Machine Learning Based Seismic Assessment of Regular and Irregular RC Buildings on Hard and Soft Soil in Seismic Zone V Using STAAD. Pro

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***Abstract*—The study emphasizes that a building's seismic performance is strongly affected by both its structural configuration and the supporting soil conditions, a concern reinforced by the updated provisions of IS 1893:2025. In severe seismic zones such as Zone V, issues like mass and stiffness irregularities and unfavorable dynamic properties become more critical, especially when buildings rest on soft or highly deformable soils. These factors significantly influence lateral deformations, force distribution, and overall stability. Accordingly, the study aims to evaluate the combined effects of soil type and structural irregularity by comparing the seismic behavior of regular and irregular reinforced concrete buildings on soft and hard soils.**

The study analyzes the seismic behavior of regular and irregular reinforced concrete buildings designed as per IS 1893:2016, considering both soft and hard soil conditions. Key response parameters—lateral displacement, base shear, and bending moment—were evaluated. Results indicate that soil flexibility plays a dominant role in seismic response, with buildings on soft soil exhibiting significantly higher displacements, forces, and moments than those on hard soil. Linear regression models with R^2 values above 0.99 confirmed strong predictive capability. The findings highlight that the combination of structural irregularity and weak soil greatly increases seismic vulnerability, reinforcing the importance of soil–structure interaction and supporting performance-based seismic design in high seismic zones in line with IS 1893:2025.

***Index Terms*—Seismic analysis, Displacement, Base shear, Bending moment, Regression modeling, R^2 validation, Performance-based seismic design.**

I. INTRODUCTION

Earthquakes pose a serious threat to both human life and infrastructure, making the seismic evaluation of multi-storey buildings increasingly important in rapidly urbanizing cities. A building's earthquake response depends on several interrelated factors, including ground motion, soil conditions, structural geometry, material properties, and structural system, where even minor variations can significantly affect performance. In reinforced concrete frame structures, the distribution of mass and stiffness strongly influences deformation and force redistribution during seismic events. Regular buildings generally exhibit more uniform and predictable behavior, while irregular buildings—such as those with re-entrant corners or T-shaped plans—tend to experience complex dynamic responses, including torsion, uneven displacements, and stress concentration, increasing their vulnerability during strong earthquakes. Additionally, soil–structure interaction plays a crucial role, as soft soils amplify ground motion and increase building displacements and drift, whereas hard soils reduce vibration amplification. Understanding the combined effects of structural configuration and soil type is therefore essential for designing safe, resilient, and earthquake-resistant buildings.

The study aims to evaluate the seismic behavior of regular (rectangular) and irregular (T-shaped) G+10 reinforced concrete buildings using STAAD.Pro, with particular emphasis on the effect of soft and hard soil conditions in India's most seismically vulnerable zone. By analyzing key response parameters—lateral displacement, base shear, and bending moment—the research examines how building configuration and soil stiffness jointly influence seismic performance. The inclusion of linear regression analysis further helps in identifying relationships between structural characteristics and seismic responses, providing predictive insights to support more effective and informed earthquake-resistant design.

Objectives:

- To model G+10 regular (rectangular) and irregular (T-shape) buildings in STAAD.Pro.
- To evaluate structural response under soft and hard soil conditions.
- To compare displacement, base shear, and bending moment for both building configurations.
- To analyze the influence of irregularity on overall seismic behaviour.
- To develop linear regression models to predict seismic responses based on structural parameters.
- To provide engineering interpretation and recommendations for safe structural design.

II. LITERATURE REVIEW

The literature review for title “Machine Learning Based Seismic Assessment of Regular and Irregular RC Buildings on Hard and Soft Soil in Seismic Zone V Using STAAD.Pro” are as follows:

Ahmad et al. (2025) showed that asymmetric G+7 RC buildings experience higher roof displacement, torsional drift, and column shear, requiring substantially more reinforcement to meet IS code limits, highlighting the importance of symmetric planning at early design stages.

Poudel and Gyawali (2025) similarly found that asymmetric eight-storey buildings developed greater inter-storey drift, column shear, and punching shear demand, along with increased steel and concrete quantities, emphasizing the economic and safety implications of plan irregularity in seismic zones.

Bhatta and Dang (2024) demonstrated that machine-learning models using plan irregularity indices can accurately and quickly identify severely damaged asymmetric buildings after earthquakes, greatly reducing post-disaster evaluation time.

Demir et al. (2024) further confirmed that plan irregularity is a key parameter influencing seismic demand, with machine-learning models accurately predicting drift and base shear while significantly reducing computational effort. Overall, the literature highlights that asymmetric buildings are more vulnerable under seismic loading, incur higher material costs, and benefit from both careful architectural planning and modern predictive tools for design and assessment.

Di Domenico et al. (2023) demonstrated that fiber-based distributed inelasticity models more accurately capture stiffness degradation and peak drift compared to lumped plasticity models, though at the cost of significantly higher computational time. Their work underscores the importance of selecting an appropriate modeling strategy based on the desired balance between accuracy and efficiency.

Georgioudakis and Plevris (2023) showed that combining response spectrum analysis with regression-based machine learning can rapidly and accurately predict peak floor accelerations, making such surrogate models highly effective for preliminary design and large-scale assessments. Alcantara and Saito (2023) applied convolutional neural networks for post-earthquake damage classification using images, achieving high accuracy while revealing additional challenges in assessing asymmetric buildings. Together, these studies illustrate how advanced modeling techniques and machine learning tools are enhancing seismic performance evaluation, rapid assessment, and performance-based design, particularly for irregular structures.

Kiran Devi and Subhankar Petal (2023) emphasized the importance of seismic analysis for ensuring structural safety under earthquake loading. Both ordinary moment-resisting frames and special moment-resisting frames were examined as part of the seismic assessment. In the investigation, a G+8 reinforced concrete structure was analyzed across three seismic zones—III, IV, and V—according to the provisions of IS 1893 (Part 1): 2016. The comparison focused on design base shear, longitudinal steel percentage, and reinforcement detailing. Findings indicated that base shear values increased progressively with the severity of the seismic zone, from Zone III to Zone V.

Shivam Gautam et al. (2023) investigated the progressive collapse behavior of five 15-storey reinforced concrete framed structures, comprising one regular model and four models with vertical member removal. Nonlinear static (pushover) analysis was carried out using SAP2000 v23, with loading applied in accordance with GSA (2003) guidelines, for a trapezoidal plan building with a 7×10 bay configuration located in seismic Zone V. Key response parameters include demand–capacity ratios, base shear versus maximum storey displacement relationships, and hinge formation patterns. The results indicated a high susceptibility to progressive collapse, and parametric comparisons highlight how vertical member removal significantly alters structural response.

Malekloo et al. (2022) emphasized that plan-irregular RC buildings pose major difficulties for machine-learning-based structural health monitoring due to complex torsional behavior, noting that deep learning models using full 3D response data substantially outperform traditional methods. Their work stresses the importance of physics-informed and hybrid modeling approaches to improve reliability and interpretability.

Bhardwaj et al. (2022) demonstrated that structural irregularity enhances the effectiveness of supplemental damping systems, showing that friction dampers significantly reduce torsion-induced responses in setback towers while also offering economic benefits through reduced steel demand. This study confirms the practicality of passive control devices for improving seismic performance of irregular high-rise buildings.

Syriac and Tannu (2021) compared seismic analysis methods and found that simplified equivalent static procedures significantly underestimate torsional effects in irregular buildings, whereas dynamic methods provide more accurate demand estimates. Collectively, these studies underline the need for advanced analysis techniques, supplemental control strategies, and improved code provisions when dealing with irregular structures in seismic regions.

III. METHODOLOGY

For the present study, two categories of buildings are considered to evaluate the impact of structural regularity on seismic performance on the multi-floor RCC structure consists of a G+10 building in zone V. The specifications of the constructed structure are presented in Table 1, detailing the structural components, materials, and characteristics used in the study.

Regression Analysis

Artificial intelligence refers to techniques that enable machines to learn patterns from data and use them for prediction, with machine learning serving as its practical implementation by deriving rules directly from numerical data. Among machine-learning methods, linear regression is the simplest and most transparent, fitting a straight line to data by minimizing the sum of squared errors. Because it requires limited data and offers clear insight into trends, it is often used as an initial analytical tool in engineering studies.

In this study, soil flexibility is selected as the independent variable (x), numerically encoded as 1 for hard soil and 3 for soft soil, while structural responses—displacement, base shear, and bending moment—are taken as dependent variables (y). A simple linear regression model is applied to establish predictive relationships between soil condition and each seismic response, yielding equations of the general form:

$y = mx + c$

The study adopts a clear three-step methodology integrating numerical simulation, data processing, and predictive modeling. First, three-dimensional STAAD.Pro models of regular rectangular and irregular T-shaped buildings are developed and analyzed across three soil classes and two seismic zones, resulting in twelve distinct cases. For each case, key outputs such as member forces and global displacements are extracted and compiled into a master dataset.

Second, the collected data are processed using basic statistical techniques. Maximum roof displacement, base shear, and bending moment values are tabulated and visualized through bar charts and color heat maps, enabling a clear comparison of the individual effects of soil flexibility and plan irregularity.

Finally, linear regression analysis is applied, with soil type numerically encoded to quantify its influence on each response parameter. The resulting models show very high accuracy, with R^2 values exceeding 0.99, indicating that soil condition alone explains more than 99% of the response variability. Overall, the workflow is simple, transparent, and easily repeatable, requiring no proprietary methods and allowing straightforward extension to nonlinear analyses, taller buildings, or alternative seismic design codes.

Table 1 Building Parameters

Type of frame	R.C.C Frame	
Type of Structure	Multistorey Residential Building	
Total storeys	G+10	
Building Height	33m	
Typical Storey Height	3 m	
Slab Thickness	125mm	
Beam Size	300x450mm	
Column Size	400x600mm	
Grade of Concrete	M-30	
Grade of Steel	Fe-500	
Type Of Soil	Soft and Hard	
Geometry of Building	Symmetrical	Irregular
Size of Building	20x15m	T-shaped plan: Overall top width = 20 m Vertical stem width = 10 m Top projection depth = 15 m Stem depth = 10 m

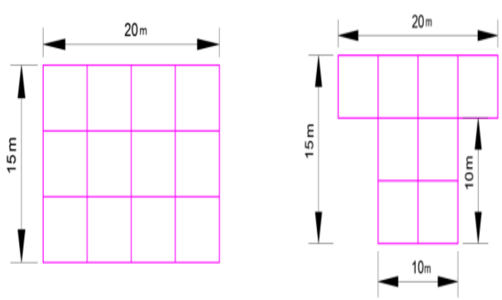
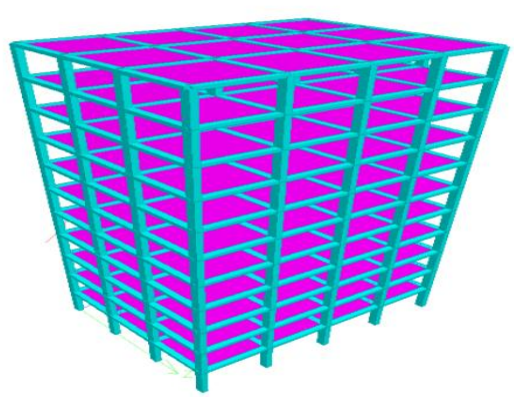


Fig. 1 Plan view



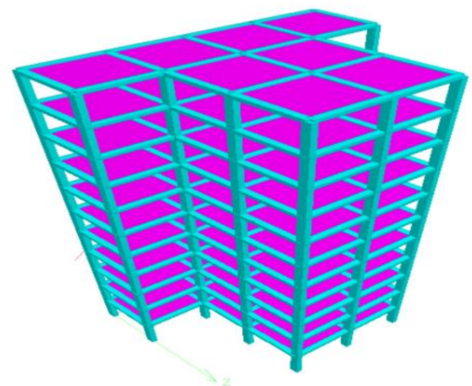


Fig. 2 3D view

IV. RESULTS AND DISCUSSION

The Results and Discussion chapter is a vital part of the research, as it converts analytical and numerical simulation outputs into meaningful engineering insights. In this section, results obtained from structural analyses are systematically presented through tables, charts, and regression models, followed by critical interpretation to identify key patterns, trends, and correlations in structural behavior.

For seismic analysis, the discussion focuses on the influence of soil flexibility, soil type, and building configuration (regular versus irregular) on critical response parameters such as displacement, base shear, and bending moment. Comparative evaluation of different cases helps identify the governing factors affecting seismic performance. The regression models further support and validate these observations by establishing predictive relationships, thereby enhancing the credibility and applicability of the study's conclusions.

Displacement effect on Soil Type

On soft soil, both buildings exhibit their maximum lateral displacements, confirming the strong influence of soil flexibility on seismic response. The regular frame shows a displacement of about 217.33 mm, whereas the irregular frame experiences a significantly higher displacement of 341.11 mm.

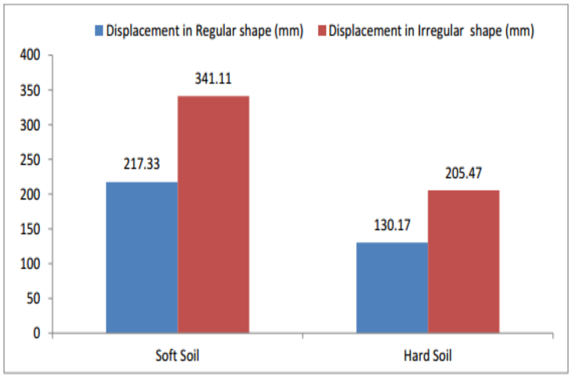


Fig. 3 Maximum Displacement in regular and irregular building with Soft and Hard Soil

This demonstrates that as soil stiffness decreases, overall structural movement increases. Soft soil amplifies seismic waves due to its longer natural period, leading to more pronounced lateral sway. In comparison, buildings founded on hard soil show substantially lower displacements, clearly highlighting the critical role of soil type in controlling seismic deformation.

Shear Force effect on Soil Type

The results indicate a clear increase in base shear with increasing soil flexibility. Buildings founded on soft soil develop the highest base shear values, reaching 1829.39 kN for the regular frame and 2386.41 kN for the irregular frame. This behavior is attributed to the amplification effects of soft soil, where lower stiffness and longer natural periods intensify ground motion and extend shaking duration, thereby increasing force demands on the structure. In contrast, buildings on hard soil experience the lowest base shear values, recorded as 1366.60 kN for the regular configuration and 1705.68 kN for the irregular configuration, further emphasizing the significant role of soil conditions in seismic force generation.

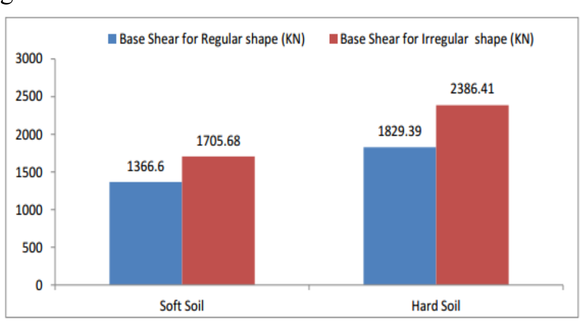


Fig. 4 Maximum Shear Force in regular and irregular building with Soft and Hard Soil

Bending Moment effect on Soil Type

The results demonstrate a pronounced increase in bending moments with increasing soil flexibility. Buildings resting on hard soil experience the lowest moment demands, with values of 253.22 kNm for the regular frame and 375.90 kNm for the irregular frame. In contrast, structures on soft soil record the highest moments, reaching 422.69 kNm for the regular configuration and 624.10 kNm for the irregular configuration. This trend confirms the amplification effect associated with soft soils, where reduced stiffness and longer natural periods intensify structural response. Compared to hard soil conditions, regular buildings exhibit approximately a 67% increase in bending moment on soft soil, while irregular buildings show a similar increase of about 66%, highlighting the combined influence of soil flexibility and structural irregularity on seismic demand.

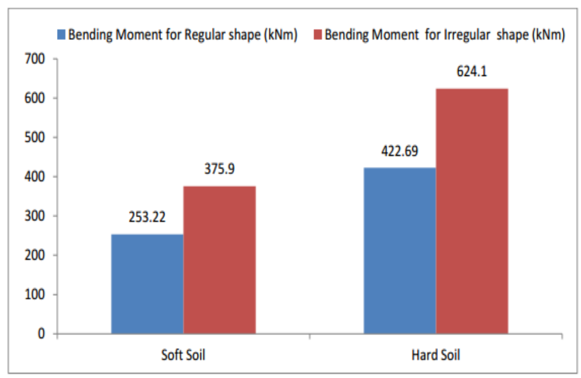


Fig.5 Maximum bending moment in regular and irregular building with Soft and Hard Soil

Displacement – Linear Regression Analysis

The heat map illustrates the maximum displacement for four combinations of soil type and building configuration, clearly indicating that soft soil conditions lead to significantly higher displacements in both regular and irregular buildings. This visual comparison highlights the strong influence of soil flexibility on lateral deformation. In addition, linear regression lines plotted separately for regular and irregular buildings (Fig. 6) show a clear positive slope in both cases, confirming that displacement consistently increases with increasing soil flexibility regardless of building configuration.

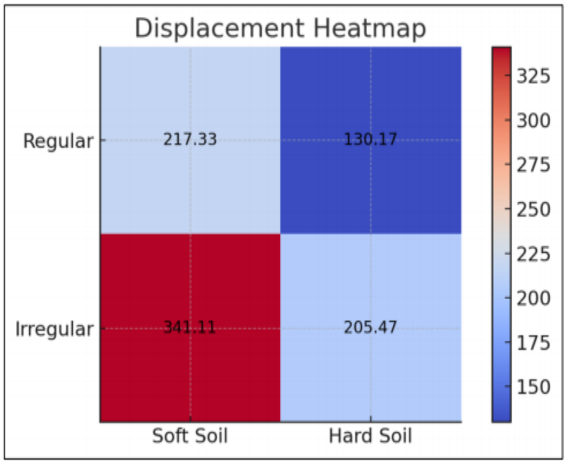


Fig. 6 Heat-map of Maximum Displacement (mm)

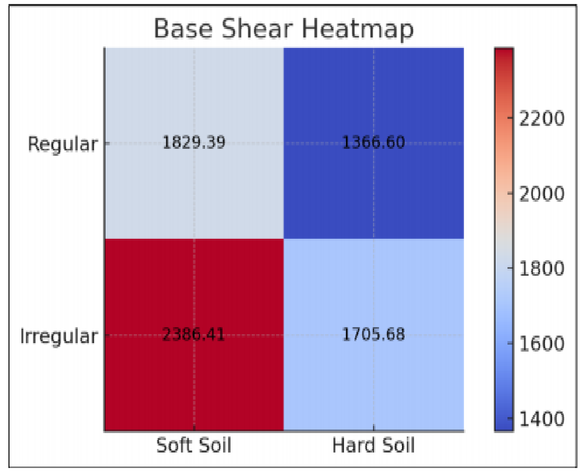


Fig. 8 Heat-map of Base Shear

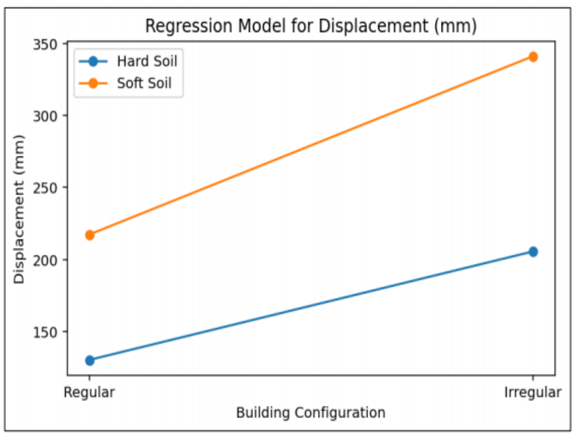


Fig. 7 Regression model for Displacement (mm)

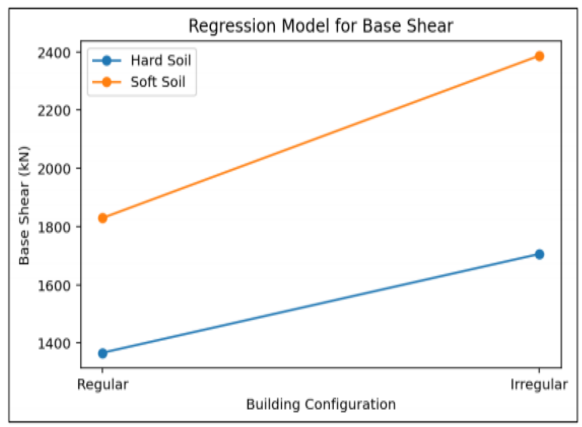


Fig. 9 Regression model for Base Shear

Base Shear - Linear Regression Analysis

The heatmap of base shear values across different soil types and building configurations illustrates clear variations in seismic force demand. It shows comparatively lower base shear values on soft soil and higher values for irregular building configurations, emphasizing the influence of structural form on force concentration. Fig. 9 further supports these observations through a regression plot relating soil type to base shear for both regular and irregular buildings. The regression lines exhibit a negative slope with increasing soil flexibility, indicating a reduction in base shear as soil becomes softer, while a consistent positive offset is observed for irregular buildings. This offset highlights that plan irregularity leads to higher base shear demand compared to regular configurations under the same soil conditions

Bending Moment - Linear Regression Analysis

The regression results reveal a clear linear relationship between soil condition and bending moment demand, with irregular buildings consistently showing higher moments than regular ones. The straight-line trends confirm the effectiveness of the linear regression model and indicate that increasing soil flexibility amplifies bending moments due to enhanced seismic response on softer ground.

This trend is also evident in the heatmap of maximum bending moment (MZ) under Zone V loading, which highlights higher moment demands on soft soil and greater bending in the irregular (T-shaped) configuration. Overall, both the regression plots and heatmap collectively demonstrate the combined effect of soil flexibility and structural irregularity in increasing bending moment demand.

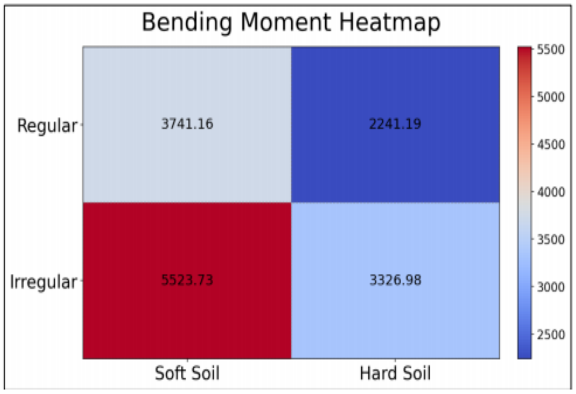


Fig. 10 Heat Map for Bending Moment

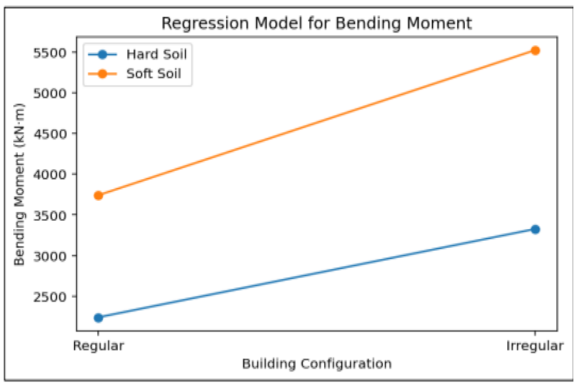


Fig. 11 Regression model for Bending Moment

V. CONCLUSIONS

This study presents a detailed seismic assessment of a G+10 RCC multi-storey building based on numerical performance indicators, the following conclusions were drawn:

- Displacement: In Zone V, soft soil causes maximum displacements, with irregular buildings experiencing about 60% higher values than regular ones. The most critical case is an irregular building on soft soil, exceeding 341 mm displacement.
- Base shear: Base shear increases from hard to soft soil, and irregular buildings attract 25–30% higher forces. The maximum demand occurs for irregular buildings on soft soil (2386.41 kN).
- Bending moment: Moments rise significantly with soil flexibility, with irregular buildings showing roughly 48% higher values. The highest moment demand is observed for irregular buildings on soft soil (624.10 kNm).

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