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Structural Performance Evaluation of Multi Storey Building, Considering Soil Structure Interaction for Different Soil Conditions using Tekla Structural Designer

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Abstract: During an earthquake, seismic waves travel from the fault plane through the soil to the structure, creating relative motion between the foundation and superstructure—known as Soil-Structure Interaction (SSI). This study analyses the dynamic response of a multi-storey building under seismic loads, focusing on modal, drift, sway, shear, and reinforcement characteristics. The fundamental time period across all cases ranges between 1.23–1.33 seconds, with frequencies of 0.75–0.81 Hz. The first two modes contribute over 78–82% of mass participation, while higher modes account for about 11–12%, indicating a well-represented dynamic behaviour. Storey drift values remain within 1–2 mm, confirming stiffness and stability as per IS 1893 standards. Sway in both directions is nearly identical, showing excellent structural symmetry, with top floor sway varying between 53–96 mm across cases. Storey shear patterns demonstrate predictable behaviour—maximum at upper levels and gradually decreasing toward the base—ensuring efficient lateral load transfer. Reinforcement analysis reveals that beams and columns contribute the majority of steel consumption, with total reinforcement ranging from 201–360 tonnes. Overall, the structure exhibits-controlled deformation, adequate strength, and reliable seismic performance, satisfying both stability and safety requirements.
Keywords: Modal frequencies; Experimental investigation; Seismic drift; Critical sway; Storey forces; Storey shear; Material listing; Tekla structural designer4.

I. INTRODUCTION

Soil–structure interaction (SSI) refers to the way a building and the supporting soil influence each other's behaviour. When soil beneath a foundation is flexible, it affects how the structure responds to loads, and at the same time, the presence of the structure changes how the soil itself behaves. A complete soil–foundation–structure system includes the building's superstructure, its foundation, and the supporting soil, as shown in Figure 1. Because of variations in soil properties, different parts of the foundation may settle unevenly (differential settlement), which can alter the axial forces and bending moments in the building's structural members. Most civil engineering structures have elements that directly rest on the ground. When external forces like earthquakes act on them, the movement of the soil and the movement of the structure are closely linked—they cannot be considered separately. This interaction, where soil behaviour affects structural movements and structural movements in turn influence the soil's response, is known as soil–structure interaction (SSI).

The extent of this interaction depends mainly on two factors: the rigidity of the structure and the load–settlement characteristics of the supporting soil. Over the years, many studies have been carried out to understand and quantify these effects.

In conventional design, SSI effects are often neglected, which is acceptable for light structures built on stiff soils—like low-rise buildings or simple rigid retaining walls. However, for heavy structures on softer soils—such as nuclear power plants, skyscrapers, and highways—the influence of SSI becomes much more significant.

An SSI analysis evaluates how the combined system of soil, foundation, and superstructure responds together to a given earthquake. In simple terms, SSI describes the two-way relationship: soil affects how a structure moves, and the structure's movements affect how the soil responds.

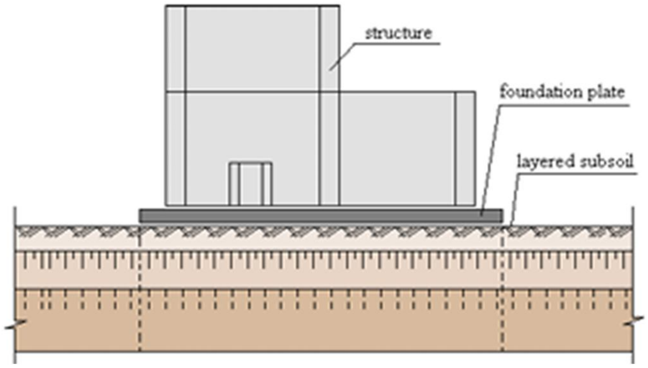

Fig.1: Interaction between structure, foundation plate and soil

II. TEKLA STRUCTURAL DESIGNER

Tekla structural designer (TSD) is advanced structural analysis and design software developed by Trimble. Created for structural engineers to design and analyse buildings, combining both analysis and design into a single, seamless process. Traditional tools require separate modelling, analysis and design platforms, TSD allows engineers to create a single 3D model that integrates all aspects of the structure.

III. PROJECT DESCRIPTION

Table 1: Preliminary structure data

Type of the building	Commercial building
No. of storeys	G+7
Built up area (Square meters)	625
Height of the building (meters)	26.4
Shape of building	Square
Type of soil	Soft, medium and hard
Types of foundation	Isolated footings, mat foundation and pile foundation.
Height of each floor (meters)	3.3
Grade of concrete	M30
Grade of steel	Fe 550
Slab thickness (meters)	0.23
Method of analysis	Response spectrum analysis (RSA)
Column sizes (mm)	750 X 750, 600 X 600, 450 X 450
Beam sizes (mm)	230 X 600

Table 2: Static loads applied

Main wall load	15kN/m (IS:875 part1)	Dead load
Partition wall load	6kN/m (IS:875 part 1)	Dead load
Floor finish	1kN/m^2 (IS:875 part 1)	Dead load
Live load	5kN/m^2 (IS:875 part 2)	Imposed load

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Table 3: Dynamic loads applied

Seismic zone	Zone II
Site class	Type II-medium soils
I-importance factor	1.2
Z-zone factor	0.1
Percentage damping	5%
Damping factor	1.000
Vertical and plan irregularities	No
Analysis procedure to be used	Model response spectrum analysis
Structure type	RC MRF buildings without any masonry infills
T-approx. fundamental period	0.947
R-response reduction factor	3.000

Figures 2 to 4 shows the models on different soil conditions.

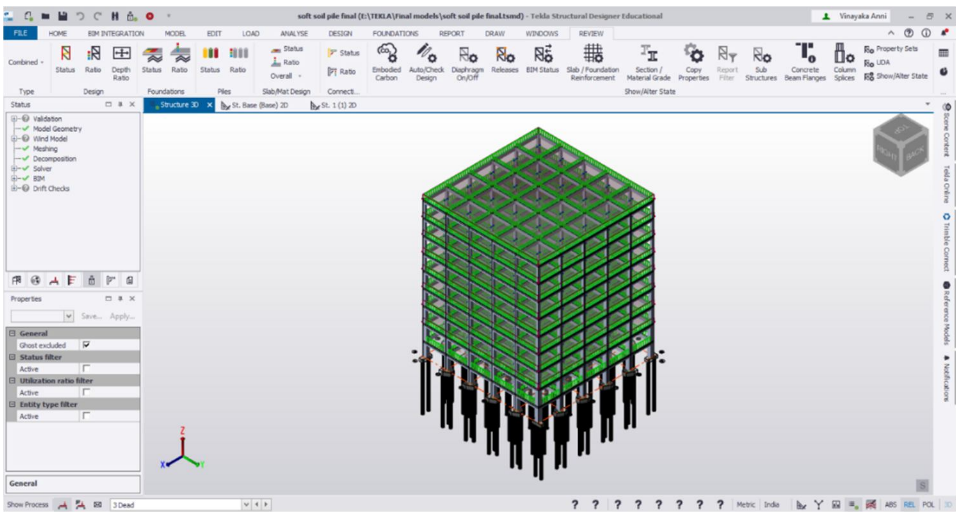

Fig.2: Model on soft soil with pile foundation

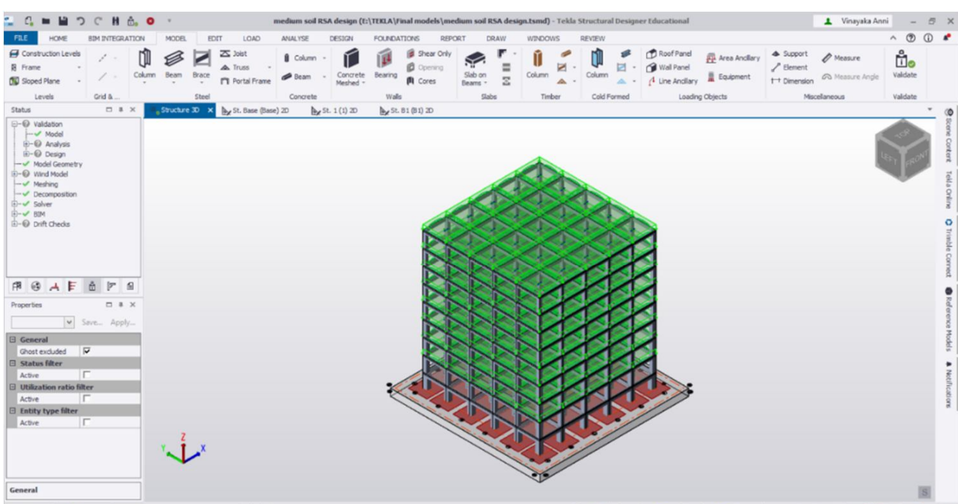

Fig.3: Model on medium soil with mat footing

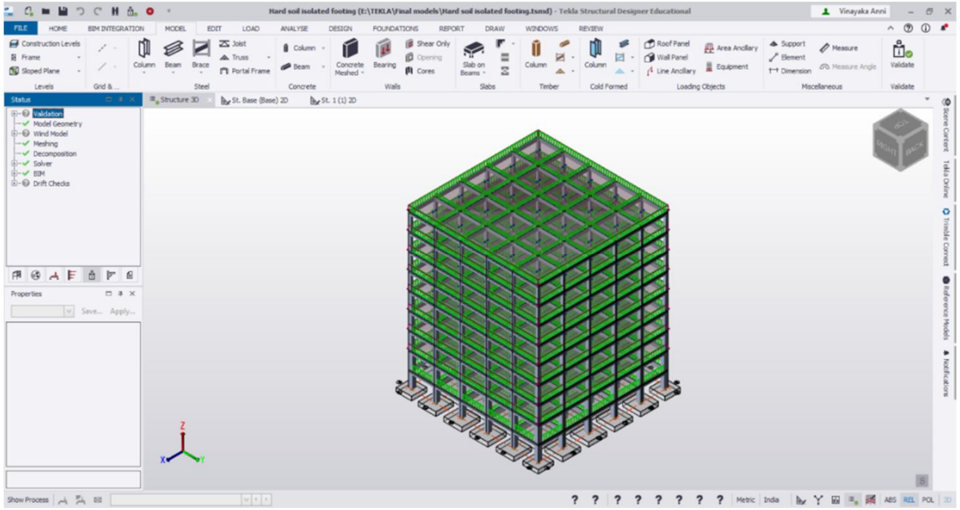

Fig.4: Model on hard soil with isolated footing

IV. RESULTS AND DISCUSSIONS

A. Modal Frequencies

The modal analysis of the structure founded on different soil conditions reveals significant vibrations in dynamic behaviour. For soft soil, the maximum time period is 1.31 seconds, while for medium soil increases to 1.33 seconds, and for hard soil reduces to 1.236 seconds. This indicates that structure on soft soil experience longer vibration cycles due to low stiffness, whereas hard soils enhance stiffness, thereby reducing time period. Correspondingly, the natural frequencies ranges between 0.75 Hz to 0.81 Hz, with higher frequency observed in hard soil, reinforcing effect of increased stiffness. In terms of mass participation, soft soil exhibits a max in Direction 1at Mode 1 (80.67%) in Direction 2 at mode 2 (80.67%). Medium soil, however, shifts dominance, with Direction 1 controlled by Mode 2 (78.85%) and Direction 2 by Mode 1 (78.8%). For hard soil, both direction directions exhibit max participation in Mode 2 and Mode 1 respectively, each above 82%, showing a more efficient distribution of dynamic response. The maximum modal mass also increases gradually from soft (37889.4 kN) to hard soil (38618.9 kN), implying enhanced stability. Overall, hard soil provides better seismic performance due to shorter time periods, high frequencies, and greater modal mass participation.

B. Seismic Drift

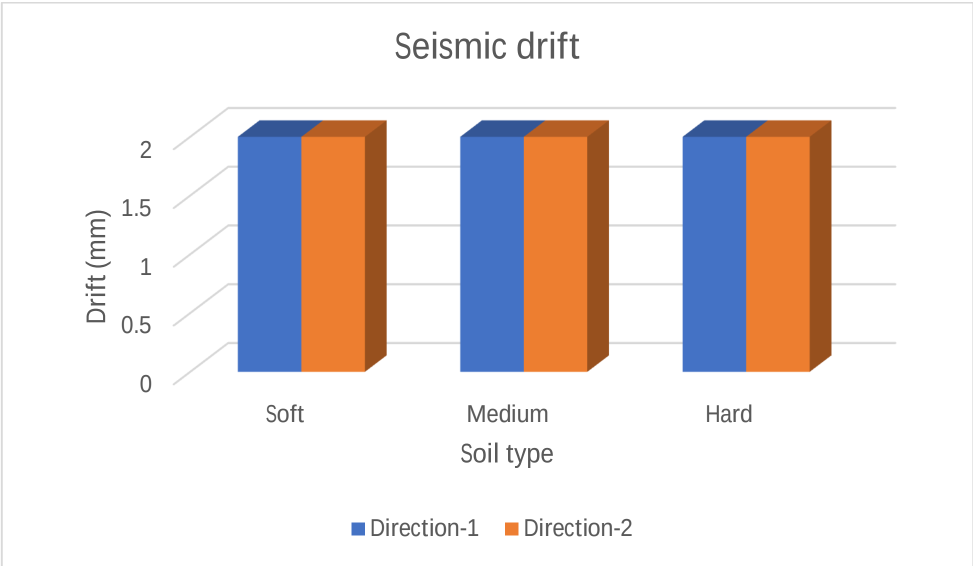

Fig.5: seismic drift for different soil conditions

The seismic drift values shows that building performs consistently across all soil types in both direction 1 and 2. The maximum drift is only 2 mm which reflects strong lateral stiffness and stability. This consistency suggest that soil conditions have little effect on drift performance in this case. Such low drift values ensure the building remains safe, durable and comfortable for occupants. Overall, the structure shows the resistant to seismic movements regardless of supporting soil profile.

C. Critical Sway

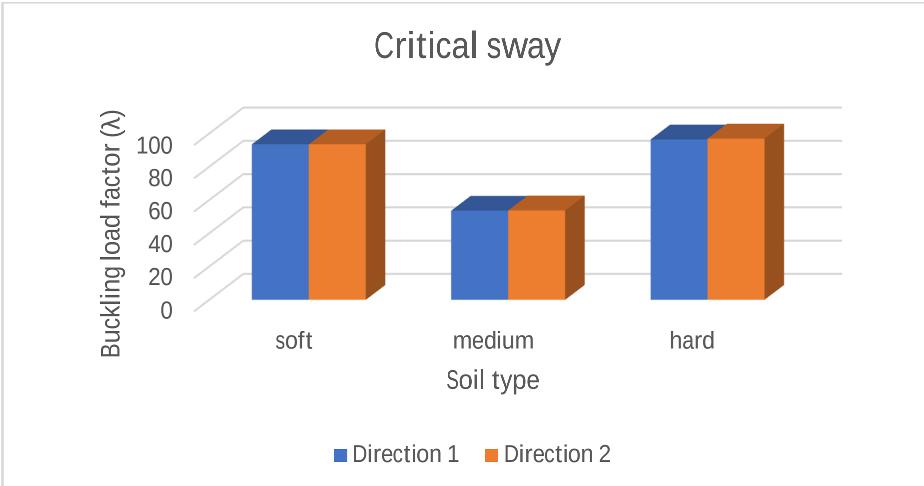

Fig.6: Critical sway for different soil conditions

The sway and twist results highlights influence of soil type on lateral displacement of structure. For soft soil, the maximum sway values are nearly equal in both directions, around 93.5 mm, with a twist of 1 mm. This suggests higher flexibility and greater lateral movements due to reduced stiffness in supporting soil. In contrast, medium soil shows significantly reduced sway values, about 53.6 mm in both directions, while maintain the same twist. This reduction demonstrates that medium soil offers better resistant to lateral displacement, improving overall stability. Interestingly, for hard soil, the sway values increase again, reaching 96.4 mm and 96.9 mm in two directions, with constant twist of 1 mm. this higher sway on hard soil may be attributed to increased stiffness transferring greater seismic energy to structure. Thus, medium soil conditions provide most favourable performance with minimized sway compared to soft and hard soil.

D. Storey Forces

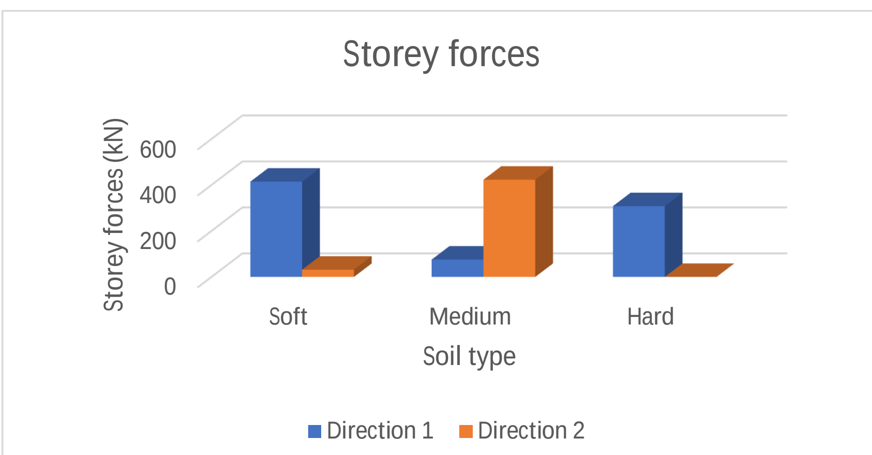

Fig.7: Storey forces for different soil conditions

The results show how type of soil affects the forces act on a building. On soft soil the structure takes very high forces in one direction (414.54 kN) while the other direction carries very little (31.7 kN). This means building tends to sway more strongly in a single direction on soft ground. On medium soil situation is different.

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The forces in first direction are lower (75.38), but in second direction they become high (422.75 kN). This shows that soil shift load to other side, giving a more balanced response. On hard soil, the forces in first direction are again high (308 kN), but in the second direction they are almost zero (0.01 kN). Overall, study proves that soil type greatly changes how forces are shared, with medium soil offering most stable and balanced response.

E. Storey Shear

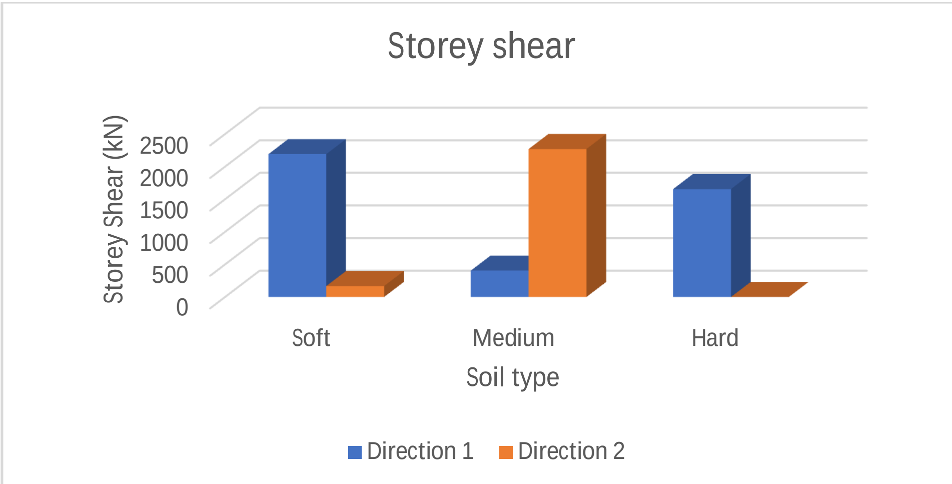

Fig.8: Storey shear for different soil conditions

The maximum shear values clearly demonstrate how soil type influence the seismic response of structure. In soft soil, the shear force is highly concentrated in Direction 1, reaching 2191.57 kN, while Direction 2 remains lower at 167.61. this indicates that soft soil amplifies shear along one primary axis, leading to directional dominance. In medium soil, the behaviour is reversed with direction 1 shear dropping significantly to 404.46 kN, but Direction 2 rising to 2270.04 kN. This shift highlights that medium soil condition redistribute shear more heavily along second direction. For hard soil, shear in Direction 1 is again considerably high at 1655.80 kN, while Direction 2 is negligible at 0.04 kN, showing imbalance. Overall, results prove that soil conditions strongly control how shear forces act, with medium soil creating the highest demand in Direction 2, while soft and hard soils concentrate forces in Direction 1.

F. Material Listing

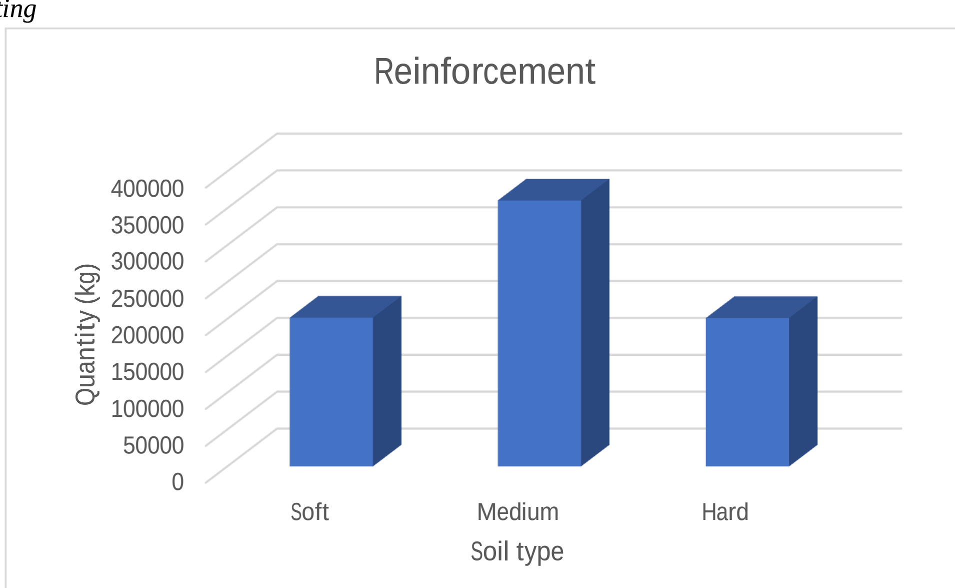

Fig.9: Material listing for different soil conditions

The reinforcement quantities vary considerably with soil type, reflecting how foundation interaction influences material demand. In soft soil, the required reinforcement is about 201,585 kg, while in hard soil it decreases slightly to 201182.29 kg, showing that both conditions require relatively moderate quantities. However, in medium soil, the reinforcement demand rises sharply to 360,566 kg, which is nearly double compared to soft and hard soils. This significant increase suggests that medium soil conditions generate higher stresses within the structural system, leading to the need for additional reinforcement to maintain safety and serviceability. The results also indicate that while soft and hard soils produce similar reinforcement requirements, medium soil imposes more critical design demands due to its stiffness characteristics.

V. CONCLUSION

In this study, we examined how the structure behaves on different soil conditions in RSA seismic design on soft, medium and hard soil conditions. The results were compared through tables and graphs, which provided clear understanding of structural response on different soil conditions, based on these observations the following conclusions were drawn.

1) In soft soil, the maximum time period is 1.31 s, while for medium soil increases to 1.33 s, for hard soil reduces to 1.236 s. This indicates structure on soft soil experience longer vibration cycles due to low stiffness, whereas hard soils enhance stiffness, thereby reducing time period. Correspondingly, the natural frequencies ranges between 0.75 Hz to 0.81 Hz, with higher frequency observed in hard soil. The maximum modal mass also increases gradually from soft (37889.4 kN) to hard soil (38618.9 kN), implying enhanced stability. Overall, hard soil provides better seismic performance due to shorter time periods, high frequencies, and greater modal mass participation.
2) The seismic drift values shows that building performs consistently across all soil types in both direction 1 and 2. The maximum drift is only 2 mm which reflects strong lateral stiffness and stability. This consistency suggest that soil conditions have little effect on drift performance in this case. Such low drift values ensure the building remains safe, durable and comfortable for occupants.
3) For soft soil, the maximum sway values are nearly equal in both directions, around 93.5 mm, with a twist of 1 mm. This suggests higher flexibility and greater lateral movements due to reduced stiffness in supporting soil. In contrast, medium soil shows significantly reduced sway values, about 53.6 mm in both directions, while maintain the same twist. This reduction demonstrates that medium soil offers better resistant to lateral displacement, improving overall stability. Interestingly, for hard soil, the sway values increase again, reaching 96.4 mm and 96.9 mm in two directions, with constant twist of 1 mm. this higher sway on hard soil may be attributed to increased stiffness transferring greater seismic energy to structure.
4) On soft soil the structure takes very high forces in one direction (414.54 kN) while the other direction carries very little (31.7 kN). This means building tends to sway more strongly in a single direction on soft ground. On medium soil situation is different. The forces in first direction are lower (75.38), but in second direction they become high (422.75 kN). On hard soil, the forces in first direction are again high (308 kN), but in the second direction they are almost zero (0.01 kN). Overall, study proves that soil type greatly changes how forces are shared, with medium soil offering most stable and balanced response.
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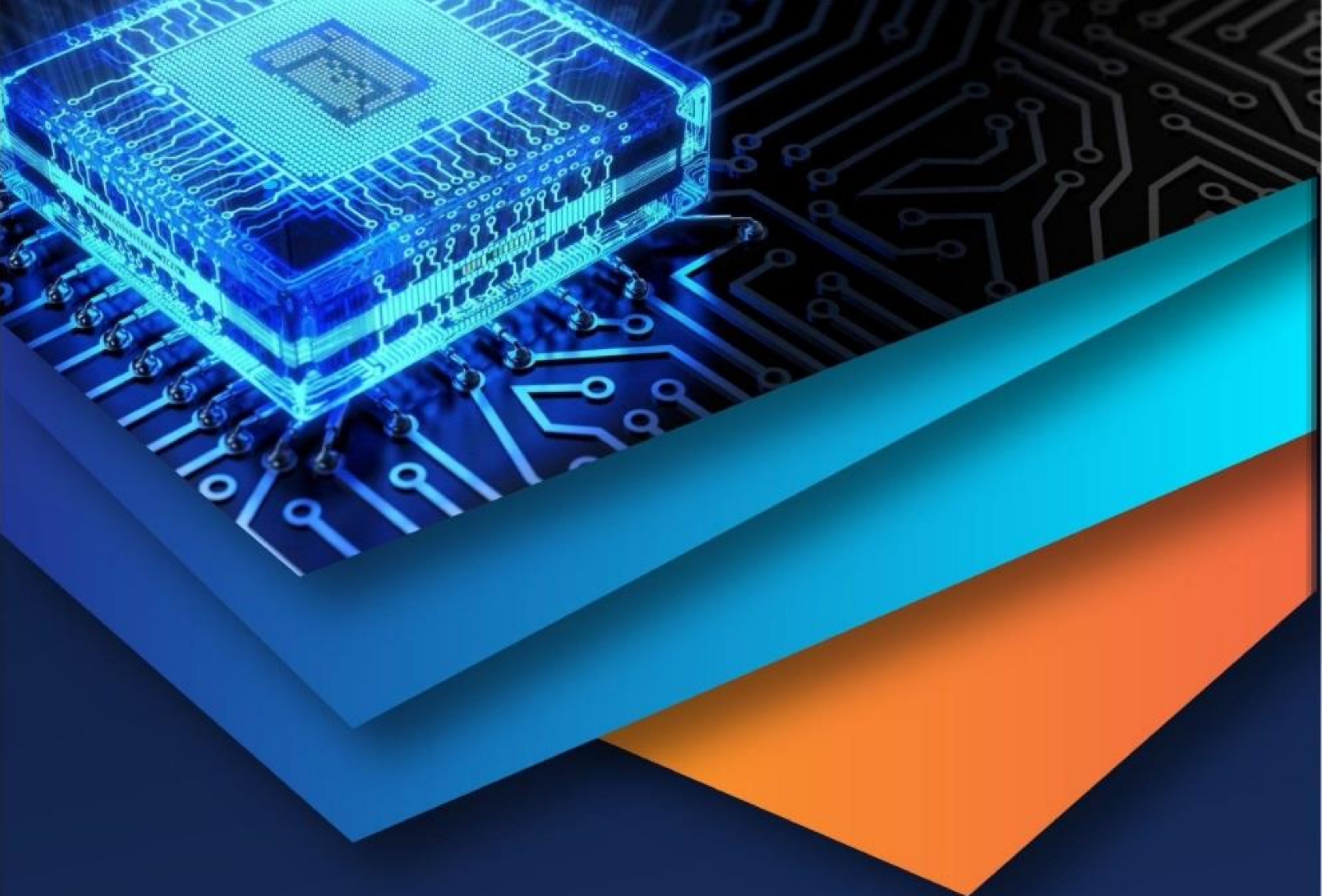
6) The reinforcement quantities vary considerably with soil type, reflecting how foundation interaction influences material demand. medium soil conditions generate higher stresses within the structural system, leading to the need for additional reinforcement to maintain safety and serviceability. The results also indicate that while soft and hard soils produce similar reinforcement requirements, medium soil imposes more critical design demands due to its stiffness characteristics. In conclusion, material usage is highly sensitive to soil conditions, with medium soil creating the most reinforcement-intensive design, highlighting the importance of soil–structure interaction in overall construction planning.

REFERENCES

[1] Arshad Jamal and Jadhav H S (2019) "Evaluation of R.C. Multi-storey Building Response under the Effect of Soil-Structure Interaction" International Research Journal of Engineering and Technology (IRJET), Vol. 6, Issue 4, e-ISSN: 2395-0056, p-ISSN: 2395-0072.

[2] Paraskevi K. Askouni and Dimitris L. Karabalis (2022) “The Modification of the Estimated Seismic Behaviour of R/C Low-Rise Buildings Due to SSI” Buildings Vol. 12, Issue 7.
[3] Pandi mani and Tanikonda Siva Sankar (2023), “Impact Assessment of SSI on the Structural Performance of RC Buildings under Lateral Forces” Research square, ISSN 2693-5015.
[4] P.Nagasri Anjaneyulu and Dr. Dumpa Venkateswarlu (2021), “Analysis and Design of Reinforced Concrete Multi-Stored Building (G+5) by using Tekla Software” International Journal for Modern Trends in Science and Technology, ISSN: 2455-3778.
[5] Rahul Raghunath Kharade and Nagendra M V (2020), “Study of Soil Structure Interaction on Framed Structure using ETABS” International Research Journal of Engineering and Technology (IRJET), Vol. 7, Issue 8, e-ISSN: 2395-0056, p-ISSN: 2395-0072.
[6] IS 800.2007, "Indian Standard Code of Practice for General Steel Construction", Bureau of Indian Standards, New Delhi, India.
[7] IS 875 (Part 1)-1987. "Indian Standard Code of Practice for Design Loads (Other than Earthquake) for buildings and Structures. Part 1 - Dead Loads-Unit weights of building materials and stored materials", Bureau of Indian Standards, New Delhi, India.
[8] IS 875 (Part 2)-1987, "Indian Standard Code of Practice for Design Loads (Other than Earthquake) for buildings and Structures. Part 2-Imposed Loads- Unit weights of building materials and stored materials", Bureau of Indian Standards, New Delhi, India.
[9] IS 1893 (Part 1)-2016 "Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi, India.
[10] IS 6403: 1981 – Code of practise for determination of bearing capacity of shallow foundations.



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