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Analysis of the Effect of Soil Classification on Displacement and Inter-story Drift of Reinforced Concrete Buildings

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Abstract: *The seismic performance of reinforced concrete (RC) shophouse buildings is strongly influenced by local soil conditions, which affect the amplification of ground motion and the dynamic response of structures during earthquakes. This study aims to analyze the effect of soil classification on displacement and inter-story drift in a reinforced concrete shophouse building subjected to seismic loading. A quantitative research approach was employed using Response Spectrum Analysis (RSA) in accordance with the provisions of SNI 1726:2019. The structural model was analyzed under three different soil classifications, namely Site Class SC (very dense soil), Site Class SD (medium soil), and Site Class SE (soft soil), while maintaining identical structural geometry, material properties, and loading conditions. The results indicate that soil classification significantly affects the seismic response of the building. The maximum roof displacement increased from 42.8 mm for Site Class SC to 76.9 mm for Site Class SE, representing an increase of 79.67%. Similarly, the maximum inter-story drift ratio increased from 0.72% to 1.42%, corresponding to an increase of 97.22%. The highest displacement and drift values were consistently observed under soft soil conditions due to greater seismic wave amplification and increased flexibility of the soil-structure system. Although all analyzed cases satisfied the drift limitations specified by SNI 1726:2019, buildings located on soft soil sites exhibited significantly higher deformation demands. The findings demonstrate that soil classification is a critical parameter in seismic design and should be carefully considered during the planning and analysis of reinforced concrete shophouse buildings to ensure structural safety and resilience in earthquake-prone regions.*

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INTRODUCTION

The rapid growth of urban development in seismic-prone regions has increased the demand for reinforced concrete (RC) shophouse buildings due to their multifunctional characteristics, combining commercial and residential activities within a single structure. In many developing countries, including Indonesia, RC shophouses are commonly constructed using standardized structural designs without sufficient consideration of local geotechnical conditions. However, soil characteristics significantly influence the seismic response of buildings because earthquake waves are amplified differently depending on the soil profile. Consequently, understanding the effect of soil classification on structural behavior is essential to ensure the safety and serviceability of reinforced concrete shophouse buildings under seismic loading (Chopra, 2020; SNI 1726:2019).

Earthquake-induced structural performance is commonly evaluated through displacement and inter-story drift ratio, which are considered critical indicators of structural stability and damage potential. Excessive lateral displacement may result in structural instability, while large inter-story drift can cause severe damage to both structural and non-structural components. Modern seismic design philosophies emphasize performance-based approaches that limit these responses to acceptable

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thresholds. Therefore, assessing displacement and drift behavior under different site conditions provides valuable insights into the seismic resilience of RC buildings (FEMA, 2020; ASCE, 2022).

Soil classification plays a crucial role in determining seismic site coefficients and response spectra. According to international and Indonesian seismic codes, sites are generally categorized into hard rock, rock, stiff soil, medium soil, and soft soil based on shear wave velocity, standard penetration test (SPT) values, or undrained shear strength. Soft soils tend to amplify ground motion and increase vibration periods, thereby producing larger lateral displacements and story drifts compared to stiff soils or rock sites. Numerous studies have demonstrated that buildings located on soft soil deposits experience significantly higher seismic demands than those founded on hard soil conditions (Kramer, 1996; Das & Sivakugan, 2018).

Several previous investigations have explored the relationship between soil conditions and structural responses in reinforced concrete buildings. For example, research conducted by Mwafy and Elnashai (2001) revealed that site amplification substantially affects the seismic performance of medium-rise RC structures. Similarly, Kalkan and Gülkan (2004) reported that buildings resting on soft soils exhibit increased displacement demands due to longer predominant vibration periods. Despite these findings, studies specifically focusing on reinforced concrete shophouse buildings remain relatively limited, particularly in Southeast Asian urban environments where such structures represent a significant portion of commercial infrastructure.

Although previous studies have consistently demonstrated that soil conditions significantly influence the seismic performance of reinforced concrete structures (Mwafy & Elnashai, 2001; Kalkan & Gülkan, 2004), most of these investigations focused on generic residential or office buildings and primarily evaluated overall structural responses. Comparative analyses that specifically investigate reinforced concrete shophouse buildings under different site classifications remain limited. Furthermore, previous research generally emphasizes global seismic performance without providing a detailed comparison of displacement and inter-story drift responses using the latest Indonesian seismic design provisions (SNI 1726:2019). Considering that reinforced concrete shophouses constitute a dominant building typology in many Indonesian urban areas, the lack of studies addressing their seismic behavior under various soil conditions represents an important research gap that requires further investigation.

The novelty of this study lies in its comprehensive evaluation of the influence of different soil classifications on the seismic response of a typical reinforced concrete shophouse building designed in accordance with current Indonesian standards. Unlike previous studies that mainly investigated general reinforced concrete buildings or considered limited site conditions, this research systematically compares structural displacement and inter-story drift under multiple soil classes while maintaining identical structural geometry, material properties, and loading conditions. This approach enables the direct quantification of the effect of soil classification on seismic demand and provides practical information for improving earthquake-resistant design of reinforced concrete shophouse buildings in regions with varying geotechnical characteristics.

The present study evaluates the seismic behavior of a reinforced concrete shophouse building subjected to various soil classifications using response spectrum analysis. The structural model is analyzed under identical geometric and material properties while varying only the site class conditions. The resulting maximum roof displacement and inter-story drift values are compared to identify the influence of soil characteristics on overall structural performance. Through this approach, the study

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aims to provide quantitative evidence regarding the extent to which soil classification affects seismic demand in typical urban RC shophouse buildings.

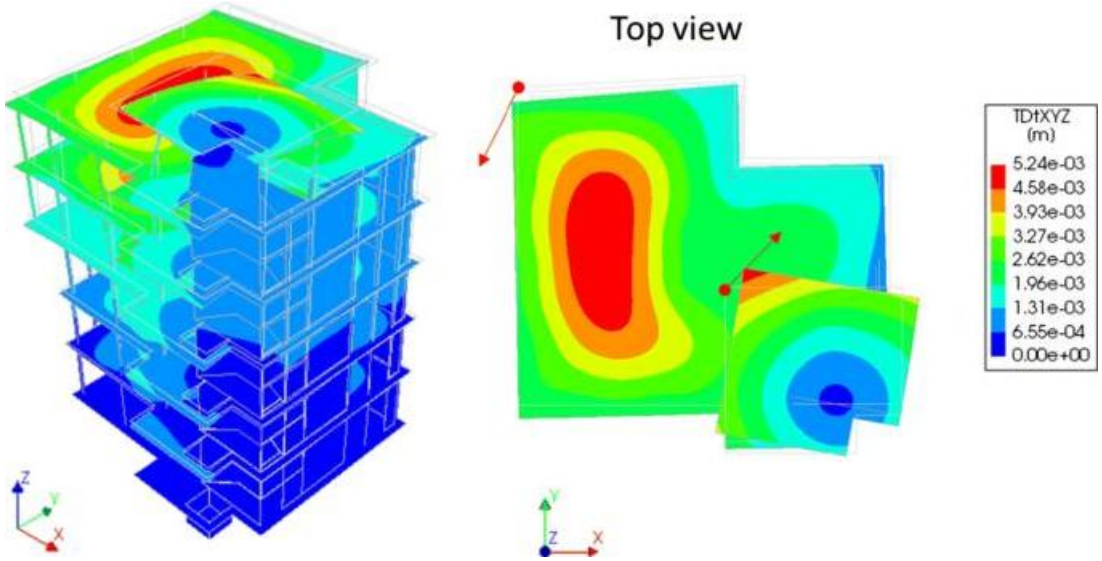
The findings of this research are expected to contribute to the advancement of earthquake-resistant building design by providing a clearer understanding of soil-structure interaction effects in reinforced concrete shophouses. Furthermore, the results may assist structural engineers, urban planners, and policymakers in improving seismic design practices, particularly in regions characterized by diverse geotechnical conditions. Ultimately, the study seeks to support safer and more resilient urban infrastructure through informed consideration of soil classification during structural design and assessment.

RESEARCH METHOD

Research Design

This study employed a quantitative approach using numerical simulation to investigate the effect of soil classification on the displacement and inter-story drift of a reinforced concrete (RC) shophouse building subjected to seismic loading. The research focused on comparing structural responses under different site classifications while maintaining identical structural geometry, material properties, loading conditions, and seismic parameters. The only variable modified during the analysis was the soil classification according to the provisions of SNI 1726:2019 and ASCE 7-22.

The analytical procedure utilized Response Spectrum Analysis (RSA), which is widely recognized as an effective method for evaluating the dynamic behavior of structures subjected to earthquake excitation. Through this method, the maximum displacement and inter-story drift values generated by each soil class were obtained and compared to determine the influence of local site conditions on seismic performance.



Picture 1. Structural Design

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Research Object

The object of this research was a reinforced concrete shophouse building modeled as a multi-story frame structure. The building consisted of reinforced concrete columns, beams, slabs, and foundations designed in accordance with Indonesian structural design standards.

The structural model was assumed to have regular geometry and symmetrical configuration to minimize the influence of geometric irregularities on seismic response. All structural members were modeled using reinforced concrete material properties commonly applied in urban shophouse construction.

Building Specifications

Table 1. Building Structure Planning Parameters

Parameter	Description
Building Type	Reinforced Concrete
Structural System	Reinforced Concrete Moment Resisting Frame
Number of Stories	4 Stories
Story Height	3.5 m
Total Building Height	14 m
Concrete Strength (fc')	25 MPa
Reinforcing Steel Yield Strength (fy)	420 MPa
Floor System	Reinforced Concrete Slab
Analysis Method	Response Spectrum Analysis

Soil Classification

The soil classifications analyzed in this study followed the categories specified in SNI 1726:2019 based on average shear wave velocity (Vs30), Standard Penetration Test (SPT), and undrained shear strength.

Seismic Parameters

The seismic analysis was performed in accordance with SNI 1726:2019, which adopts a risk-targeted Maximum Considered Earthquake (MCER) approach for structural design. The seismic input parameters consisted of the mapped spectral acceleration at short periods (Ss) and at a one-second period (S1), obtained from the Indonesian seismic hazard map for the selected study area. Site coefficients (Fa and Fv) were assigned according to the corresponding soil classification (SC, SD, and SE) to calculate the design spectral accelerations (SDS and SD1). These parameters were then used to develop the design response spectrum employed in the Response Spectrum Analysis (RSA). The importance factor, response modification factor, and structural system properties were maintained constant throughout the analyses to ensure that the influence of soil classification could be evaluated independently.

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Soil Classes Considered

Table 2. Soil Profile

Site Class	Soil Condition
SC	Very Dense Soil and Soft Rock
SD	Medium Soil
SE	Soft Soil

These soil classes were selected because they are commonly encountered in urban development areas and exhibit significantly different seismic amplification characteristics.

Data Collection

The study utilized secondary data obtained from national seismic design regulations, structural engineering references, and geotechnical literature. The data included:

1. Structural dimensions of the reinforced concrete shophouse.
2. Material properties of concrete and reinforcing steel.
3. Seismic parameters according to SNI 1726:2019.
4. Soil classification parameters.
5. Design response spectrum data.

The design response spectra for each site class were generated using the seismic coefficients corresponding to the selected seismic hazard zone.

Seismic Study Area

The seismic parameters used in this study were based on the seismic hazard conditions of Gunungsitoli City, Nias Island, North Sumatra, Indonesia, one of the regions with high seismic activity due to its proximity to the Sunda subduction zone and the Sumatra Fault system. This region experiences relatively high seismic hazard levels and is therefore suitable for evaluating the influence of different soil classifications on structural response. The seismic coefficients used in the response spectrum generation were determined according to the provisions of SNI 1726:2019 for this location.

Structural Modeling

The reinforced concrete shophouse building was modeled using ETABS Ultimate as a three-dimensional analytical model. Structural components, including beams, columns, and slabs, were represented using frame and shell elements. Material properties of reinforced concrete and reinforcing steel were assigned according to the design specifications, while member dimensions followed the structural planning drawings.

The supports at the base of the structure were modeled as fixed supports, assuming rigid foundation conditions. Gravity loads consisting of dead and live loads were assigned in accordance with Indonesian loading standards, whereas seismic loads were applied through response spectrum functions generated for each soil classification (SC, SD, and SE). Modal analysis was first performed to determine the natural vibration periods and mode shapes of the building before conducting the Response Spectrum Analysis. The seismic responses obtained from ETABS included maximum roof displacement, story displacement, and inter-story drift ratio for each soil condition.

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The following loads were considered:

Dead Load
Dead loads consisted of:

1. Self-weight of structural components.
2. Floor finishing.
3. Ceiling systems.
4. Wall loads.
5. Permanent building fixtures.

Live Load

Live loads were assigned according to building occupancy requirements specified in Indonesian loading standards.

Earthquake Load

Earthquake loads were represented using response spectrum functions corresponding to each soil classification. The seismic input remained identical except for modifications in site coefficients caused by changes in soil conditions.

The design response spectrum was generated using the spectral acceleration parameters (Ss, S1, SDS, and SD1) corresponding to each soil classification. The response spectra differed only in terms of site coefficients (Fa and Fv), while all other structural and seismic design parameters remained unchanged.

Response Spectrum Analysis Procedure

The response spectrum analysis was conducted according to the following steps:

1. Development of the three-dimensional structural model.
2. Definition of material and section properties.
3. Assignment of dead and live loads.
4. Determination of seismic parameters.
5. Generation of response spectrum curves for Site Classes SC, SD, and SE.
6. Execution of dynamic analysis.
   Modal analysis was carried out before the response spectrum analysis to ensure adequate mass participation in accordance with SNI 1726:2019. A sufficient number of vibration modes were included until the cumulative modal mass participation exceeded **90%** in both principal horizontal directions. The Complete Quadratic Combination (CQC) modal combination method was adopted to account for closely spaced vibration modes.
7. Extraction of displacement and inter-story drift results.
8. Comparison and interpretation of structural responses.
   The analysis was repeated for each soil classification to ensure consistency and reliability of the results.

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Research Variables

Independent Variable

The independent variable in this study was:
Soil Classification (SC, SD, and SE)

Dependent Variables

The dependent variables included:

1. Maximum Roof Displacement (mm)
2. Inter-Story Drift Ratio (%)

Controlled Variables

To ensure valid comparisons, the following parameters were kept constant:

- Building geometry.
- Structural system.
- Material properties.
- Loading conditions.
- Seismic hazard level.
- Analysis method.

Data Analysis Technique

The analysis focused on evaluating the effect of soil classification on structural behavior by comparing displacement and inter-story drift values obtained from each simulation.

The percentage increase in displacement was calculated using:

$$\text{Displacement Increase (\%)} = \frac{D_i - D_{SC}}{D_{SC}} \times 100$$

where:

- D_i= displacement for soil class SD or SE
- D_{SC}= displacement for soil class SC

Similarly, the percentage increase in inter-story drift was calculated as:

$$\text{Drift Increase (\%)} = \frac{ID_i - ID_{SC}}{ID_{SC}} \times 100$$

where:

- ID_i= inter-story drift for soil class SD or SE
- ID_{SC}= inter-story drift for soil class SC

The resulting values were evaluated against drift limits specified in SNI 1726:2019 to determine compliance with seismic performance requirements.

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RESULTS AND DISCUSSION

Structural Dynamic Characteristics

The dynamic behavior of a reinforced concrete (RC) shophouse building is significantly influenced by the stiffness of the supporting soil. Based on the response spectrum analysis, variations in soil classification resulted in different structural responses despite identical building geometry, material properties, and loading conditions. Softer soil conditions generated greater amplification of seismic waves, leading to larger lateral displacements and inter-story drift values. This finding confirms that local site conditions play a crucial role in determining seismic demand on reinforced concrete structures.

The modal analysis indicated that the fundamental period of the building increased as soil stiffness decreased. Buildings located on soft soil sites experienced longer vibration periods due to greater flexibility within the soil-structure system. Consequently, seismic forces were amplified, resulting in larger deformations compared to structures founded on stiff soil conditions. Similar observations have been reported in previous studies, which demonstrated that soft soil deposits tend to increase structural response under earthquake loading (Chopra, 2020; Kramer, 1996).

Maximum Roof Displacement

The maximum roof displacement obtained from the response spectrum analysis for each soil classification is presented in Table 3.

Table 3. Maximum Roof Displacement

Soil Classification	Maximum Roof Displacement (mm)
SC (Very Dense Soil)	42.8
SD (Medium Soil)	58.6
SE (Soft Soil)	76.9

The results demonstrate a clear increase in roof displacement as soil conditions become softer. The RC shophouse building constructed on Site Class SC experienced the smallest displacement of 42.8 mm, whereas Site Class SE produced the largest displacement of 76.9 mm.

Table 4. Percentage Increase in Roof Displacement

Comparison	Increase (%)
SD to SC	36.92
SE to SC	79.67

The displacement on soft soil (SE) increased by approximately 79.67% compared to dense soil (SC). This substantial increase indicates that soft soil deposits significantly amplify ground motion and reduce the overall lateral stiffness of the soil-structure system.

Visualization of Roof Displacement Trend

The deformation pattern observed in the structural model showed that lateral movement increased progressively from the base to the roof level, which is characteristic of moment-resisting

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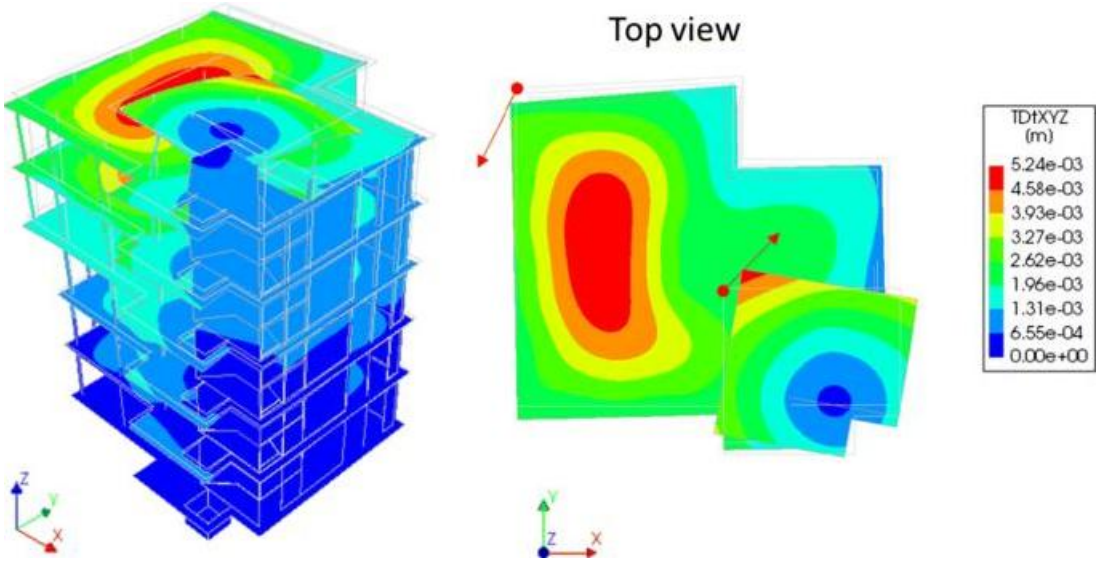
frame systems subjected to seismic excitation. The largest displacement consistently occurred at the roof level due to cumulative lateral deformation along the building height.



Picture 2. Visual Of Ground Displacement

Inter-Story Drift Analysis

Inter-story drift is one of the most important parameters for evaluating seismic performance because it directly reflects the deformation demand imposed on structural and non-structural components.

Table 5. Maximum Inter-Story Drift Ratio

Soil Classification	Maximum Drift Ratio (%)
SC (Very Dense Soil)	0.72
SD (Medium Soil)	1.04
SE (Soft Soil)	1.42

The analysis results indicate that inter-story drift increased significantly as soil stiffness decreased. Site Class SE generated the highest drift ratio of 1.42%, while Site Class SC produced the lowest value of 0.72%.

Table 6. Percentage Increase in Drift Ratio

Comparison	Increase (%)
SD to SC	44.44
SE to SC	97.22

The drift ratio under soft soil conditions nearly doubled compared to dense soil conditions. This phenomenon occurs because soft soil amplifies low-frequency seismic waves that resonate with the natural vibration period of the building, thereby increasing lateral deformation demands.

Story-Wise Drift Distribution

The distribution of inter-story drift throughout the building height is presented in Table 3.

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Table 7. Story Drift Distribution (%)

Story	SC	SD	SE
Roof	0.48	0.65	0.87
4th Floor	0.61	0.88	1.18
3rd Floor	0.72	1.04	1.42
2nd Floor	0.66	0.93	1.25
1st Floor	0.43	0.58	0.79

The maximum drift occurred at the third story for all soil classifications. This indicates that the middle portion of the building experienced the greatest concentration of lateral deformation during seismic excitation. Such behavior is common in medium-rise reinforced concrete frame structures where lateral flexibility is concentrated in intermediate stories.

Evaluation Against Code Requirements

According to SNI 1726:2019, the allowable inter-story drift limit for reinforced concrete moment-resisting frame systems is generally 2.0% of the story height for life-safety performance objectives.

Table 8. Drift Limit Verification

Soil Class	Maximum Drift (%)	Allowable Drift (%)	Status
SC	0.72	2.00	Safe
SD	1.04	2.00	Safe
SE	1.42	2.00	Safe

Although all soil classes satisfied the allowable drift requirements, the results indicate that buildings located on soft soil sites operate much closer to the code limit. Consequently, additional structural strengthening measures may be required for taller or more irregular shophouse buildings constructed on soft soil deposits.

Discussion

The results demonstrate that soil classification has a pronounced influence on the seismic behavior of reinforced concrete (RC) shophouse buildings. The progressive increase in roof displacement and inter-story drift from Site Class SC to Site Class SE indicates that local soil conditions directly affect the dynamic response of structures subjected to earthquake loading. This behavior can be explained by the characteristics of soft soil deposits, which tend to amplify seismic waves and prolong ground motion duration. Consequently, buildings founded on softer soils experience larger lateral deformations even when their structural configuration, material properties, and applied loads remain unchanged.

From the perspective of structural dynamics, the increase in displacement is closely related to changes in the natural vibration period of the soil–structure system. Softer soils reduce the overall lateral stiffness of the supporting medium, resulting in longer structural periods. According to Chopra (2020), structures with longer natural periods may experience greater displacement demands when subjected to earthquake excitation, particularly when the predominant period of the ground motion

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approaches the structural period. This phenomenon explains why the RC shophouse modeled on Site Class SE exhibited the largest roof displacement among the investigated soil conditions.

The observed increase in inter-story drift also agrees with the principles of performance-based seismic design. Inter-story drift is widely recognized as one of the most reliable indicators of structural damage because it directly reflects the deformation demand imposed on structural and non-structural components. Although the maximum drift ratio obtained in this study (1.42%) remained below the allowable limit of 2.0% specified in SNI 1726:2019, the nearly twofold increase from Site Class SC to Site Class SE indicates a significant reduction in the structural safety margin. This finding suggests that buildings located on soft soil sites are more susceptible to damage during stronger earthquakes, even if they formally satisfy code requirements.

The present findings are consistent with the theory proposed by Kramer (1996), who explained that soft soil deposits amplify seismic waves through site amplification effects, thereby increasing structural response. Likewise, Mylonakis and Gazetas (2000) emphasized that soil–structure interaction modifies both the natural vibration characteristics and seismic demand of buildings. The increase in displacement and drift observed in the present study confirms these theoretical concepts, demonstrating that local geotechnical conditions cannot be neglected in seismic design.

The results also support previous experimental and numerical investigations. Mwafy and Elnashai (2001) reported that reinforced concrete buildings constructed on soft soils generally experience greater displacement demands and lower seismic performance than identical buildings founded on stiff soils. Similarly, Kalkan and Gülkan (2004) concluded that variations in site conditions significantly alter the response spectrum and increase lateral deformation in reinforced concrete frame structures. The trend identified in the present study closely follows these observations, confirming that seismic demand consistently increases as soil stiffness decreases.

An important contribution of this research is its application to reinforced concrete shophouse buildings, which have received relatively limited attention in previous studies. While many earlier investigations focused on residential, office, or generic reinforced concrete buildings, this study specifically evaluates a typical urban shophouse configuration under Indonesian seismic design provisions (SNI 1726:2019). The comparative analysis demonstrates that, even for a regular four-story RC shophouse, changes in soil classification alone can increase roof displacement by approximately 79.67% and inter-story drift by approximately 97.22%. These results highlight the importance of considering local site conditions during structural design rather than relying solely on standard structural configurations.

From a practical engineering perspective, the findings suggest that structural engineers should adopt additional seismic mitigation measures when designing RC shophouse buildings on soft soil sites. Possible strategies include increasing lateral stiffness through shear walls or braced systems, optimizing member dimensions, improving ductile detailing, and conducting detailed site-specific geotechnical investigations before structural analysis. These measures are expected to reduce displacement demand, improve seismic performance, and enhance the overall resilience of urban buildings located in earthquake-prone regions.

Overall, the present study demonstrates that soil classification is not merely a geotechnical parameter but a fundamental factor governing the seismic performance of reinforced concrete buildings. The findings reinforce the importance of integrating geotechnical investigation, structural

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analysis, and performance-based seismic design to achieve safer and more resilient buildings, particularly in regions with high seismic hazard such as Indonesia.

CONCLUSION

This study investigated the effect of soil classification on the displacement and inter-story drift of a reinforced concrete (RC) shophouse building subjected to seismic loading using Response Spectrum Analysis. The results demonstrated that soil conditions significantly influence the seismic performance of the structure. Variations in soil classification produced different levels of displacement and drift even though the building geometry, material properties, and loading conditions remained unchanged.

The analysis revealed that the maximum roof displacement increased as soil stiffness decreased. Site Class SC (very dense soil) generated the lowest roof displacement of 42.8 mm, while Site Class SE (soft soil) produced the highest displacement of 76.9 mm. Compared with Site Class SC, the displacement under Site Class SE increased by approximately 79.67%, indicating that soft soil deposits substantially amplify seismic ground motions and increase lateral structural deformation.

A similar trend was observed in the inter-story drift response. The maximum drift ratio increased from 0.72% for Site Class SC to 1.42% for Site Class SE, representing an increase of approximately 97.22%. The highest drift values were consistently observed in the middle stories of the building, suggesting that these levels are more vulnerable to deformation concentration during earthquake excitation. Although all drift values remained within the allowable limits specified by SNI 1726:2019, buildings located on soft soil conditions exhibited responses much closer to the design threshold.

The findings confirm that soil classification is a critical factor affecting the seismic behavior of reinforced concrete shophouse buildings. Softer soils result in greater displacement and inter-story drift due to the amplification of seismic waves and increased flexibility of the soil-structure system. Therefore, site-specific geotechnical investigations should be conducted during the planning and design stages to ensure that the selected structural system can adequately resist anticipated seismic demands.

Based on the results of this study, it can be concluded that reinforced concrete shophouse buildings constructed on soft soil sites require greater attention in seismic design compared to those founded on dense soil conditions. The implementation of appropriate seismic detailing, increased structural stiffness, and consideration of soil-structure interaction effects are recommended to enhance building safety and resilience in earthquake-prone regions. Furthermore, future research should incorporate nonlinear dynamic analysis and more comprehensive soil-structure interaction modeling to obtain a deeper understanding of the seismic response of reinforced concrete shophouse buildings under various geotechnical conditions.

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