefore, this paper has been carried out to investigate the effects of different soil profiles on the amount of damages and the behavior of buildings during earthquakes. In this paper the flexibility of soil or soil structure interaction (SSI) has not been considered and the conventional method (equivalent static lateral force procedure) which assumed that the structure is fixed at the base has been used for analysis. Three dimensional (٣D) Model of eight storey residential building with plan dimensions of ٢٠mX١٢m, each storey having a height of ٣.٢ m have been developed to analyze and compare the effect of seismic forces on multistory building by commercially available computer program, ETABS ٢٠١٦. Various seismic parameters have been taken from ASCE٧-١٠ and Iraqi Seismic code ٢٠١٣ for Halabja city and five soil profile types (SA, SB, SC, SD and SE) have been considered during analysis according to both codes. The base shears, storey moments, max story displacements, and inelastic storey drift responses with respect to change in storey level and soil conditions of the structure have been calculated. Based on the current paper, It has been observed that the soil profile type have significant influences on the behavior of the building during earthquakes. Additionally, the seismic forces are significantly reduced for harder soil profiles which could be one of the most important factors behind having small damages during Halabja earthquake.

Keywords: Soil profile types, RC buildings, Standard Codes, Seismic behaviour, Halabja city.

١. INTRODUCTION

The Earthquake causes different shaking intensities at different site locations. Nowadays, it is significant to avoid damaging the structure while having earthquake at high level of intensity. This is because earthquake might destruct the buildings due to causing different shaking intensities. On November ٢٠١٧ an earthquake hit the city of Halabja which is located at Iraq-Iran border with the magnitude of ٧,٣ by Richter scale according to the United States Geological Survey (USGS) [١]. However, the damages still can be considered not that huge comparing to the intensity of the earthquake shake. There are many aspects that have a clear impact on the intensity of shaking of the building, such as the strong shaking and its duration, the profile of the soil type in the area, frequency content of the motion, and distance from fault or epicenter [٢]. The research and investigations conducted in the last decades, demonstrate a dynamic relation between the firmness of the structure and the type of soil on which it is built on. This dynamic soil-structure interaction (SSI) can sometimes have a remarkable role in determining the amount of displacements and forces faced to the built structure. The process of analyzing high rise RC of buildings is facilitated in the way that a fixed base is assumed and the influence of SSI is neglected. However, various types of soil can influence the dynamic and static characteristics of the building structures and consequently control the structures' dynamic and static behavior. In order to analyze the building structures with regard to their dynamic and static loadings, certain parameters such as storey bending moments, the basic natural periods, storey displacements or drifts, and base shear forces should be taken into consideration and assessed appropriately [٣].

Anand N, et la ٢٠١٠ [٤] carried out an investigation in which they analyzed one to fifteen storey three dimension frames, once with shear wall and once without, along with three various kinds of soil and then analyzed them according to the codal provision and compared the results in different regards. It was shown that the base shear values in the three kinds of soil for frames up to three storeys were similar. However, the base shear values for frames above three storeys grew with change of soil type from hard to medium and medium to soft.

A. Massumi and H.R. Tabatabaiefar [٥] considered SSI influences in seismic design of ductile RC- Moment Resisting Frame Systems (MRFS) according to Iranian code. Dynamic SSI is necessary for assessing structural safety during earthquakes. For this reason four types of buildings consisting ٣, ٥, ٧ &١٠ stories resting on three different types of soils according to Iranian codes were analyzed. Soil was modeled by Finite Element method. The results led to a conclusion that SSI is necessary for buildings higher than three stories on soil type whose Vs<١٧٥ m/s and for buildings greater than seven stories on soil type ١٧٥< Vs<٣٧٥m/s. However, due to reducing the computational effort, and the lack of information about local soil data to determine the soil profile types for Halabja city, this paper followed the foundation modeling of

ASCE٧-١٠ [٦] and UBC ١٩٩٧ [٧] which permitted to consider the structure to be fixed at the base for the purposes of determining seismic forces.

٢. ANALYSIS APPROACH

The Case study involves assessing the seismic performance of eight story residential regular building while varying site conditions. Nevertheless, the local soil profile data for Halabja city was not available due to not having previous site soil investigations in this regard in the city. Therefore, the building site soil classes were assumed 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 ٧-١٠ [٦]. The flexibility of soil or SSI has not been considered and the building was assumed to be fixed at the base. Commercially available computer program, ETABS ٢٠١٦ (CSI ٢٠٠٧) [٨] has been used to compare the seismic forces, displacements and drifts in a (٣D) model of multistory building.

٢,١.The Building Model

The structure analyzed in this study is residential reinforced frame building, which consists of ٥ grids in X-direction and ٤ grids in Y-direction. To withstand lateral forces, a system consisting of special moment resisting frames (SMRF) was used assuming fixed base joints at the ground surface. A floor height of ٣.٢ m was assumed for all stories except ground level with ٤ m. The details of the building are shown in Figure ١ and Figure ٢.

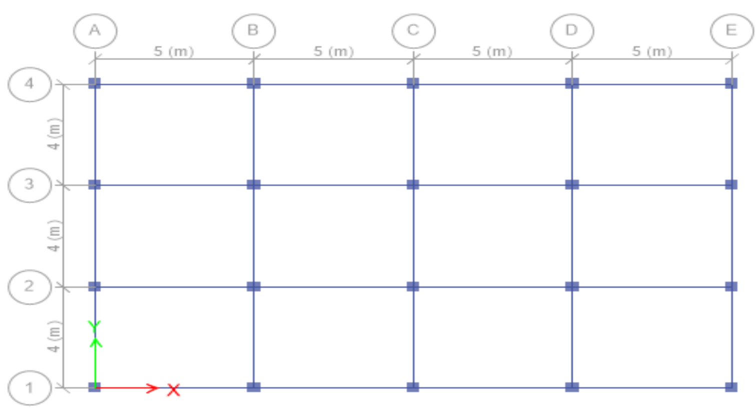

FIGURE ١: Typical Building Floor Plan

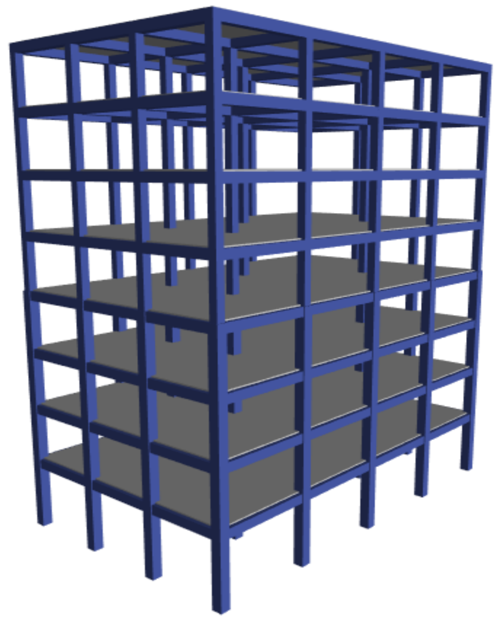

FIGURE ٢: Typical ٣D model

The materials were selected for the building based on their availability in the Kurdistan region market. It was assumed that the ultimate compressive strength of concrete f'c = ٢٥MPa; the reinforcement yield strength fy = ٤٢٠MPa, and a modulus of elasticity of ٢٠٠GPa.

The gravity dead loads assigned to the building are 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 modeled as a superimposed uniform dead load equal to ٤kN/m٢. A uniform live load of ٢kN/m٢ was used for all residential areas based on the ASCE ٧-١٠ [٦] load requirement criteria.

The Column dimensions are ٠,٥x٠,٥ m up to storey four and ٠,٤x٠,٤ m for upper stories. The beams were ٠,٥m in depth and ٠,٤m in width with the floor slab depth of ٠,١٥m.

٢,٢.Seismic Analysis

As an internationally acceptable method for this type of regular buildings (Equivalent Lateral Force Analysis) has been used to calculate all seismic forces and displacements according to ASCE٧-١٠ Code [٦] and the Iraqi seismic code ٢٠١٣ [٩] which is mainly adopted from ASCE٧-١٠ [٦]. The seismic coefficients and parameters have been taken from both previous codes as shown in table ١.

TABLE.١

Seismic Load Parameters

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
Ie = the importance factor (residential Building)	1
Ta = approximate fundamental period of the Building	0.886 sec.
Risk Category	II

٣. RESULTS AND DISCUSSIONS

٣,١ STOREY DISPLACEMENTS

Figure ٣ and Figure ٤ shows the maximum story displacements in both directions of the building. The results showed that, the max. Storey displacements for both directions significantly reduced through changing the soil profiles. For instance, the max. Story displacement at storey ٨ in X direction is only ٣٤,١١ mm for soil profile type SA. However, this value dramatically increased to ٩٢ mm for soil profile type SE. On the other hand, the Y direction follows the same trend with ٣٦ mm and ٩٩ mm max. storey displacements at storey ٨ for soil profile types SA and SE respectively. However, Y direction displacements are relatively larger than the other direction due to smaller width compared to the length of the building. Similar results were found in other studies [٤].

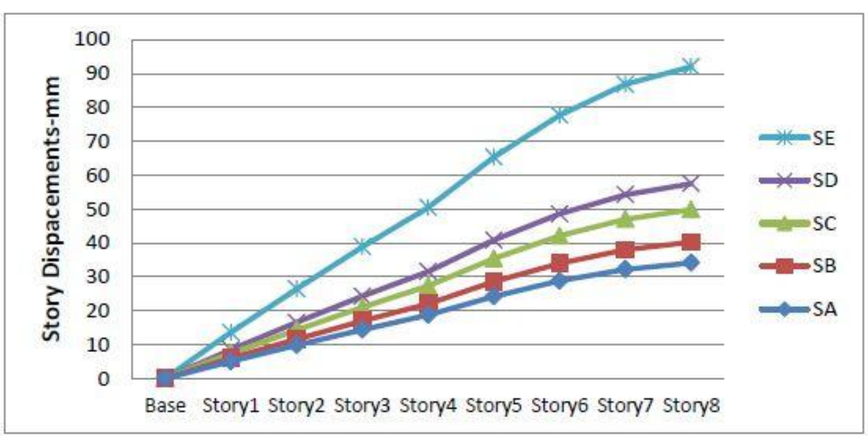

FIGURE ٣. Max Storey Displacements in X direction

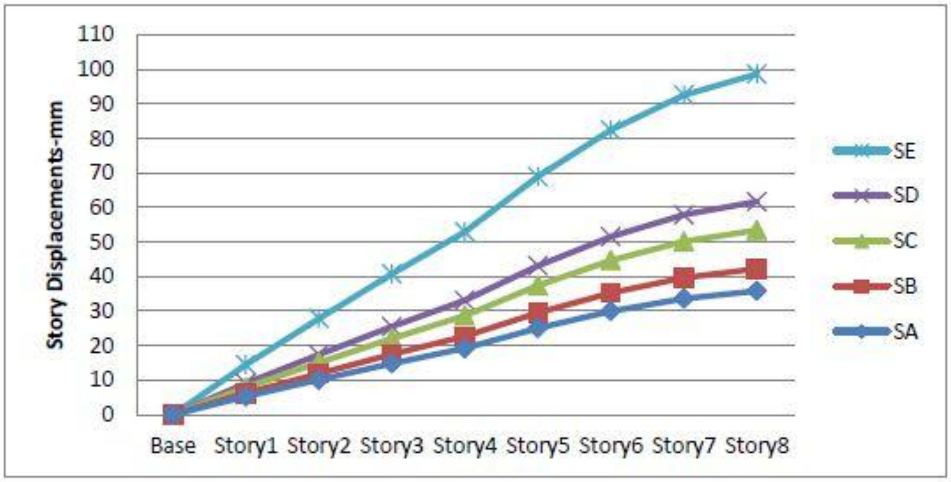

FIGURE ٤.Max Storey Displacements in Y direction

٣,٢ INELASTIC STOREY DRIFTS

The inelastic storey drift results are presented in Figure ٥ and Figure ٦ for both X and Y directions. The figures illustrate that the inelastic storey drift will not necessarily occur at the top level and for the analyzed building it occurs at level ٥. The highest inelastic storey drift values occurred in Y direction with approximately ٨٨ mm for soil profile type SE at level ٥. However, the lowest values were calculated for soil profile type SA in X direction with approximately ١٠,٦ mm at level ٨. Therefore, it can be said that with increasing the soil flexibility the inelastic storey drifts significantly increased especially for soil profile type SE.

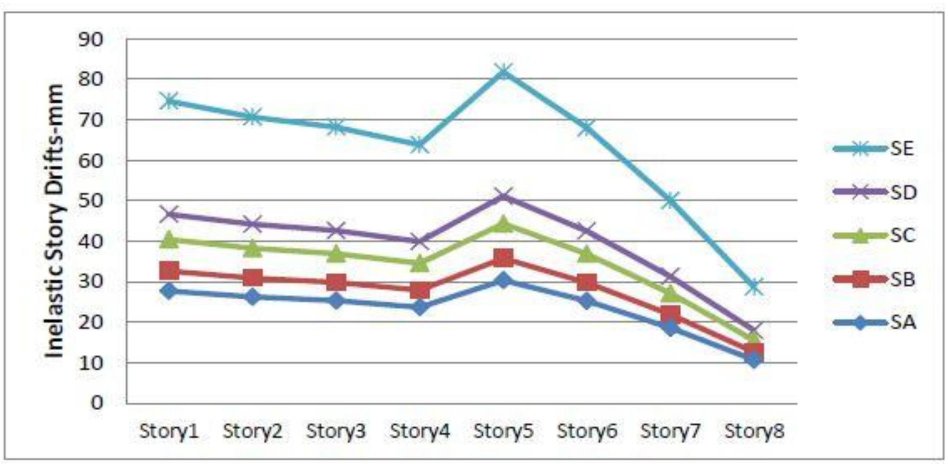

FIGURE ٥. Inelastic Storey Drifts in X direction

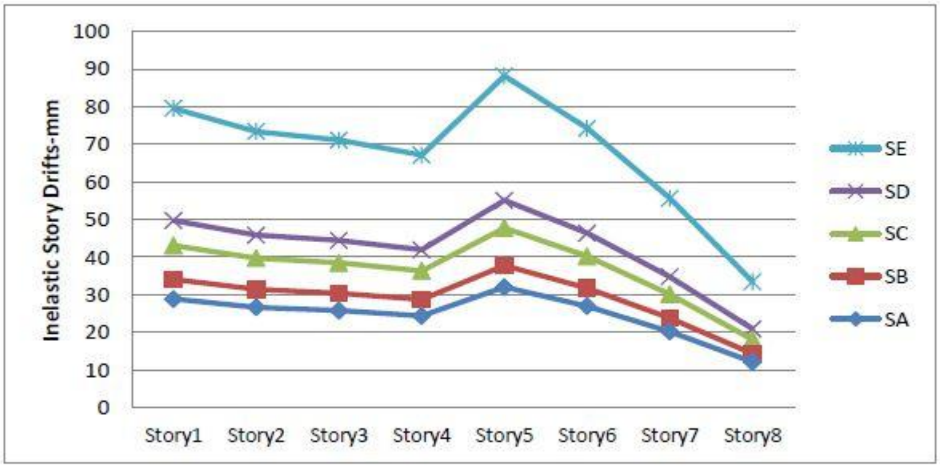

FIGURE ٦. Inelastic Storey Drifts in Y direction

٣,٣ STOREY SHEARS

The results shown in Figures ٧ demonstrate that the soil profile type has a significant contribution in increasing the storey shear of the building. This influence is more marked in buildings built on softer soils. The maximum storey shear was found at the base of the structure for soil profile type SE with ٣٣٨٤KN. There was about ٪٢٧٠ increase in storey shear at the base of the building when the soil profile type changed from SA to SE. Similar results were observed in previous studies [١٠]

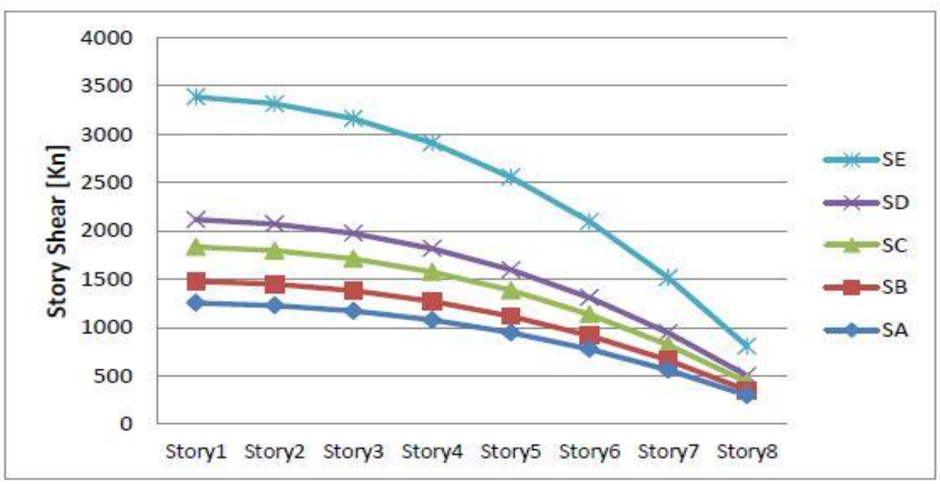

FIGURE ٧. Storey Shear

٣,٤ STOREY MOMENTS

Figure ٨ demonstrates the storey moments for different soil profile types and varying storey levels. The results show that there was a systematical increase in story moments through changing the soil profile type from SA to SE. There is also about ٪٢٧٥ increase in storey moment at the base of the building when the soil profile type changed from SA to SE. However, the results indicated that the soil profile types SA and SB have approximately the same effect on the storey moments.

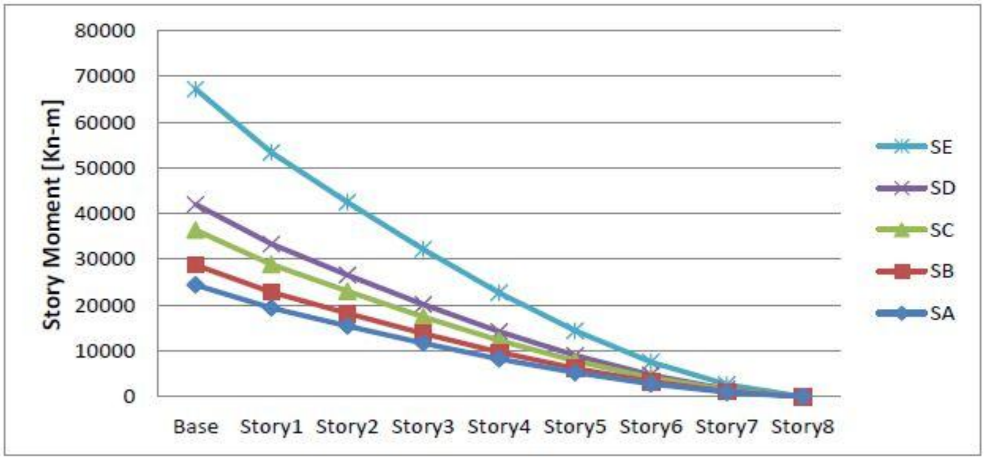

FIGURE ٨. Story Moment

٤. CONCLUSION

In the present study, a reinforced concrete ٨ storey regular residential building was analyzed under different soil profile types to determine the effect of soil flexibility on the seismic forces and behavior of the building. Based on the previous results, it was found that seismic forces and response of structures is influenced greatly by soil profile types. Ignoring the soil site investigation to determine the soil profile type for a specific site can significantly affect the performance of the structures during earthquake and lead to devastating effects. Additionally, the seismic forces and displacements are significantly reduced for harder soil profiles which could be one of the most important factors behind having small damages during Halabja earthquake.

٥. RECOMMENDATIONS

There is no local soil data available for Halabja city to specify the soil profile types. Therefore, it seems that it is crucial to hold soil site investigations in the city to determine shear wave velocity and other related factors which are important to specify the soil types of the city. Then, a profound case study for buildings in the city could be conducted by considering soil structure interaction during analysis.

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