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RESEARCH ARTICLE Open Access

Seismic Performance Assessment Of Steel Structures Considering Soil Effects

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Abstract:
Nowadays, extreme need for construction of buildings in rural area increased the floor number of buildings, in which, the soil under foundation can affect the performance of buildings. In this research, soil effects were investigated to show soil type effects on the performance levels of steel structures. To do this, the 2-, 4-, 6-, and 8-story structures were modeled using ETABS software; then, the models were verified in Opensees software for collapse state analysis. Incremental Dynamic Analyses (IDAs) are employed using far field, near field records having pulse like and no pulse effects. The results of analysis provide informations regarding the influence of soil types of B, C, D, and E on the seismic performance level of steel structures. The results confirmed that the soil types have remarkable effect on performance levels and it should be considered in seismic design process. To consider the soil types effects, it is recommended to compare the results of analysis achieved in this study to find out the percentage of variations, and use them as a reference for seismic design process. In addition, it is possible to have modification factors for amending the performance levels.

Keywords: *Soil Effects, Incremental Dynamic Analyses, Seismic Performance Levels, Steel Structure.*

1. Introduction

The seismic performance assessment of steel structures aimed at comprehensively evaluating their ability to withstand seismic forces and mitigate potential damage. Traditional assessment methodologies have predominantly focused on the structural characteristics of steel elements, often overlooking the significant influence of soil conditions on seismic response. However, recent advancements in structural engineering have underscored the importance of integrating soil effects into the assessment process to enhance the accuracy and reliability of predictions. This formal description involved in conducting seismic performance assessments of steel structures while accounting for soil effects [1-3].

The profile of soil can vary from area of construction in the rural area. Therefore, for each structure, the condition of soil under the foundation can influence the building behavior. Shakib and Homaei [4] used a probabilistic framework to evaluate the impact of soil on the lateral response of steel structures. They examined a collection of 10-story steel structures with various setback ratios while two orthogonal seismic excitation were acting simultaneously. Their results indicated that the interaction between soil and structures decreased the seismic capabilities and the life safety allowable limit.

Bolisetti and Whittaker [5] utilized numerical simulations of steel structures and a 2-story structure having shear wall to investigate the soil impact in up to mid-rise buildings. They compared their results to observations from earlier research that examined information from a series of centrifuge experiments. With better soil consideration, the consequences of soil effects on the structures were studies by Cilsalar and Cadir [6]. The findings showed that columns upgrading lowers superstructure demand and frame collapse likelihood. The findings showed that improving columns lowers the demand on superstructures and the frame collapse risk.

Kazemi et al. [7-9] introduced a machine learning-based procedure to approximately predict the behavior of structures considering the soil types effects. Their investigations showed that the soils may import some reductions on the performance assessments of structures, and recommended to improve the designing and modeling by considering the soil under the foundation. In addition, soil effect cannot be neglected due to its influence and structures should not be assumed as fixed base.

In this research, nonlinear dynamic analysis is conducted to evaluate the structural response under various seismic scenarios, considering both elastic and inelastic behavior. The analysis accounts for the dynamic characteristics of the soil, including soil damping and frequency-dependent properties. Sensitivity analyses are performed to assess the influence of key parameters such as soil stiffness, ground motion characteristics, and structural configurations on the seismic performance of the steel structure. Finally, the results of the assessment are interpreted to derive meaningful insights into the structural vulnerabilities, potential failure modes, and recommendations for design enhancements or retrofitting measures.

2. Modeling of Buildings

In this section, the modeling of structures are defined. The 2-, 4-, 6-, and 8-story structures were modeled using ETABS software. To model structures, ASCE/SEI 7-16 [10] was used for seismic code and four soil types are selected for conditions of stiff to flexible soils, respectively. In soil B, the seismic parameters of S_{DS} and S_{D1} are considered equal to 1.31 and 0.46, respectively, and for soil type C, are selected as 1.57 and 0.65, respectively. For soil D and E, the values of 1.57 and 0.65, and 1.62 and 0.66, respectively, are used according to Kazemi et al. [7, 9] and Kazemi and Jankowski [11, 12]. It should be added that the soil effects were considered in modeling process and determining lateral loads. Figures 1 and 2 present the three-dimensional view of four and eight story buildings.

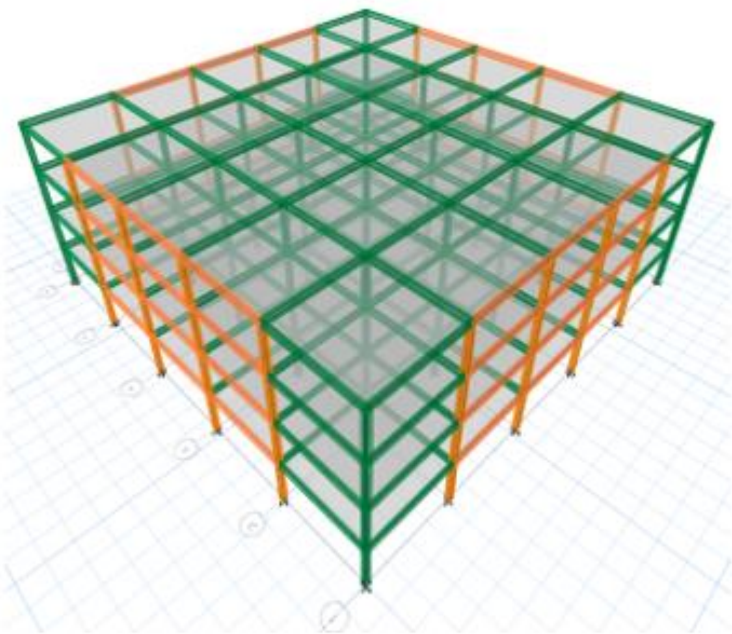

Figure 1: Four-story building designed in ETABS software.

According to Figures 1 and 2, the orange color frames were modeled as Special Moment-Resisting Frames to resist the lateral loads in each directions, and other connections assumed as pin connection.

Therefore, it is possible to use two-dimensional model instead of three-dimensional having same structural behavior. To model two-dimensional structures in Opensees [14] software based on the three-dimensional, the procedures used by Mohebi et al. [15, 16], and Kazemi et al. [17-20] were used. According to their procedure, two-dimensional models were models using the loads and structural elements of outer frames, and the effects of other columns and gravity loads were modeled using leaning column [21-23]. Leaning column can models the rest of structure and facilitate the modeling process while the two-dimensional model can be verified by three-dimensional model [24-26].

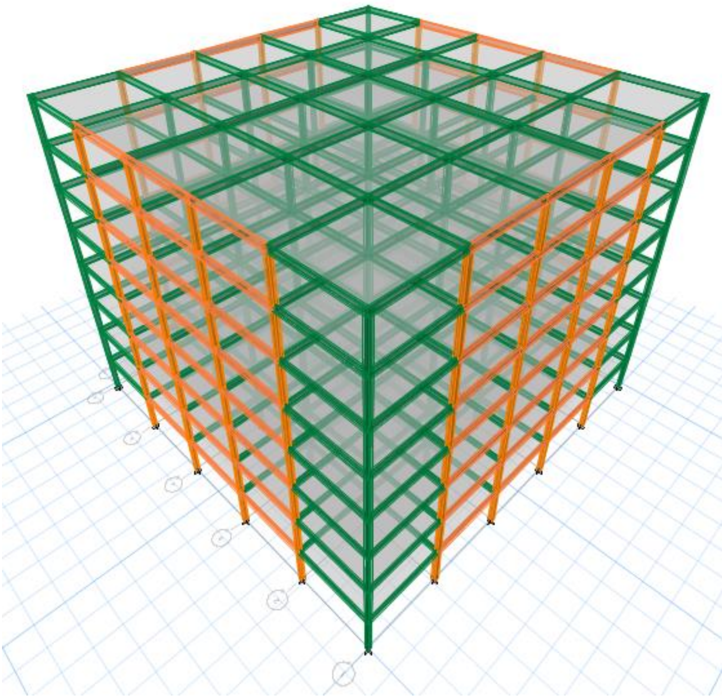

Figure 2: Eight-story building designed in ETABS software.

3. Incremental Dynamic Analysis

Incremental Dynamic Analysis (IDA) was selected for performing collapse state analysis, in which, the total collapse of structure is occurred. The collapse state is a condition in which the structure failures during lateral loads and no further resisting observes. To perform IDAs, the far-field, near-field records having and neglecting the pulse like effects were selected (for details of records see [10, 12, 24]), which have the important seismic excitations occurred during the past years. In addition, the hunt & fill method was developed in the OpenSees [14] software to increase the efficiency of program for IDAs and reduce the time of analysis [27, 28]. Figures 3, 4, 5, and 6 present the IDA curves of 2-, 4-, 6-, and 8-story structures assuming soil D subjected to near fault pulse like records. As shown, all structures after 8% interstory drift ratio reached their collapse state and the IDA curves were flatted.

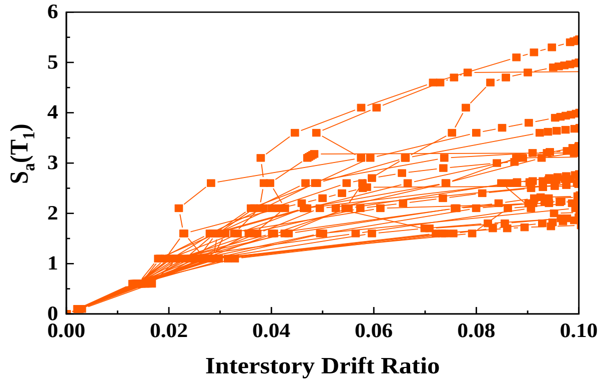

Figure 3: IDA curve of the 2-story struture having soil D including near field pulse like records.

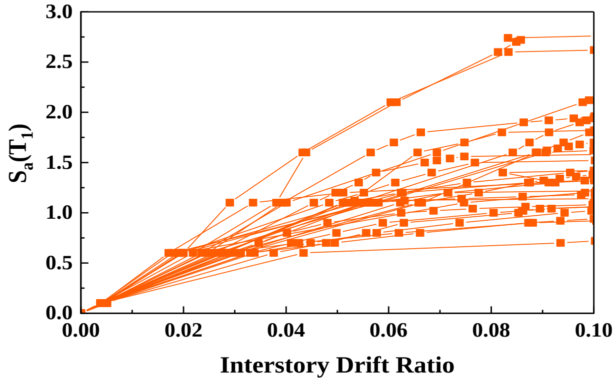

Figure 4: IDA curve of the 4-story struture having soil D including near field pulse like records.

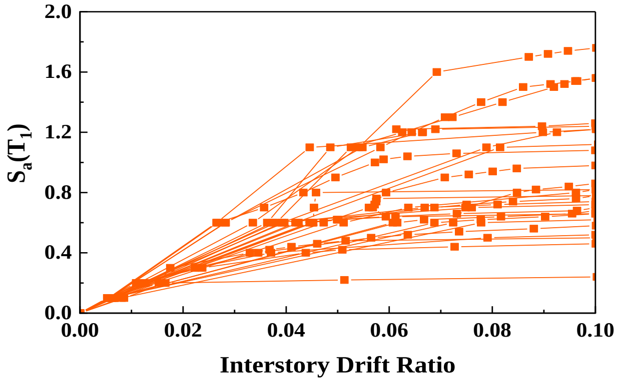

Figure 5: IDA curve of the 6-story struture having soil D including near field pulse like records.

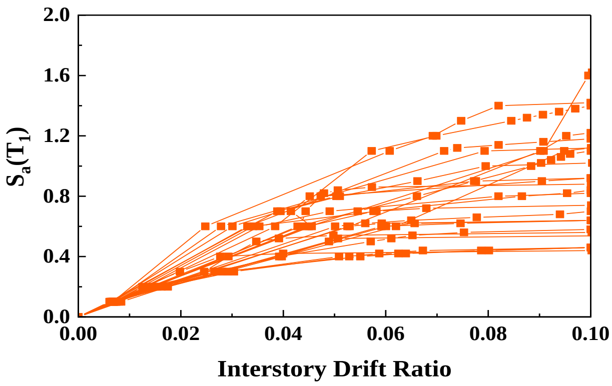

Figure 6: IDA curve of the 8-story struture having soil D including near field pulse like records.

4. Results and Discussions

In this section, soil types effects on the performance levels of structures are discussed. For comparison, four seismic performance levels of Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) and Total Collapse (TC) were assumed based on the interstory drift ratio of 0.7%, 2.5%, 5%, and 10% [11, 12, 29-31]. Then, in each record subset, the Median of IDA curves (Med_{IDA}) for all aforementioned structures were determined and compared.

Figure 7 presents the Med_{IDA} of the 2-story structure having soil D including three record subsets. It can be seen that the near field pulse like records have the lowest values of $Sa(T_1)$ compare to other record subsets. In addition, the near field no pulse records have the highest values $Sa(T_1)$ compare to other record subsets. In allowable performance levels of LS, CP, and TC, the $Sa(T_1)$ values of 1.148, 1.967, and 2.574 were determined for the near field pulse like records, respectively, and the $Sa(T_1)$ values of 1.305, 2.292, and 3.335 were determined for the near field no pulse records, respectively. It could be concluded that the the near field pulse like records have higher effects on the Med_{IDA} of the 2-story structure rather than other records. Therefore, the pulse like effects cannot be neglected during the analysis.

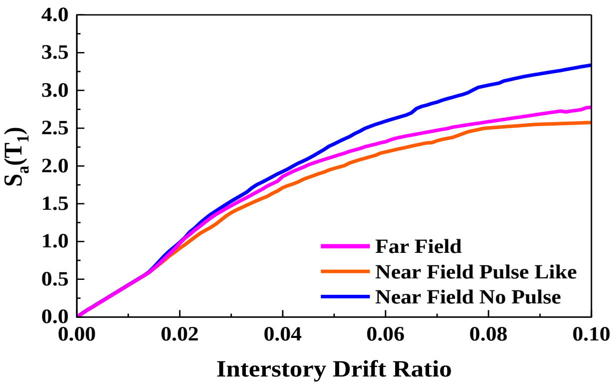

Figure 7: Med_{IDA} of the 2-story structure having soil D including three record subsets.

Figure 8 presents the Med_{IDA} of the 6-story structure having soil B including three record subsets. Similarly, it can be observed that the near field pulse like records have the lowest values of $Sa(T_1)$ and the near field no pulse records have the highest values $Sa(T_1)$. For the near field pulse like records, the $Sa(T_1)$ values of 0.281, 0.47, and 0.562 were achieved for LS, CP, and TC performances, respectively. For the far field records, the $Sa(T_1)$ values of 0.288, 0.502, and 0.595 were determined for LS, CP, and TC performances, respectively. For the near field no pulse records, the $Sa(T_1)$ values of 0.309, 0.517, and 0.645 were calculated for performance levels of LS, CP, and TC, respectively. In general conclusion, the near field pulse like records have higher effects on the Med_{IDA} of the structures rather than other records. For brevity only the results of 2-story and 6-story structures were presented while similar results were observed from other structures.

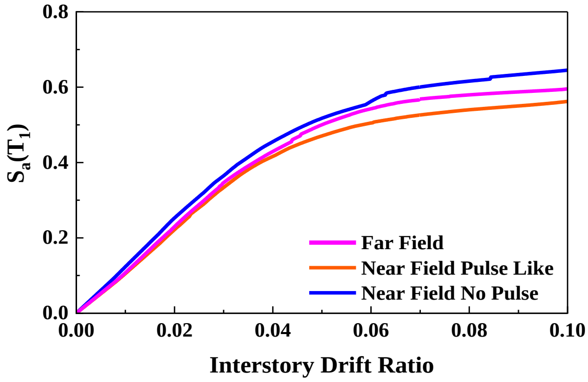

Figure 8: Med_{IDA} of the 6-story structure having soil B including three record subsets.

Figure 9 illustrates the Med_{IDA} of the 4-story structure having all soil types including near field no pulse records. Figure 9 shows the soil type influences on the performance levels of 4-story structure.

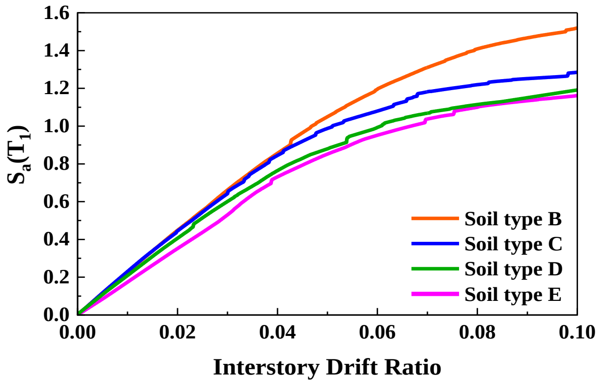

Figure 9: Med_{IDA} of the 4-story structure having all soil types including near field no pulse records.

For instance, in CP performance, the $Sa(T_1)$ values of 1.049, 0.987, 0.851, and 0.879, were determined for B, C, D, and E soil types, respectively. In addition, for TC performance, the $Sa(T_1)$ values of 1.52, 1.285, 1.192, and 1.162, respectively. It can be seen that by increasing the flexibility of soil type (i.e. from soil B to E), the $Sa(T_1)$ values significantly decreased and soil E has the lowest value. By changing soil type from B to E, the CP and TC performances decreased by 16.2% and 23.55%, respectively. Moreover, it is observed that the CP performance has the most percentages of reduction compared to other performance levels.

Figure 10 illustrates the Med_{IDA} of the 8-story structure having all soil types including near field pulse like record subsets. Similarly, as observed, the flexibility of soil can affect the performances of 8-story structure. For CP performance, the $Sa(T_1)$ values of 0.589, 0.556, 0.535, and 0.504, were determined for B, C, D, and E soil types, respectively. While in TC performance level, the $Sa(T_1)$ values of 0.798, 0.730, 0.711, and 0.621, were determined for B, C, D, and E soil types, respectively. Therefore, soil type C, D, and E decreased the CP performance of 8-story structure by 5.6%, 9.16%, and 14.43%, respectively, and the TC performance of 8-story structure by 8.52%, 10.9%, and 22.18% compared to soil type B.

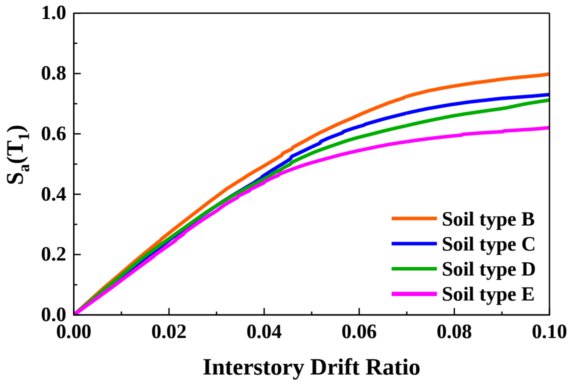

Figure 10: Med_{IDA} of the 8-story structure having all soil types including near field pulse like records.

5. Conclusions

In this study, the soil type effects on the performance levels of the 2-, 4-, 6-, and 8-story structures were investigated. To evaluate the soil effects, the Med_{IDA} of structures were plotted based on IDA curves achieved by far field, near field records having and neglecting pulse like effects. The result of study showed that the near field pulse like records had the lowest values of $Sa(T_1)$. In addition, it can be observed that the flexibility of soil can considerably reduce the seismic performance level of structures. For instance, in the CP performance of 8-story structure in soil type C, D and E decreased by 5.6%, 9.16%, and 14.43%, respectively, and in TC performance, the seismic performance level of 8-story structure in soil type C, D, and E decreased by 8.52%, 10.9%, and 22.18% compared to soil type B. Therefore, it can be recommended to consider the soil effects in lateral response assessment of structures. In addition, comparing the IDA curves of models can provide informations regarding the effects of soil types and engineers can use them as reference for design process.

6. Author's Contribution

We confirm that all named authors have read and approved the manuscript. We also confirm that each author has the same contribution to the paper. We further confirm that all authors have approved the order of authors listed in the manuscript.

7. Conflict of Interest

There is no conflict of interest for this paper.

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