

Influence of Foundation Soil Variability on the Dynamic Response of Regular High Rise Frame Building Subjected to Long Duration Seismic Sequences

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Abstract: Soil conditions can vary from one location to another; therefore, it is essential to give this factor due consideration during the analysis process. This study examined a 20-story building with a frame structural system, analyzing its performance under various soil types as defined by the American code. The impact of soil variation on shear force, displacement, and internal column forces was evaluated. Results indicated a difference of up to 100% in shear force between stiff and soft soils, with shear force increasing as the soil transitioned from stiff to soft.

Keywords: Soil, Seismic, Frame structure, Soil Classification

Introduction

Every structure requires a strong, solid foundation—a necessity that becomes increasingly critical as building height rises. With many nations seeking to optimize space utilization, there has been a shift toward constructing high-rise buildings. Construction quality is intrinsically linked to the type of foundation and the underlying soil, as well as to how the forces acting upon the building's structural elements vary; consequently, the soil demands significant attention. Forces within the building's load-bearing systems—whether frame structures, shear walls, or mixed structural systems—can fluctuate based on the soil conditions beneath the structure. Depending on the soil type, these forces may shift between compression and tension, or undergo amplification or attenuation. This highlights the importance of the current study, as it sheds light on these real-world variations and quantifies the resulting disparities.

Literature review

Soil is classified in numerous international codes based on several criteria—most notably soil bearing capacity as follows:

1. Seismic Soil Classification according to ASCE 7 Standard In seismic design codes, particularly the American Society of Civil Engineers standard (ASCE 7-22), the local soil conditions are categorized into six distinct Site Classes (labeled A through F) to quantify site amplification effects during earthquake ground motions. This classification is primarily determined based on the average shear wave velocity in the top 30 meters of the soil profile V_{s30} supplemented by geotechnical parameters such as the Standard Penetration Test (SPT) blow count (N) and undrained shear strength (Su):
 - Site Class A (Hard Rock): Characterized by $V_{s30} > 1500 \text{ m/sec}$, representing competent crystalline rock formations.

- Site Class B (Medium Rock / Soft Rock): Encompasses rock profiles with V_{s30} ranging between 760 m/s and 1500 m/s. Site Class C (Very Dense Soil and Soft Rock): Dense sands, gravels, or hard clays with V_{s30} between 360 m/s and 760 m/s.
- Site Class D (Stiff Soil): Medium dense cohesionless soils or stiff cohesive soils with V_{s30} ranging from 180 m/s to 360 m/s.
- Site Class E (Soft Clay / Soft Soil): Loose sands or soft cohesive soils exhibiting $V_{s30} < 180$ m/s or thick soft clay layers.
- Site Class F (Soils Requiring Site-Specific Evaluation): Vulnerable soils susceptible to liquefaction, highly organic clays, or peat.

While the allowable bearing capacity (q_a) and dynamic subgrade modulus are used in the calculation process according to ASCE 7, they are inherently connected to the shear wave velocity. As the classical relations in dynamic soil mechanics state (Keçeli, 2012), both of these factors – q_a and dynamic shear modulus ($G_0 = \rho V_s^2$) directly depend on V_s . Therefore, Site Classes A and B with higher stiffness properties ensure high values of q_a and low dynamic deformations, while softer Site Classes D and E provide low bearing capacity, higher dynamic flexibility, and increased spectral accelerations.

2. Effect of Soil Types Variation on Structural Response (Previous Studies) Many researchers examined the effect of variations in the soil type beneath a structure on its dynamics response and load demand: Mylonakis & Gazetas (2000): Questioned the commonly used code assumption that Soil Structure Interaction (SSI) on softer soils always proves to be advantageous due to the increase of period and energy dissipation. Their research showed that the elongation of the period in soft soil profiles (Class E) could make the structural load demand fall in the amplified part of seismic response spectrum, thus increasing lateral displacements and ductility demands.

Bolisetti et al. (2018): Studied the seismic behavior of framed buildings for various soil classes as per the ASCE 7 standard. The researchers came to a conclusion that changing from Site Class C (stiff soil) to Site Class E (soft soil) causes a significant alteration in modal shapes and a transfer of locations of maximum dynamic stresses from the upper stories to the lower structural frames and foundation level. Lu et al. (2024): Examined the seismic performance of high-rise frame structures exposed to long periods of seismic vibration over different ground media. The authors pointed out the fact that softer sites cause less base shears as the structure period becomes longer, but they increase the total lateral displacements, which results in a complicated distribution of internal bending moments and shears throughout the vertical structural members.

3. Novelty and Rationale of Present Study Although the previous studies were able to determine the main influences of SSI over different soil classes, the important aspect that remains unknown is the internal force redistribution within the structural components (columns, beams, and foundations) under the action of multiple repetitions of the long-duration seismic sequences on non-homogeneous soil medium. Most of the traditional design methods fail to account for

Aim of the research

The aim of the current research is to study the effect of varying soil types beneath a structure on the forces generated within the building.

Methodology of the research

This study focuses on a hypothetical 20-story building located in Iraq. The analysis accounts for both dead and live loads, with seismic analysis performed using the response spectrum method. The primary variable examined is the soil type beneath the building and its impact on the forces generated within the building's structural system—specifically, a frame system. A numerical model developed using ETABS 2016 software will be used for the analysis. The soil types considered correspond to those specified in US codes—specifically UBC97—comprising five categories (SA, SB, SC, SD, and SE), resulting in five distinct models.

Building model

The building to be analyzed is a hypothetical structure with a 25-meter square footprint, featuring six rows of columns in each direction, with six columns per row. The load-bearing columns measure 60 cm by 80 cm, the ribbed slabs are 33 cm thick, and the characteristic strength of the concrete used is 300 kg/cm².

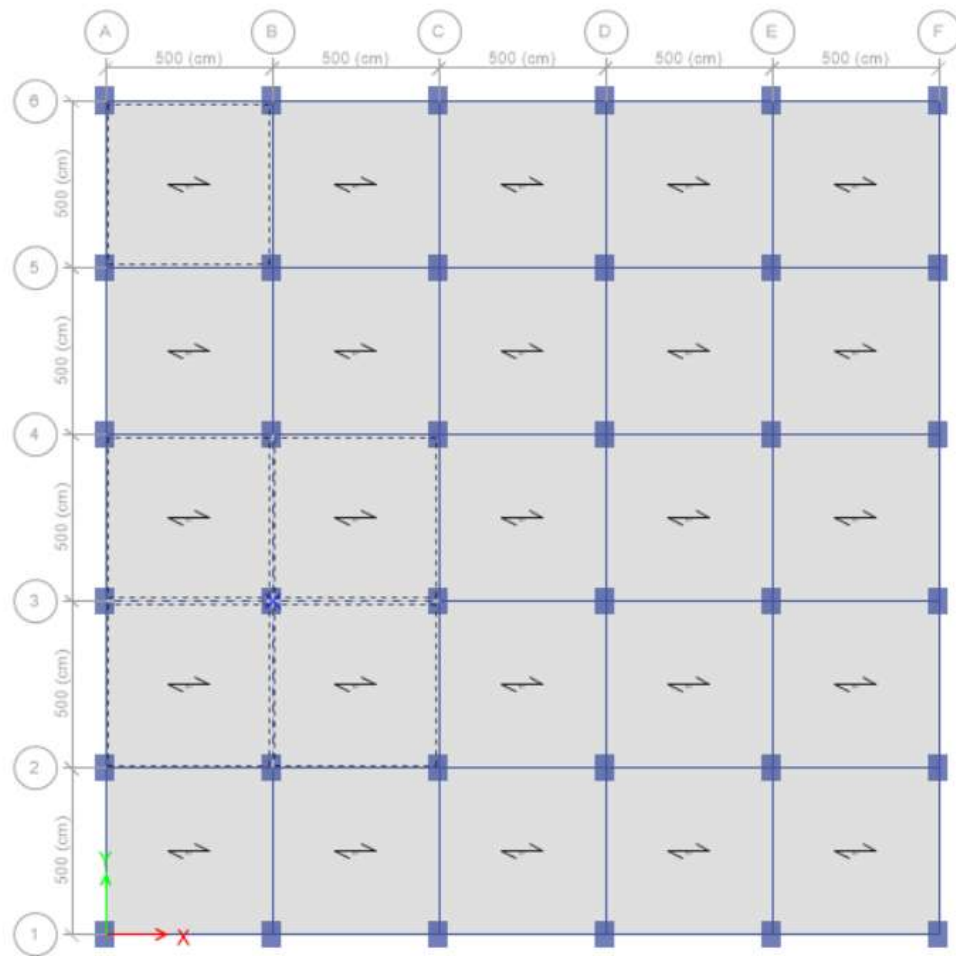


Figure1. Model Plane.

The structure was subjected to two types of loads: dead load (300 kg/m²) and live load (200 kg/m²), in addition to the self-weight of the structural elements. A model was constructed using ETABS and prepared for analysis incorporating dead loads, live loads, and response spectrum loading, in order to conduct a comparison based on the type of soil used.

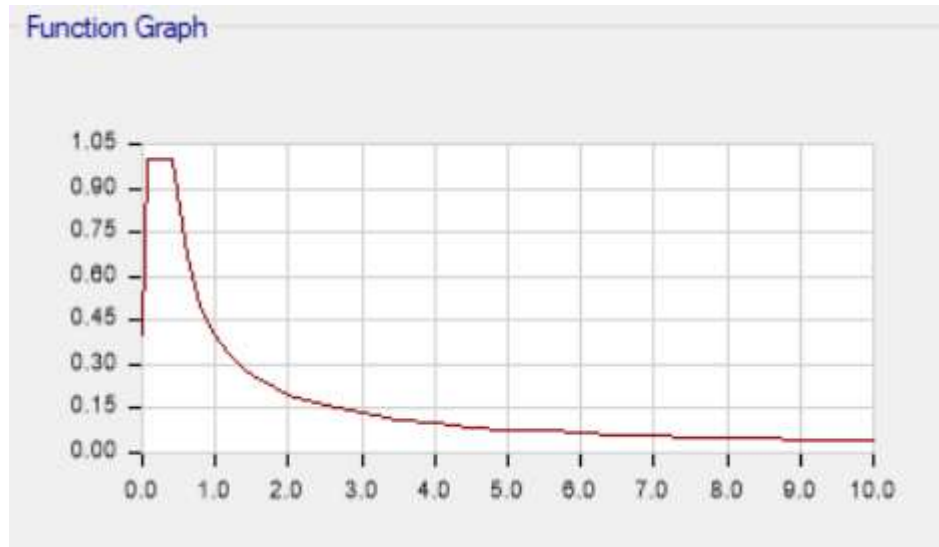


Figure 2. Response Spectrum.

Results and Discussions

Through the structural analysis process, we will first compare the five models using charts and numerical values. This comparison covers the induced base shear, the displacement at the top story, and the maximum tensile and compressive forces in the columns (including their locations). The model analyzed is illustrated in the following figure.

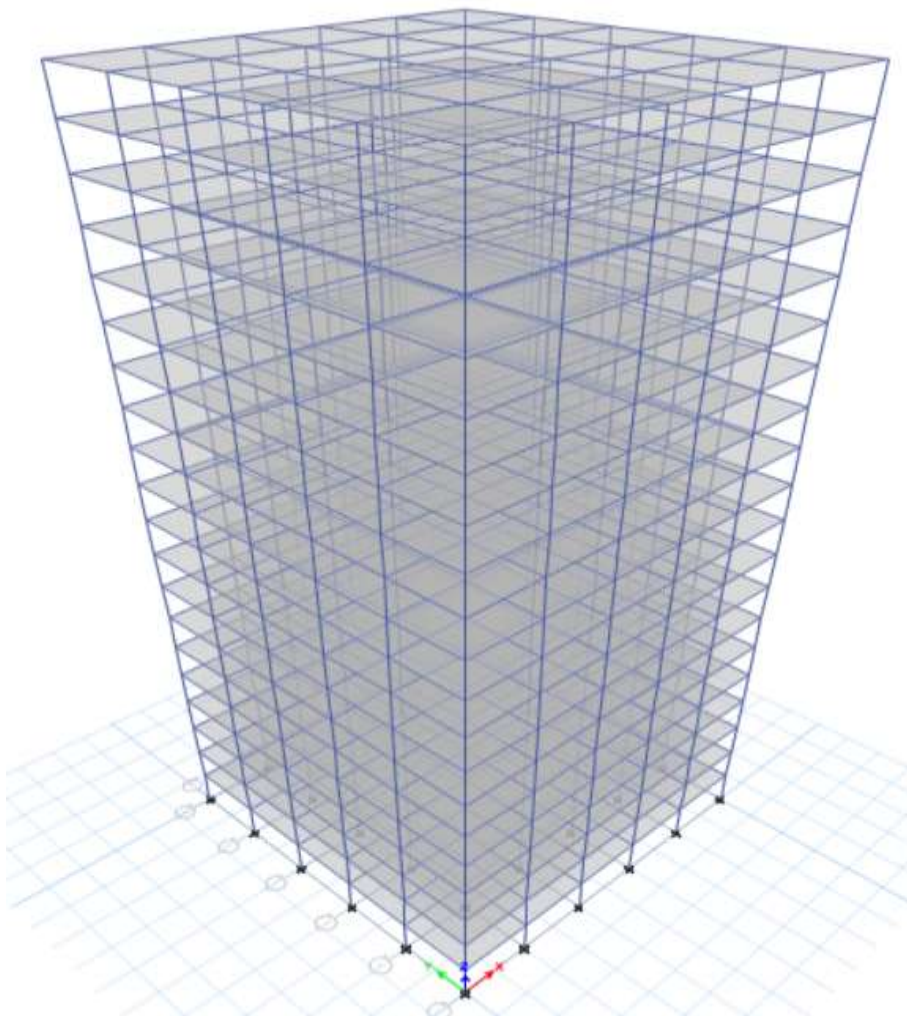
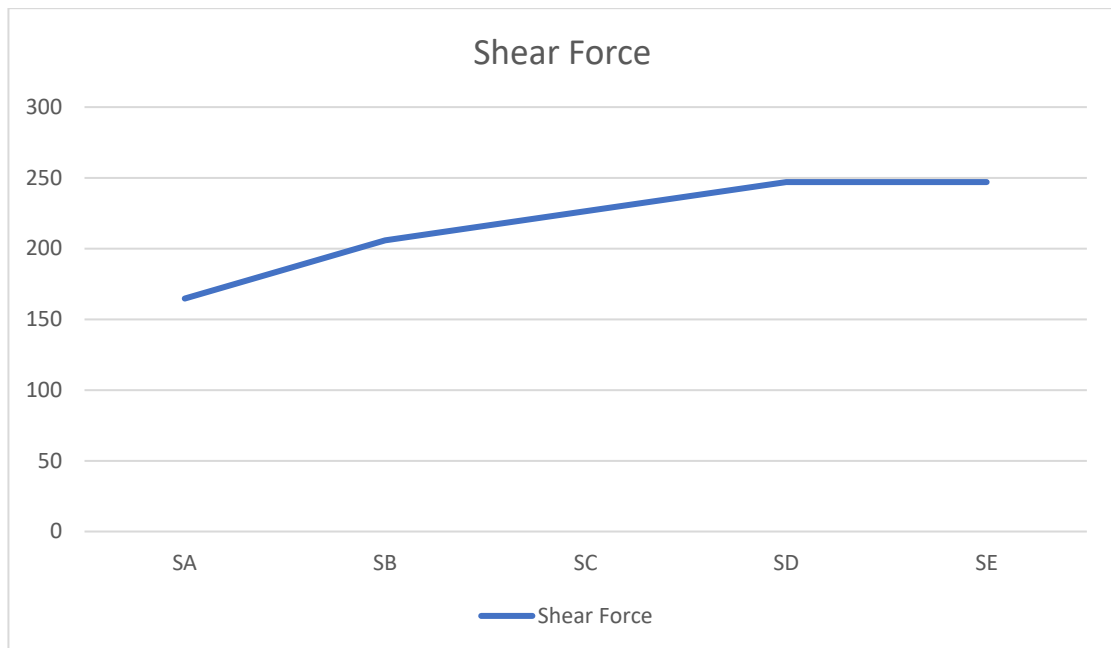


Figure 3. Model

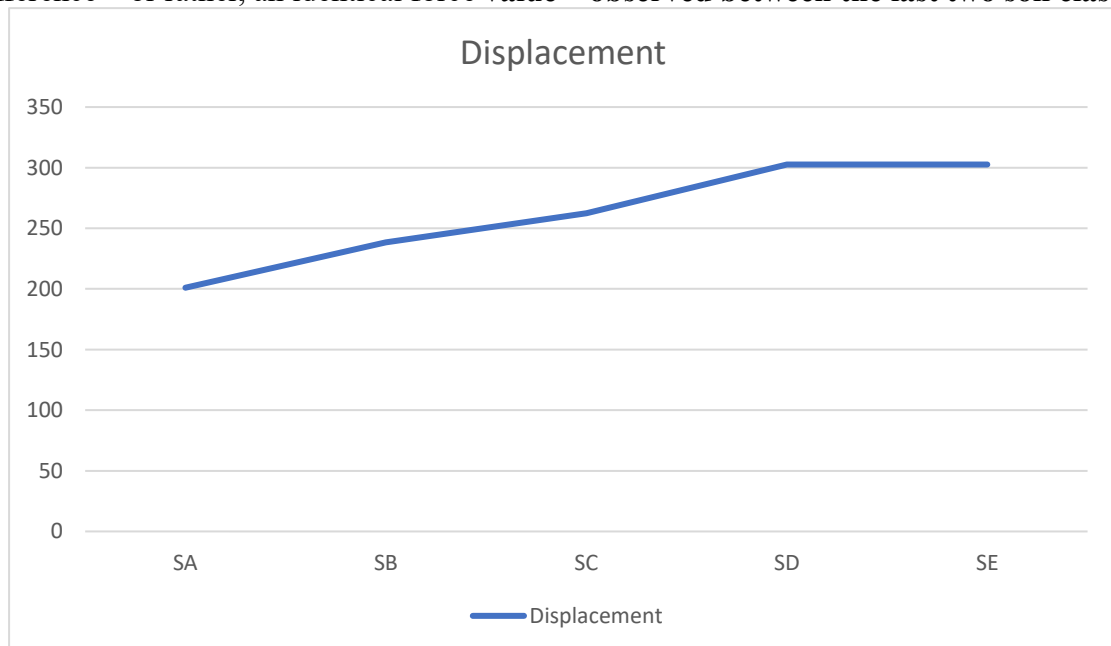
Shear Force:

The following chart illustrates the variations in shear force resulting from static loading as the soil classification shifts from Class I to Class II and then to Class III. Shear force increases with the soil class—that is, as soil bearing capacity decreases. This increase is significant, reaching approximately 100% between the first and last soil classes. Notably, there was virtually no difference in shear force between the final two soil classes; the values were essentially identical.



MAX Moment in Column

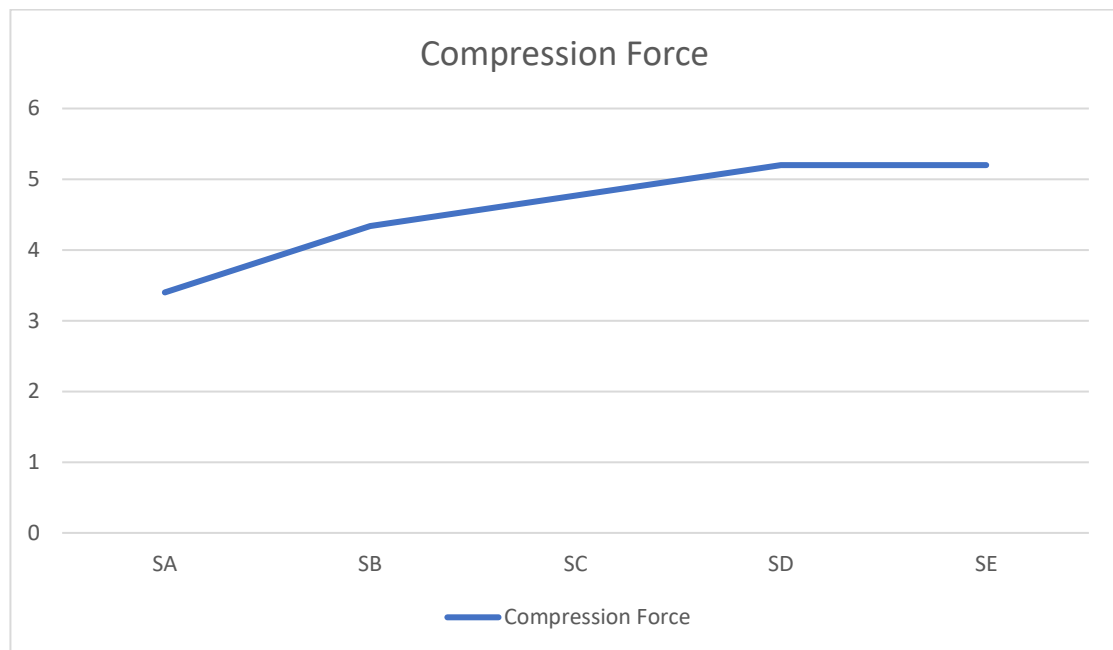
The following diagram illustrates the changes in the moment generated at the base of the first-floor columns due to static forces. It shows how these forces increase as the soil classification shifts from Class I to Class II and then to Class III—meaning the force rises as the soil class increases (i.e., as soil bearing capacity decreases). This increase is significant, reaching approximately 50% between the first and last soil classes; notably, there was virtually no difference—or rather, an identical force **value**—**observed between the last two soil classes**.



Max Displacement

The following chart illustrates the changes in displacement resulting from static loading, showing how displacement increases as the soil class shifts from Class I to Class II and then to Class III; specifically, displacement at the top of the building rises with the soil class—reflecting a decrease in soil bearing capacity. This increase is significant, reaching approximately 25% between the first and last soil classes. Notably, there was virtually no difference in displacement between the last two soil classes, indicating identical results.

A correspondence in forces was also observed between the models, regarding both self-weight and the forces resulting from it.



Conclusion

This study analyzed the static soil characteristics of a regular 20-story building under seismic loading using ETABS software, yielding the following results:

Base shear force doubles when transitioning from stiff soil to soft soil, thereby amplifying seismic forces within the structural system.

Bending moments in columns increase by up to 50% when shifting from stiff to soft soil.

Displacement increases by approximately 25% when transitioning from stiff to soft soil.

No significant difference was observed between soil classes SD and SE.

Based on this research, we recommend further analysis of these models using dynamic methods—such as time-history analysis and pushover analysis—to better understand the impact of soil conditions on their behavior.

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