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Analysis of Buildings with Irregular Plan using Strong Column-Weak Beam Concept

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ABSTRACT: The project investigates the potential of buildings with irregularity to withstand earthquakes using the Strong Column-Weak Beam (SCWB) concept. The research involves analysis of various types of building including regular shapes and those with variation such as L-shaped buildings and varying/irregular floor heights. The effect of SCWB concept on different moment capacity factors is assessed via simulations and performance evaluations. Result shows that the SCWB concept can be maintained in regular structures where a higher moment capacity factor leads to an improved performance and controlled hinge formation at beams. However, it's a different case for irregularly shaped buildings or those that have different stiffnesses like L-shaped and stiffness varied structures. This is because, due to torsional effects, there are difficulties in maintaining SCWB concept in these types of irregularities through uneven stress distribution leading to premature formation of hinges in columns thereby reducing general seismic resilience. Undoubtedly, the research underscores the certainty that performance with regard to regular buildings is improved by higher moment capacity factors; however, they tend to be ineffective in mitigating geometric and stiffness irregularities-induced complexities. For seismic design to be effectual, SCWB principles must be considered together with building-specific irregularities that guarantee structural safety and resistance during seismic events.

KEYWORDS: Strong Column-Weak Beam (SCWB), seismic performance, irregular buildings, moment capacity factors, structural resilience.

I. INTRODUCTION

Structural engineering is a field that focuses on designing and constructing large-scale structures like buildings and bridges. One principle commonly used is the 'strong column-weak beam concept'. By making columns more moment-resistant than beams, the plastic hinges shift to the beam, avoiding global damage. This allows for adequate evacuation time and beam failure to only limit to a specific storey. Uneven buildings pose a greater danger due to their large base shear, and the breakdown of regular frames without major structural irregularities is another issue. The strong beam-weak columns concept ensures the stability and integrity of the structure. If columns are weak enough to withstand compressive forces, they may buckle or collapse, leading to the entire structure's collapse. Conversely, if beams are too strong and rigid, they may not deflect and absorb bending and flexural stresses, leading to deformation and failure. The strong column-weak beam idea enables engineers to employ lighter, smaller beams without sacrificing the stability and strength of the structure, leading to a more economical use of resources. This may result in less money spent on building and materials, in addition a lighter structure that is simpler to maintain and fix. This idea is followed by international codes, which have numerous values for β (beta) for various nation codes.

$$\sum M_c \geq \beta \times \sum M_b$$

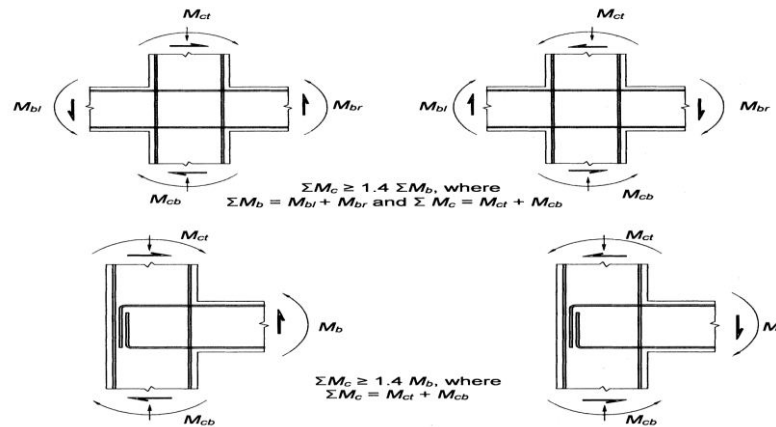


Fig 1. Strong column-weak beam requirement

Ductile design and detailing provisions were revised in 2016 by the BIS. It introduced (SCWB) provision for beam-column joint.

II. LITERATURE REVIEW

Numerous scholars have conducted in-depth investigations on the Strong Column-Weak Beam (SCWB) concept and its role in enhancing seismic performance. Sadeghi and Moctar (2023) [10] explored the plastic hinge formation in RC and steel frames, finding that RC frames provide better safety and stiffness. Poudel (2023) [3] studied the impact of SCWB on longitudinal rebar quantity (LRQ) in columns, showing significant increases in seismic zones, especially in Zone III and IV. Yadav and Manu (2022) [13] confirmed SCWB's effectiveness in reducing displacement and improving overall structural stability in a G+14 Special Moment Resisting Frame (SMRF). Raut et al. (2021) [11] highlighted SCWB's contribution to improved ductility and steel savings in beams. Similarly, Kurmi and Halder (2020) [1] emphasized the SCWB ratio's role in improving ductility and seismic resilience in buildings designed under revised seismic codes. Irfani and Vimala (2019) [2] studied the collapse mechanisms of varying SCWB ratios in buildings of different heights, showing that higher SCWB ratios improve failure patterns in columns and beams. Thakur and Chand (2019) [13] analysed various RC frames using nonlinear static procedures, noting that SCWB enhances column moment resistance. Surana et al. (2018) [14] performed incremental dynamic analyses, concluding that SCWB significantly reduces the collapse probability of RC buildings in severe seismic zones. Finally, Doshi and Doshi (2016) [8] underscored the importance of SCWB in improving lateral load-carrying capacity, while Swamy et al. (2015) [5] explored how soil type and seismic zones affect SCWB's performance, finding that structures with stronger columns and stiffer soils exhibit better seismic resilience. Collectively, these studies highlight SCWB as a crucial design approach for improving seismic safety and structural efficiency.

III. OBJECTIVES

1. Conduct a comprehensive structural analysis to be aware of how the strong column-weak beam philosophy can be applied and optimized for buildings with irregular plan.
2. Evaluate the effectiveness of the strong column-weak beam concept in mitigating the consequences of lateral loads, particularly seismic forces, on irregular shaped buildings.
3. Analysing the structure by adopting pushover analysis by taking structures with different moment capacity factor.
4. Identify potential locations for plastic hinge formation and ensure they occur in beams rather than columns.

IV. METHODOLOGY

1. SPECIFICATIONS OF MODELS

This study investigates the impact of varying moment capacity factors on the structural performance of buildings, focusing on the strong column-weak beam (SCWB) concept. We analyse both regular and irregular buildings-L-shaped and those with stiffness irregularities, across moment capacity factors of 1.2, 1.4, and 1.6. The object is to discern the

optimal strength distribution between columns and beams to ensure stronger columns relative to beams, thereby reducing the risk of column failure during earthquakes. This research aims to intensify the design of buildings for improved earthquake resistance and safety.

2. SOFTWARE USED

Modelling and analysis of buildings is conducted using ETABS software. ETABS (Extended Three-dimensional Analysis of Building Systems) is a premier software developed by Computers and Structures, Inc. (CSI) for design and structural analysis of buildings. Renowned for its advanced modelling capabilities, it allows engineers to design complex structures, including multi-story buildings, with precision. ETABS supports a wide range of loads (dead, live, wind, seismic, thermal) and offers both static and dynamic analysis. It includes numerous international design codes and standards for varied materials such as steel, concrete, and timber.

3. BUILDING MODELLING

The building is first modelled in ETABS, a widespread software utilized for structural analysis and design. The structural elements which include beams, columns, slabs, and walls, are defined accord with building's architectural plans and design specifications. The material properties, such as concrete strength and steel grade, are assigned as stated by the design requirements and relevant codes.

Grade of concrete	M25
Grade of steel	Fe550
Beam size	230mm×500mm
Column size	300mm×400mm
Slab thickness	150mm

Table 1. Material and section property

A. Regular building model

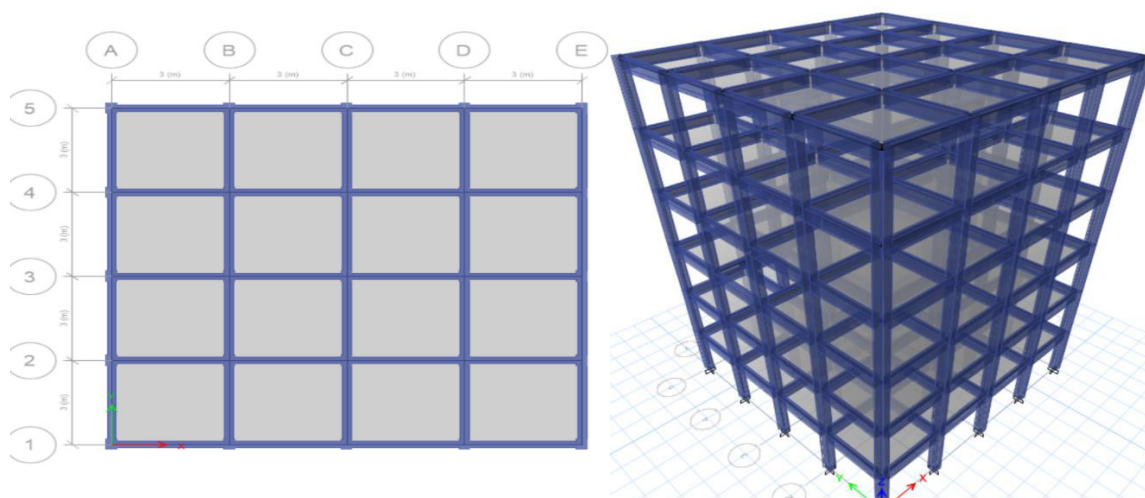


Fig 2. Plan and Elevation of Model of regular plan building

B. L-shaped (irregular plan) building

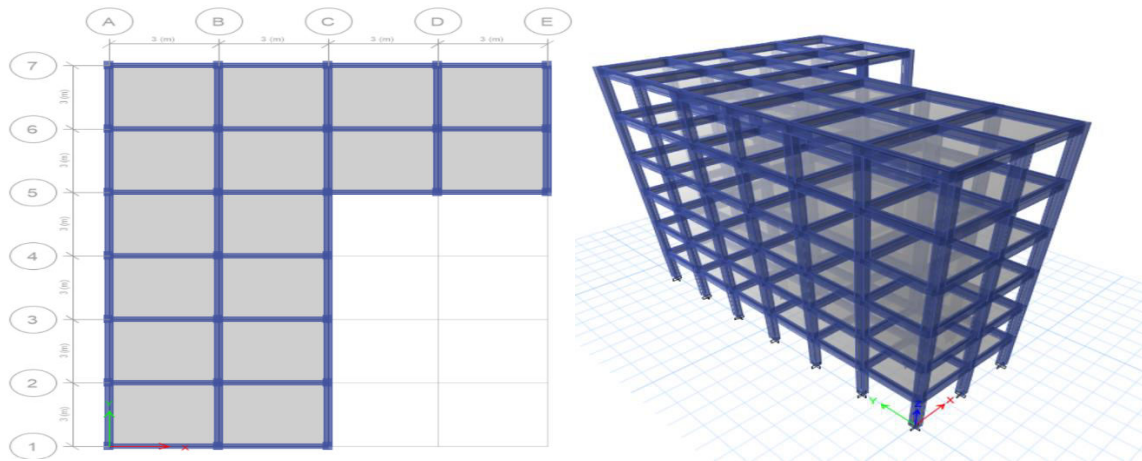


Fig 3. Plan and Elevation of Model of irregular plan building

Building has re-entrant corner type of irregularity. Movement of the wings of an L-shaped building during an earthquake result in high shear stresses combined with a stress concentration at the re-entrant corner; this is aggravated by torsional effects which develop since the centre of mass and the centre of rigidity cannot coincide in this form.

C. Building with stiffness irregularity (one storey of different height)

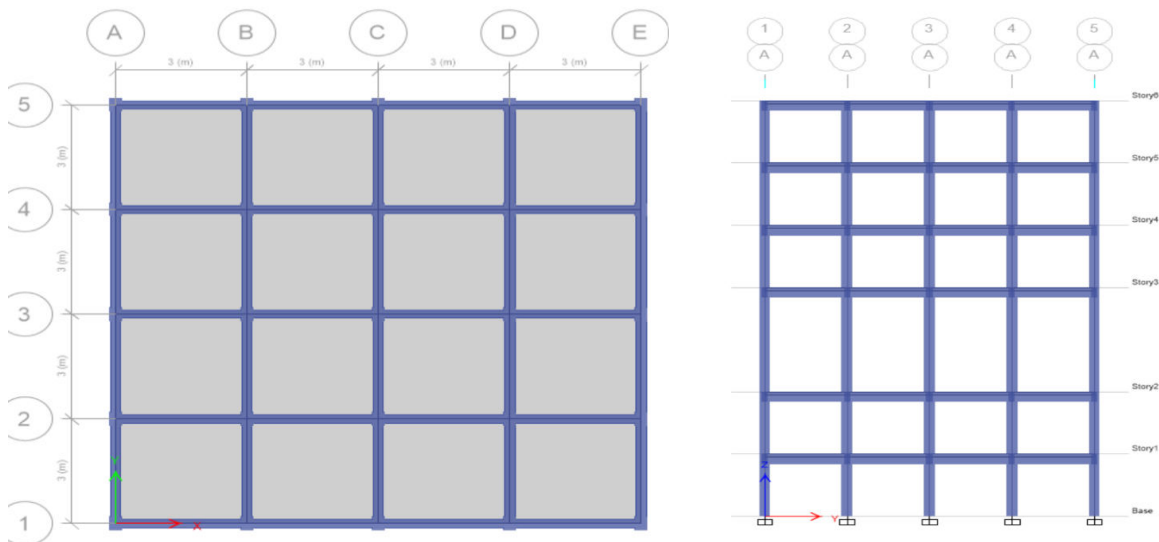


Fig 4. Plan and Elevation Model of stiffness irregular building

In this case that is the floor height and hence if the height is more, obviously the stiffness is lesser. This can create stiffness variation across floors and make the building susceptible to seismic or lateral loads. This situation is another form of irregularity and needs special attention as it qualifies in to this soft storey or weak storey case and sometimes in to both.

4. LOAD CASES AND LOAD COMBINATIONS

LOAD CASE DETAILS	
Load cases	Dead Super dead Live Seismic load (EQx and EQy)
Floor finish	1 kN/m ²
Live load	3 kN/m ² 0.75kN/m ² (Roof)
Seismic load details	Zone – 5 Site type – 2 (Medium soil)

Table 2. Load case details

LOAD COMBINATIONS			
1	1.5(DL + LL)	8	1.5(DL + EQY)
2	1.2(DL + LL + EQX)	9	1.5(DL - EQY)
3	1.2(DL + LL - EQX)	10	0.9DL + 1.5EQX
4	1.2(DL + LL + EQY)	11	0.9DL - 1.5EQX
5	1.2(DL + LL - EQY)	12	0.9DL + 1.5EQY
6	1.5(DL + EQX)	13	0.9DL - 1.5EQY
7	1.5(DL - EQX)		

Table 3. Load combinations

5. ACHIEVING STRONG COLUMN-WEAK BEAM FACTOR

To achieve the desired moment capacity ratio (SCWB factor), the reinforcement in the columns was varied systematically. The moment capacity factor, denoted as M_c/M_b (where M_c is the moment capacity of the column and M_b is the moment capacity of the beam), was adjusted to three different target values: 1.2, 1.4, and 1.6.

The column reinforcement was adjusted by varying the amount and configuration of longitudinal rebars and the column cross-sectional dimensions, while ensuring that the design met the required strength and ductility criteria. This was done iteratively within ETABS to ensure that the desired SCWB ratios were attained for each analysis case.

6. ANALYSIS OF MODELS

Pushover analysis is a nonlinear analysis that involves gradually pushing a structure following a predefined load pattern distribution. It aims to determine the maximum structural nonlinear response to seismic loads, which is determined by plotting the base shear against the control node's lateral displacement. The Pushover curve represents the building's capacity to resist lateral loads, while the response spectrum represents the seismic demand imposed by the earthquake. The object is to find a common point between the structure's capacity and the seismic response spectrum, known as the performance point, to decide the structure's ability to withstand earthquake loads.

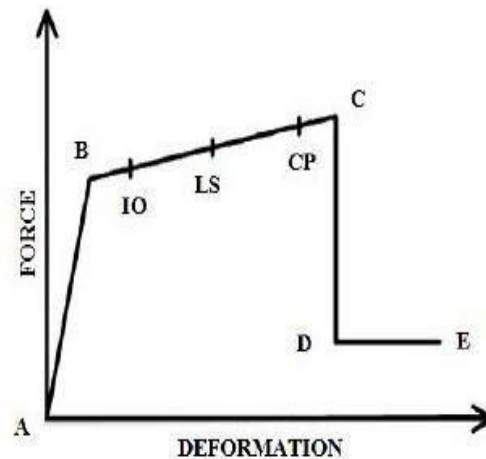


Fig 5. Typical pushover curve

To assess the advancement of plastic hinges and validate the effective implementation of the SCWB concept, a study was conducted on a model building. Making sure hinges formed in the beams was the main objective in order to keep columns from collapsing during seismic occurrences. The optimal reinforcement plan was identified by collating the results of the evaluation of the building's performance for the three SCWB factors (1.2, 1.4, and 1.6).

V. RESULTS AND DISCUSSIONS

1. HINGE RESULTS

- For regular buildings with moment capacity factors of 1.2, 1.4, and 1.6, the analysis consistently confirms the effective application of the "Strong Column, Weak Beam" design concept. Hinges predominantly form in the lower and middle story beams across all factors, with columns remaining largely unaffected. This behaviour demonstrates that beams are successfully absorbing lateral forces and yielding as intended, thereby maintaining column integrity and overall structural stability. The design effectively ensures the building's resilience to seismic forces and mitigates the risk of collapse.
- As the moment capacity factor increases from 1.2 to 1.6, the irregular L-shaped plan of the building increasingly disrupts the "Strong Column, Weak Beam" (SCWB) concept. At a factor of 1.2, the building mostly adheres to SCWB principles, though some uneven stress distribution is observed. At a factor of 1.4, stress concentrations and early column hinge formations indicate deviations from SCWB as result of plan's irregularity. By a factor of 1.6, column hinges become more pronounced, and the irregular shape exacerbates torsional effects and stress concentrations, leading to significant SCWB deviations. Overall, higher moment capacity factors exacerbate the plan's irregularities, undermining the SCWB concept and compromising the building's seismic resilience.
- The building's seismic performance is significantly impacted by stiffness irregularity across different moment capacity factors. At 1.2, the SCWB concept is partially maintained, but irregularity causes stress and potential column failure in lower stories. At 1.4, irregularity leads to severe hinge formation in beams and columns, causing stress concentrations and deviations from ideal SCWB behaviour, especially in the lower stories. At 1.6, irregularity continues to disrupt the SCWB concept, leading to significant hinge formation, particularly in the lower and middle stories. Across all moment capacity factors, retrofitting and strengthening are necessary to enhance seismic resilience and maintain structural integrity.

2. BASE SHEAR V/S DISPLACEMENT RESULTS

a. Regular building model

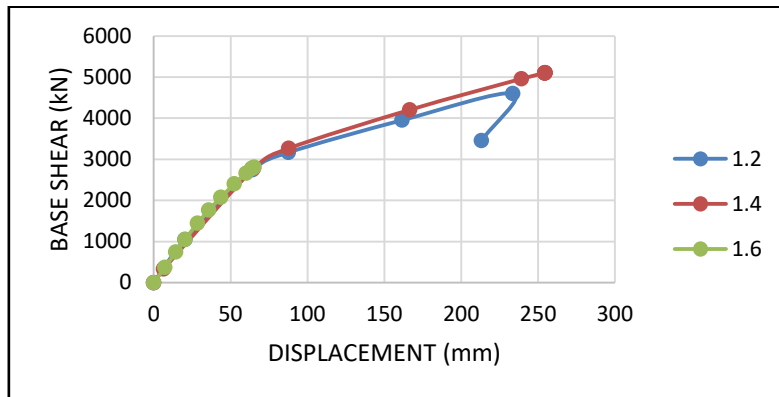


Fig 6. Base shear v/s displacement graph of regular building

The graph demonstrates that buildings designed with higher moment capacity factors (1.4 and 1.6) perform better in terms of both base shear resistance and displacement capacity. This is a direct result of a stronger implementation of the SCWB concept, where beams are designed to yield before columns, allowing for controlled energy dissipation and preventing catastrophic structural failure. In contrast, the building with a moment capacity factor of 1.2 shows earlier signs of yielding and reduced ductility, highlighting the importance of adhering to the SCWB concept for improved structural resilience.

b. L-shaped (irregular plan) building

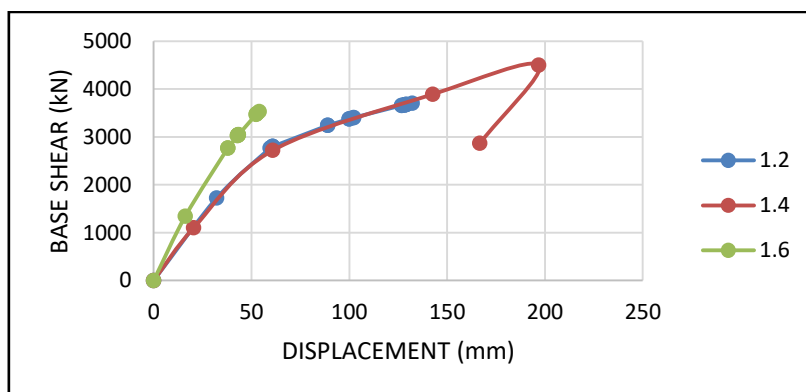


Fig 7. Base shear v/s displacement graph of L-shaped (irregular plan) building

For the lower moment capacity factor (1.2), the early drop in base shear suggests that the building may not fully adhere to the SCWB concept, potentially leading to hinge formations in columns and undesirable failure mechanisms. As the capacity factor increases to 1.4 and 1.6, it is better able to resist base shear, indicating a more robust design. However, the sharp drop in the 1.4 curve indicates that even with a higher factor, the L-shaped irregularity may cause premature or sudden failures.

c. Building with stiffness irregularity (one storey of different height)

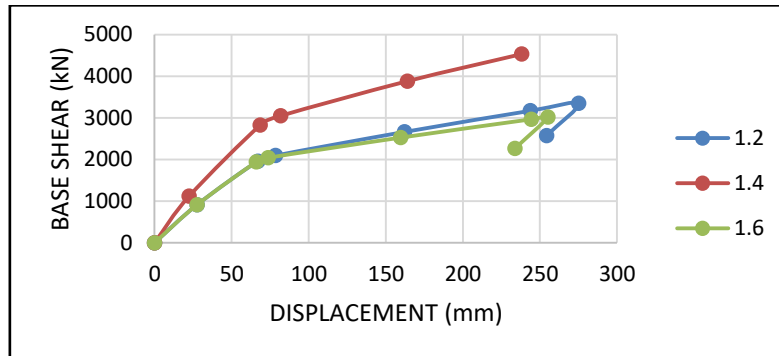


Fig 8. Base shear v/s displacement graph of building with stiffness irregularity

The building's stiffness irregularity challenges the SCWB concept by causing uneven stress and unexpected column hinge formations. With a 1.2 factor, the building struggles with irregularities, leading to early failure. The 1.4 factor shows better ductility and stability, maintaining SCWB principles despite the irregularity. However, the 1.6 factor, while initially handling higher base shear, eventually experiences a sharp performance drop, indicating that higher moment capacity alone may not offset the results of stiffness irregularity.

3. PERFORMANCE POINT RESULTS

Type of building	Regular building					
Moment capacity factor	1.2		1.4		1.6	
Direction	Push-X	Push-y	Push-X	Push-Y	Push-X	Push-Y
Shear(kN)	4417.61	4351.67	3420.04	5216.84	2669.06	3707.32
Displacement(mm)	213.3	78.9	100.65	103.26	60.54	61.88
Spectral acceleration (Sa)	0.33	0.32	0.25	0.39	0.19	0.27
Spectral displacement (Sd)	179.4	63.4	83.76	83.33	48.79	49.45
Type of building	L-shaped(irregular)					
Shear(kN)	3666.96	4082.74	4481.51	4698.01	2274.54	3425.62
Displacement(mm)	127.81	63.98	195.47	89.64	48.21	51.48
Spectral acceleration (Sa)	0.26	0.29	0.32	0.33	0.16	0.24
Spectral displacement (Sd)	105.77	52.06	167.76	73.94	38.59	41.68
Type of building	Building with stiffness irregularity					
Shear(kN)	3250.11	4702.37	2701.45	3939.15	2986.55	4346.88
Displacement(mm)	257.95	212.07	208.50	170.68	248.49	199.83
Spectral acceleration (Sa)	0.27	0.38	0.22	0.32	0.25	0.36
Spectral displacement (Sd)	226.22	183.82	184.22	151.85	221.64	174.59

Table 4. Performance point details

The performance point in pushover analysis tells the amount of lateral force and displacement the building can handle during an earthquake, indicating the likely damage level and whether the building meets safety and performance objectives. It's a vital tool for evaluating and improving a building's seismic resilience. In Regular Building, shear Capacity in Push-X direction, reduces with increase in moment capacity factor (from 4417.61 kN to 2669.06 kN). In the Push-Y direction, it initially increases and then decreases (4351.67 kN to 3707.32 kN). Displacement decreases with an increase in moment capacity factor in both directions (213.3 mm to 60.54 mm in Push-X; 78.9 mm to 61.88 mm in Push-Y). In L-Shaped (Irregular) Building, in the Push-X direction, shear capacity increases with the moment capacity factor (from 3666.96 kN to 4481.51 kN) and then decreases. In Push-Y, it follows a similar trend (4082.74 kN

to 3425.62 kN). Displacement reduces with increasing moment capacity factor (127.81 mm to 48.21 mm in Push-X; 63.98 mm to 51.48 mm in Push-Y). In Building with Stiffness Irregularity, shear capacity initially decreases in Push-X (from 3250.11 kN to 2701.45 kN), then increases slightly. In Push-Y, it decreases overall (from 4702.37 kN to 4346.88 kN). Displacement decreases as the moment capacity factor increases (from 257.95 mm to 248.49 mm in Push-X; 212.07 mm to 199.83 mm in Push-Y). Regular building shows a larger decrease in shear capacity (4417.61 kN to 2669.06 kN, ~39.6%) compared to the L-shaped (3666.96 kN to 2274.54 kN, ~38%) and stiffness irregularity building (3250.11 kN to 2986.55 kN, ~8.1%). Regular building shows a significant reduction in displacement (~71.6%) compared to L-shaped (~62.3%) and stiffness irregularity building (~3.7%).

In Push-X regular building shows higher spectral acceleration in 1.2 compared to both irregular types, but at 1.4, the L-shaped building experiences 28.1% higher acceleration. At 1.6, the regular building again shows higher S_a than the L-shaped building by 26.9%. In Push-Y regular building generally maintains higher S_a values compared to the irregular types, but the spectral acceleration becomes closer at higher moment capacity factors, especially with the stiffness irregular building. In Push-X regular building shows 41.2% higher spectral displacement at 1.2, but for higher moment capacity factors like 1.4 and 1.6, the L-shaped building outpaces it, showing 100.3% and 243.7% higher spectral displacement, respectively. In Push-Y regular building tends to have smaller spectral displacement values compared to the L-shaped and stiffness irregular buildings, showing that the irregular buildings experience more movement under seismic forces.

In conclusion, regular buildings generally perform better with lower displacements and more consistent base shear and spectral values across different directions. Irregular buildings, especially L-shaped or with stiffness irregularities, tend to experience higher deformations and reduced shear resistance, particularly in weaker directions, which may make them more vulnerable to seismic forces. However, irregular buildings, especially those with stiffness irregularity, show lower reduction in performance under increased moment capacity.

VI. CONCLUSION

This project highlights the complex interplay between building geometry, stiffness irregularity, and moment capacity factors in seismic performance. The Strong Column-Weak Beam concept, which is vital for ensuring that buildings remain ductile and can absorb seismic energy effectively, is significantly challenged by irregularities in both plan and elevation. The moment capacity factors (1.2, 1.4, 1.6) significantly influence the structural behaviour of the buildings. Higher moment capacity factors generally improve the overall performance, as seen in the base shear vs. displacement graphs, where buildings with higher factors demonstrate greater resilience and capacity to absorb seismic forces.

Regular buildings with higher moment capacity factors show better adherence to the Strong column-weak beam (SCWB) concept, with hinge formations primarily occurring in beams rather than columns. This indicates that the structural design is successful in ensuring that columns remain stronger, thereby enhancing the building's ability to withstand seismic forces. By increasing moment capacity factors (e.g., from 1.2 to 1.6) enhances adherence to the Strong Column-Weak Beam (SCWB) concept, ensuring beams yield before columns.

The irregular geometry in the L-shaped building introduces torsional effects, leading to different hinge formation patterns in the push-x and push-y directions. The moment capacity factors affect the degree of torsional response, with higher factors slightly mitigating the irregularity's adverse effects. Assigning higher moment capacity factors to critical structural parts that are more affected by the irregular geometry. For example, increase the factors in regions that are more prone to torsional effects (e.g., the ends of L-shaped buildings). Torsional Mitigation is done by strengthening elements along the longer side of L-shaped buildings with higher moment capacity factors can help balance the torsional response.

The stiffness irregularity, such as having one story with a different height, exacerbates the challenges in maintaining the SCWB concept. Lower moment capacity factors result in early hinge formations in columns, indicating that the SCWB concept is compromised. Even at higher moment capacities, the stiffness irregularity causes non-uniform stress distribution, leading to premature hinge formations in some scenarios. By focusing on increasing the moment capacity factor in the stories with stiffness irregularity (e.g., a taller or shorter story) to mitigate the adverse effects of non-uniform stress distribution. Complementing the increased moment capacity by enhancing stiffness in the irregular story

through additional bracing or reinforced concrete walls. This will help distribute forces more uniformly, reducing premature hinge formations.

Higher moment capacity factors enhance the seismic performance of regular buildings by maintaining the SCWB concept, ensuring hinges form in beams, not columns. In irregular buildings, increasing moment capacity in critical areas helps mitigate torsional effects and stiffness irregularities. By strategically optimizing moment capacity and addressing structural irregularities, buildings can achieve better ductility, resilience, and overall seismic performance.

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