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Seismic Analysis and Design Considerations for buildings with Soft-storey and Mass Irregularity using BIM

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ABSTRACT:

This research examines seismic performance of RC G+4, G+8, and G+12 buildings with Mass Irregularity (MI) and Soft Storey (SS) by applying STAAD Pro. Structural models were created based on IS 1893:2016 in order to find lateral displacement, base shear, and reinforcement details. Results indicate that soft storey configurations have higher steel demand and more drift. Mass irregular buildings showed similar behavior but with higher base shear. Section optimization minimized material waste without sacrificing safety. The results are intended to inform safer, more effective seismic design.

Keywords: Staad PRO, Soft storey, Mass irregularity, Base shear, Displacement, Drift ratio, Material Quantity, SMRF.

Introduction:

As a consequence of increasing urbanization, reinforced concrete (RC) buildings of multiple storeys have gained widespread popularity to tackle space shortages. Nevertheless, their seismic risk is a big challenge in terms of design, particularly for vertically irregular structures like Soft Storey (SS) and Mass Irregularity (MI). Soft Storey and Mass Irregularity cause stiffness and mass discontinuity, generally creating increased lateral response and instability of the structure in earthquakes. Soft storey irregularities at ground level because of open parking or commercial areas decrease lateral stiffness and produce zones of weakness. Mass irregularities due to abrupt changes in mass between floors create unbalanced forces of inertia that influence the dynamic behavior of the building. While IS 1893:2016 provides design provisions for such irregularities, further research is required on the extent of their contribution to performance at various building heights. The current research performs seismic analysis of G+4, G+8, and G+12 RC framed structures with varied irregular configurations in STAAD Pro. The models are analyzed under codal load combinations to monitor parameters like lateral displacement, base shear, and steel reinforcement demands. Through regular and irregular model comparison, the study seeks to establish patterns of vulnerability and suggest optimized structural measures for efficient and safe design.

Literature Review:

A comprehensive review of existing literature reveals several key areas of research in few significant findings of seismic analysis of multi-story buildings. Comparative studies, e.g., by Kothuri & Kumar (2018), show discrepancies in outputs between programs like STAAD Pro , underlining the relevance of choosing software. Research (2021, 2019, 2022) repeatedly emphasizes the need to include seismic considerations, even in lower-seismic zones, to maintain structural safety. Analyses (2017) of U, V, and H-shaped structures with plan irregularities show higher displacement and stress concentrations, indicating their susceptibility. Technical reports (2020, 2023) present STAAD Pro's functionalities in seismic irregularity checks according to IS 1893:2016. Additionally, comparative studies (2016, 2015, 2024) of software such as STAAD Pro, ETABS, and SAP2000 show discrepancies in results, confirming the necessity of cautious interpretation. Collectively, these conclusions highlight the central importance of seismic analysis, good software application, and compliance with design codes for guaranteeing buildings safety and resilience.

Gaps in the Literature:

One of the main areas of research lacuna in seismic building analysis is that little research has been carried out extensively investigating the combined influence of plan and vertical irregularities at different building heights, with a special emphasis on base shear, drift ratio, and displacement comparisons. Whereas research tends to study plan irregularities or vertical irregularities (e.g., soft stories and mass irregularity) in isolation, and can study these responses at individual building heights, the literature does not have extensive studies that explore how the interaction of these types of irregularities affects base shear, drift ratio, and displacement as building height varies (e.g., comparing G+4, G+8, and G+12 buildings). This requires further investigation to evolve design methodologies that take into account the intricate interactions among these factors and their influence on these seismic response parameters.

Problem Statement:

There is a great lack in the present knowledge regarding seismic behaviour in multi-story buildings with combined plan and vertical irregularities at different heights. Although several studies have dealt with the seismic performance of buildings with a single type of plan or vertical irregularity (e.g., soft story and mass irregularity), there is limited holistic research that examines the interplay of these types of irregularities and their effects on seismic response parameters critical to building safety, i.e., base shear, story drift, and displacement, as building height increases (e.g., comparing G+4, G+8, and G+12 buildings). This unfamiliarity impedes the formulation of successful design methods for guaranteeing the safety and stability of such structures in seismically active areas. The primary objectives of this research are:

- Model G+4, G+8, and G+12 structures with mixed plan and vertical irregularities.
- Conduct seismic analysis on the building models.
- Compare base shear, storey drift, and displacement between models.
- Assess the impact of irregularities and building height on seismic performance.

Methodology:

The methodology adopted in this study integrates BIM-based road design using Autodesk Civil 3D with microscopic traffic simulation in PTV VISSIM. Initially, Google Earth Pro and GPS Visualizer were used to extract accurate spatial and elevation data of the study area—Nehru Outer Ring Road, Hyderabad. This data was converted into UTM coordinates and imported into Civil 3D to create 3D road geometry, intersections, and corridor models. These BIM models were exported in IFC format and integrated into VISSIM to simulate real-world traffic conditions, including mixed traffic flow involving cars, buses, motorcycles, and auto-rickshaws.Within VISSIM, vehicle compositions, signal controllers, conflict areas, and reduced-speed zones were defined to reflect typical urban conditions. The simulation was run under multiple scenarios to test different configurations such as signal timing optimization, dedicated bus lanes, and adaptive speed control. Data was then collected through data collection points, queue counters, and vehicle travel time segments to evaluate network performance. This integrated approach allowed a high-fidelity analysis of traffic behavior and identification of congestion hotspots for accident mitigation as shown in figure 1

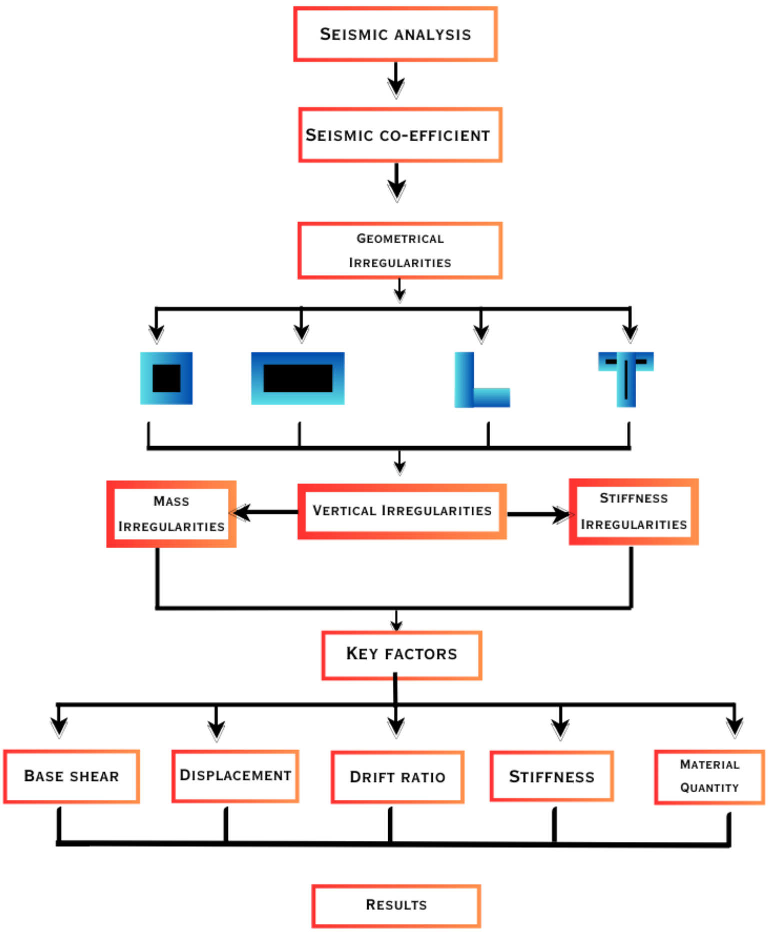

Figure 1: methodology of the study

The model that we are going to design is a Special Moment Resisting Frame (SMRF). First, we will select the Structure Wizard and create the first floor with a height of 3.94 meters. This specific height is chosen because we will be designing three different models: G+4, G+8, and G+12.

After that, click on Translational Repeat, where you can generate the remaining floors by entering the required floor height of 3.5 meters. Ensure that you select the Y-Direction, enable the Link Steps option, and then click OK.

In the G+4 model, the soft storey is placed at:

- the bottom (i.e., 1st floor),
- the middle (i.e., 3rd floor), and
- the top (i.e., 5th floor).

Similarly, you will develop models for the G+8 and G+12 structures. However, the positions of the soft storeys will vary. For better understanding, here are the soft storey placements:

- For G+8: at floors 1, 5, and 9
- For G+12: at floors 1, 7, and 13

Next, go to the Properties section and click on Prismatic. Create optimized sections for columns and beams. Assign the beam sections to the X and Z axes of the building using the Select option in the toolbar, and assign the column sections to the Y-axis.

Now go to the Supports section and create a Fixed Support. Switch to the Front View, select the lower nodes, and assign the support.

Now after that, click on DL, then go to member load first insert -17.5kN/m and add. Then after add 10.5Kn/m and -3.25kN/m over there. After that, go to floor load and click on it and then give -3kN/m and range of Y is 0 to total height of the building.

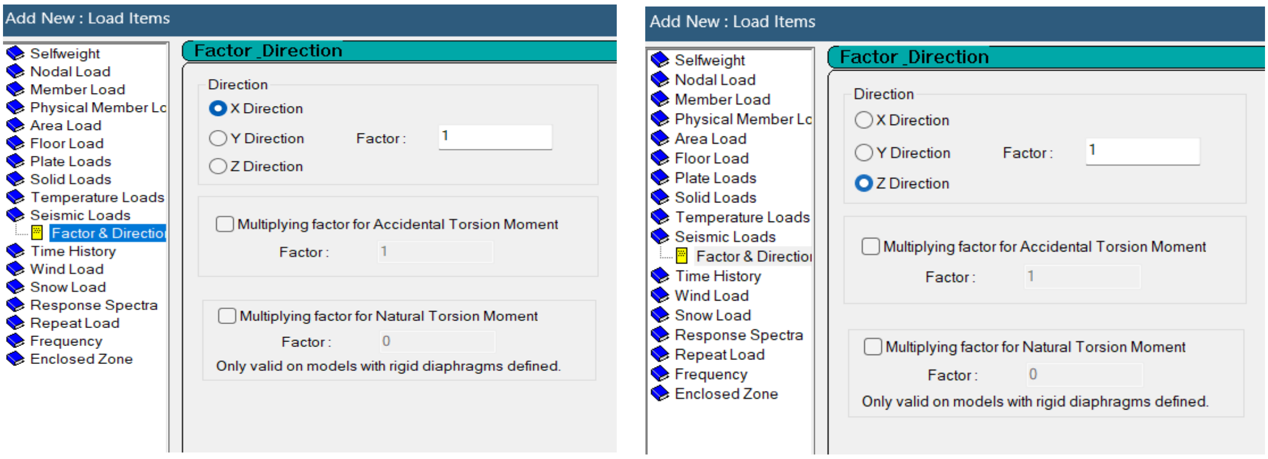

Figure 2 & 3 – Assigning of SQX & SQZ loads

Now come to LL, click on add, go to floor load, and add -4kN/m; the range is all floors except the top floor (because the load is less on the terrace). Add 2kN/m for the top floor and close.

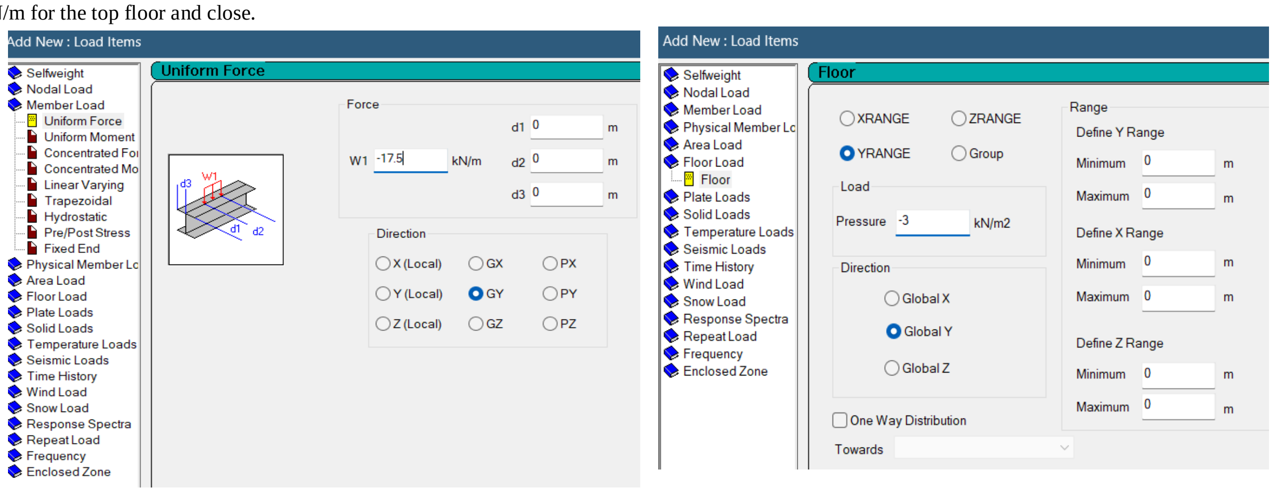

Figure 4 & 5 – Assigning of dead loads

Now, define the load combinations which we mentioned above in the define load combination section. After creating the loads, assign the loads to their respective elements. You can check the load calculation section for what and where to assign. This is how it looks after assigning the loads to the model.

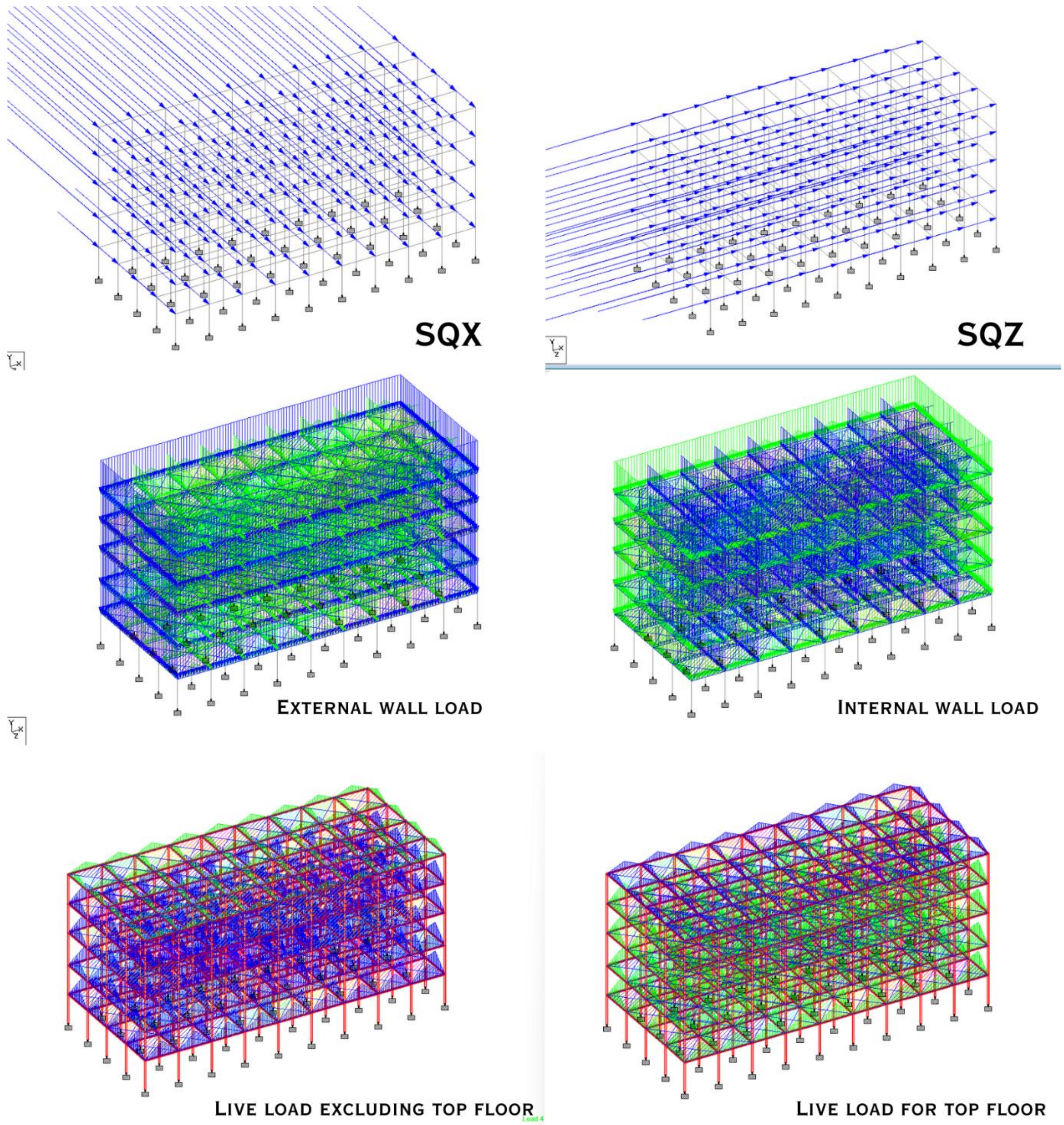

Figure 6- Loads of Rectangular shape building.

Now go to the Run & Analysis section. Click on the analysis command, you have a new display on screen choose all and click ok. Then run the command. Check the errors and warnings and rectify if any come. Now go to the command file and copy the dead load section and copy it below the zone section and change **dead load - dead weight** and remove the -ve sign and direction of load over there. Later, copy the live load and paste it down the dead weight section. Change the live load of 4kN/m to 2kN/m. Now, save the changed file. After checking that, go to the output file, where we can find the total and individual shear values over there. Note them down for further use. After completion of taking base shear values, we have to take maximum displacement for each floor. Select the front view of the building and select the first floor and click on "selected view", then take the whole view of the selected part and go to post-processing mode. Select all the combination loads and click ok. Now select the load, click on "displacement' and click "annotate." Choose max displacement there and click ok. You have your displacement on your screen. Similarly, take the loads for each floor, repeating the process mentioned above.

We have to follow the same procedure that we had done for the stiffness irregularity. But here, there will be no variation of height in any floor. But there will be a change in the live load for the floors where we changed the height in the stiffness irregularity. Here, we take the live load of 6kN/m instead of 4kN/m for that one floor and follow the same process.

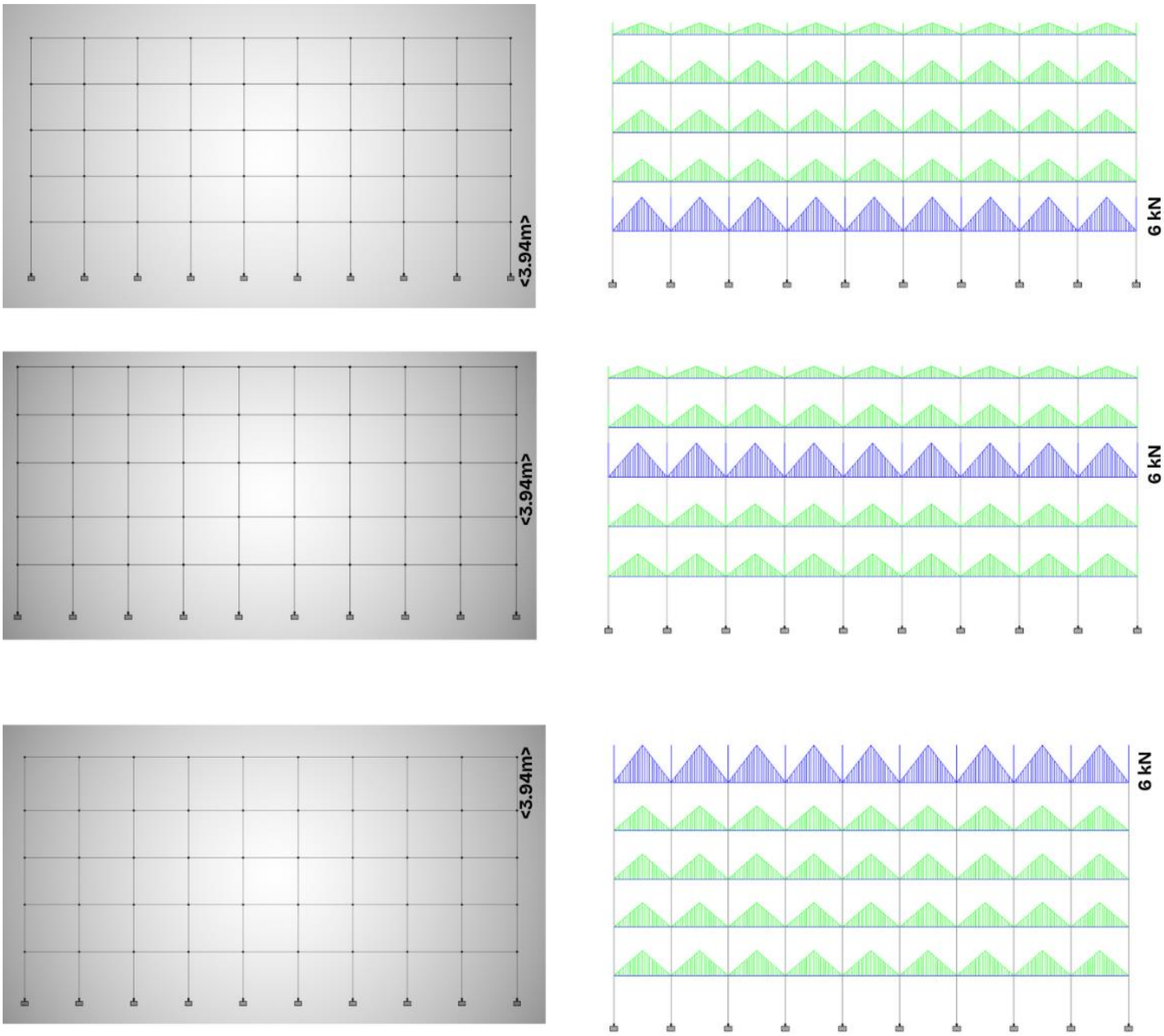

Figure 7 – Position of irregularities

Dead load (D.L)

- External wall load (w1)

= height of wall x thickness of wall x masonry density
= 3.5m x 0.25m x 20kN/m3 = 17.5kN/m.

- Internal wall load (w2)

= height of wall x thickness of wall x masonry density
= 3.5m x 0.15m x 20kN/m3 = 10.5kN/m.

- Parapet wall load (w3)

= thickness x height x masonry density
= 0.125m x 1.3m x 20kN/m3 = 3.25kN/m.

b) Live load (L.L)

- Live load on floors including floor finish (w5), except top floor = 4kN/m^2

(as per IS: 875-1987 (Part-2)).

- Live load on the top floor, including floor finish (w6) = 2kN/m^2

(as per IS: 875-1987 (Part-2)).

c) Critical load

- 1.2 DL + 1.2LL + 1.2EL_X + 0.36EL_Z

- 1.2 DL + 1.2LL + $1.2EL_Z + 0.36EL_X$
- 1.5 DL + $1.5EL_X + 0.45EL_Z$
- 1.5 DL + $1.5EL_Z + 0.45EL_X$
- 0.9 DL + $1.5EL_X + 0.45EL_Z$
- 0.9 DL + $1.5EL_Z + 0.45EL_X$

RESULTS

This section provides a comprehensive analysis of base shear, displacement, drift ratio, and material consumption for G+4, G+8, and G+12 buildings modeled using STAAD Pro. Both the Seismic Coefficient Method (SCM) and Response Spectrum Method (RSM) were used in this study to evaluate the impact of soft storey and mass irregularity at different vertical levels.

Base shear

A detailed comparison of base shear across building shapes (Square, L, Rectangle, T) for G+4, G+8, and G+12 structures reveals critical trends. In *G+4 buildings*, L-shaped plans consistently generated the highest base shear in most irregularity cases, especially in conventional (CON), soft middle, and soft top configurations, indicating torsional amplification. Square and T shapes showed moderate base shear, while Rectangle shapes had significantly lower values, suggesting reduced lateral demand.

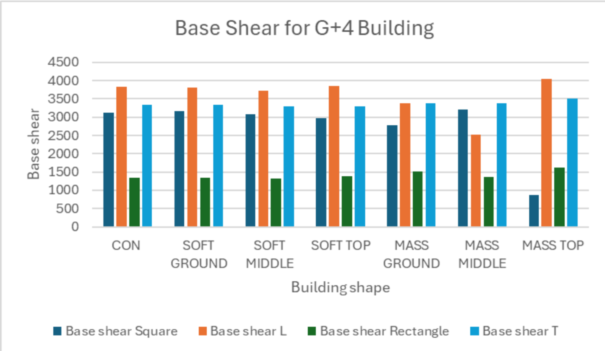

Fig 8: Base shear for G+4 buildings

In *G+8 buildings*, the pattern persisted, with L-shaped structures again producing maximum base shear in soft middle and mass top models, exceeding 4500 kN. T and Square shapes showed comparable performance in most cases, while Rectangle shapes demonstrated much lower base shear, often below 1200 kN—likely due to more flexible response and reduced stiffness.

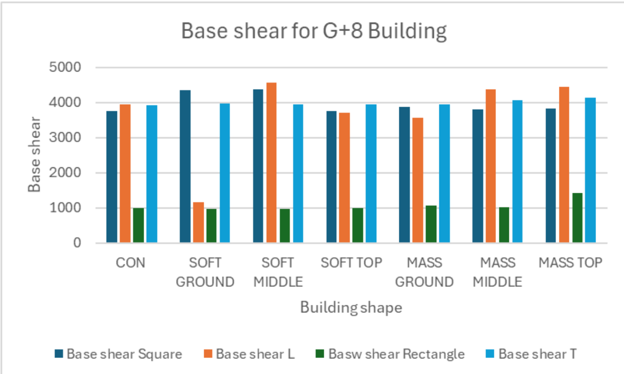

Fig 9: Base shear for G+8 buildings

For *G+12 buildings*, although not explicitly shown in graph form, trends from G+4 and G+8 suggest even greater divergence. L-shaped models can be inferred to experience amplified base shear due to taller structure height and compounded torsional effects. Meanwhile, Square and T-shaped plans remain more stable across irregularity types, while Rectangles consistently show lower shear but may be prone to excessive displacement.

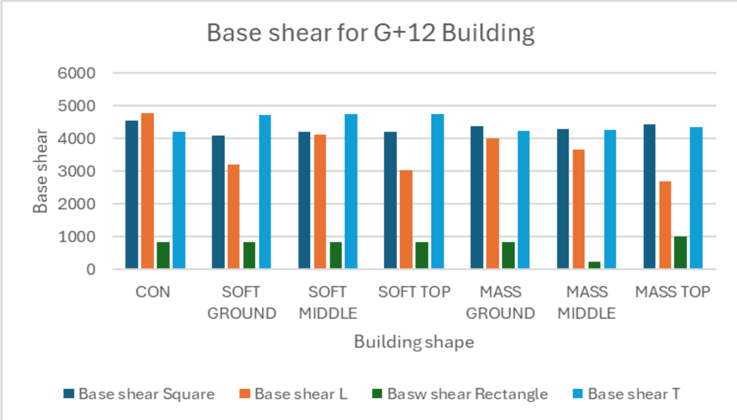

Fig 10: Base shear for G+12 buildings

Storey Displacement

Displacement is used to measure lateral sway under seismic loads. High displacement refers to flexibility and low lateral stiffness.

Effect of Shape:

- The rectangular buildings exhibited consistent displacement increases with height. Mid soft storey caused maximum displacement in G+8 and G+12, whereas low soft storey influenced lower floors more.
- Square buildings, because of their symmetric and enclosed layout, received moderate displacement when subjected to irregularities. Distribution of displacement was good, save when MI was positioned mid-height.
- L-shape buildings provided asymmetrical distribution of displacement, particularly around the re-entrant corner. Spike in displacement happened when soft storey was put mid or top, leading to stress localization.
- T-shaped structures were the most sensitive to displacement. Soft storeys at mid-level caused sudden jumps in displacement between floor levels. The combination of vertical loss of stiffness and plan irregularity exacerbated the lateral motion.

Drift Ratio (Inter-storey Drift)

Drift ratio is crucial in the determination of structural distortion and possible non-structural damage.

Effect of Form:

- Rectangular buildings managed drift effectively in regular configurations. However, mid-level soft storeys caused sharp drift peaks, especially in G+4 models, where story count was low and stiffness loss was concentrated.
- Square buildings had more continuity of drift from one floor to the next. Although drift increased with irregularity, it was very controlled because of plan symmetry.
- L-shaped buildings showed localized concentration of drift around geometric discontinuities. Mid-MI and Mid-SS were especially important, often surpassing IS code drift in G+8 and G+12 cases.

T-shaped frames were exposed to complex and non-uniform drift patterns, the most severe in G+12 MID SS models. The maximum drift ratio was at the stem-head interface of the "T".

Material Quantity Takeoff:

This graph illustrates the quantities of concrete (in cubic meters) and steel (in kilonewtons) required for various building shapes in G+4 structures. The data is presented for L-shape, square, and rectangle-shaped buildings across different structural configurations such as conventional (CON), soft storey (GROUND, MIDDLE, TOP), and mass irregularities (GROUND, MIDDLE, TOP).

From the graph, it is evident that mass irregularity at the ground level (MASS GROUND) demands the highest quantities of both concrete and steel, especially for the L-shape configuration, indicating a significant structural demand. The L-shape buildings consistently require more steel compared to other shapes in almost all configurations, while square-shaped buildings generally show a balanced requirement of materials. Rectangle-shaped buildings show lower values for both concrete and steel across most cases, which may suggest more material efficiency for G+4 buildings.

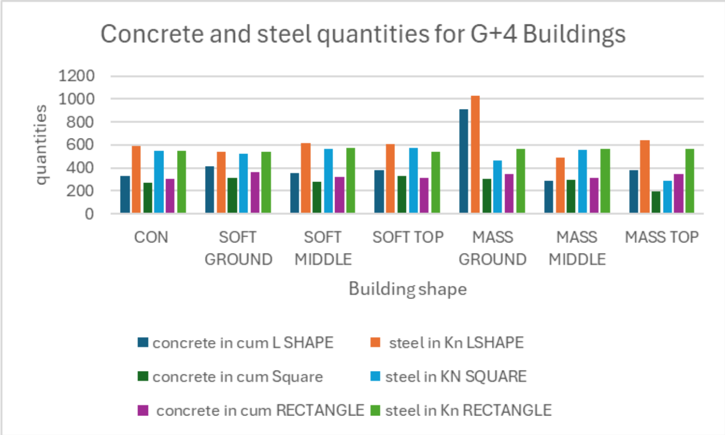

Fig 11: Material quantity for G+4 buildings

This graph is a repetition of the first one, with the same values and legends. It again highlights the concrete and steel usage for G+4 buildings. As the data is identical, the observations remain unchanged. The L-shape under MASS GROUND remains the highest consumer of materials, while rectangle buildings appear to be the most material-efficient in this height category.

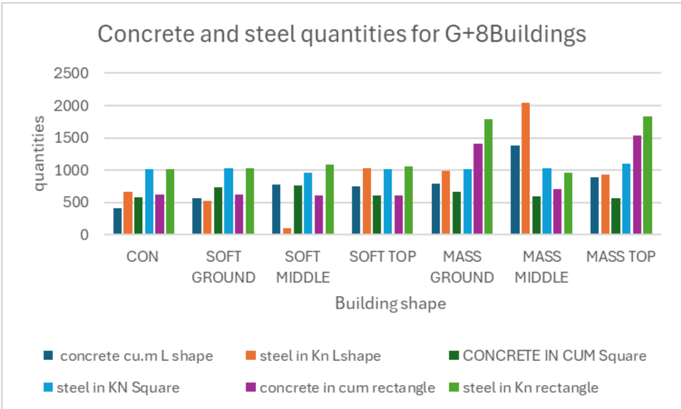

Fig 12: Material quantity for G+8 buildings.

In the case of G+12 buildings, the material demands increase significantly, as reflected in the larger scale of the graph. All shapes and configurations show higher concrete and steel quantities compared to the G+4 case. The **MASS MIDDLE configuration for L-shape buildings** shows the highest steel consumption, reaching up to 2000 kN, indicating the critical role of mid-height mass irregularities in tall buildings. Similarly, concrete usage also peaks for L-shaped buildings under the same condition. Unlike in G+4 buildings, square and rectangular shapes show more competitive values here, with **square-shaped buildings** sometimes exceeding the L-shape in concrete usage but generally requiring less steel. **Rectangular buildings**, while still relatively efficient, show increased material usage due to the height and structural demands of G+12 buildings. The data underlines the importance of building shape and irregularity placement in optimizing material consumption in high-rise constructions.

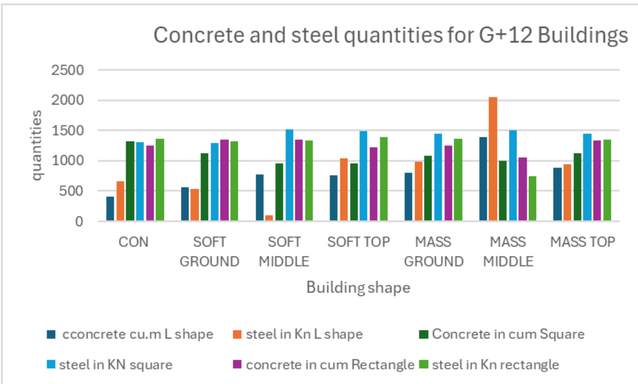

Fig 12: Material quantity for G+12 buildings

Discussions:

The integration of STAAD Pro with Building Information Modelling (BIM) proved to be an efficient methodology for seismic analysis of reinforced concrete (RCC) buildings. The analysis demonstrated that incorporating BIM in the early stages of design significantly enhances coordination, visualization, and accuracy across structural planning and execution. The study revealed that seismic forces had a substantial impact on building behaviour, particularly with respect to lateral displacements and inter-storey drifts. By analyzing the building under seismic load combinations as per IS 1893:2016, the structural response such as bending moments, shear forces, and deflection patterns could be accurately captured.

Moreover, the use of STAAD Pro facilitated detailed modelling and structural analysis, enabling efficient iteration and comparison of results across different seismic zones and building heights. When integrated with BIM tools like Autodesk Revit, the workflow became more streamlined, offering improved clash detection, real-time updates, and quantity estimations. This synergy not only reduced errors but also supported sustainable and cost-effective design decisions.

The study also indicated that buildings designed without considering seismic factors might face critical failures, especially in regions prone to high seismic activity. Thus, implementing such integrated analysis frameworks can substantially improve structural resilience and safety. Overall, the project underscores the growing importance of adopting advanced digital tools in civil engineering to meet modern challenges in seismic design and construction management.

Conclusion:

This study evaluated the seismic response of buildings with soft storey and mass irregularity using IS 1893:2016 guidelines and STAAD Pro software. G+4, G+8, and G+12 buildings with various plan shapes and irregularity placements were modeled using the Seismic Coefficient Method.

Soft Storey Effects:

- Placement at mid-storey leads to maximum displacement and drift.
- Low SS is more favorable than mid or high in shorter buildings.
- G+12 High SS caused highest steel usage due to large lateral demand.

Mass Irregularity:

- Best performance when irregularity is at top floors.
- Mid MI disrupted force distribution and increased instability.
- Mass Irregular models consumed less material than Soft Storey.

Displacement and Drift:

- Displacement increased with building height.
- Drift was concentrated between 2nd to 6th floors, depending on irregularity.
- Top MI significantly reduced drift, proving best among all vertical irregularities.

Base Shear Response:

- Higher base shear occurred in Low SS and Low MI cases.
- Mid irregularities created inconsistent shear transfer, especially in taller buildings.

Material Optimization:

- G+12 MID MI used least concrete and steel.
- G+12 HIGH SS used most resources, proving inefficient.

Shape Influence:

- Square plans ensured balanced performance.
- L and T shapes showed excessive torsion and poor force distribution.

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