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Investigation of Inter-Storey Drift and Deflection Control in Plan & Vertical Irregular Buildings Using Shear Walls, Dampers, & Base Isolators

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Abstract- Irregular buildings are highly vulnerable to seismic and wind-induced lateral forces due to unsymmetrical stiffness and mass distribution, often resulting in excessive displacements, drifts, and uneven axial load transfer. This study evaluates the effectiveness of advanced structural control systems—shear walls, viscous dampers, and combined damper–isolator systems—in improving the lateral performance of irregular reinforced concrete buildings. A G+10 irregular RC frame was modeled and analyzed in ETABS under IS 1893:2016 provisions. The performance parameters considered include story displacement, drift, axial loads, and base shear. Results show that the shear wall configuration, though reducing axial forces, produces the maximum displacements and base shear, rendering it unsuitable for irregular layouts. The damper-only system achieved the best performance, reducing displacements by up to 41% and keeping drift values well within IS code limits. The damper–isolator system showed a balanced response but introduced localized axial load spikes, requiring careful detailing. Overall, viscous dampers perform as the most effective and practical retrofit strategy for irregular buildings, ensuring enhanced safety and serviceability without significantly increasing seismic demand.

Keywords: Inter-storey Drift, Deflection Control, Plan Irregular Buildings, Vertical Irregular Buildings, Shear Walls, Seismic Dampers, Base Isolation Systems, Response Spectrum Analysis, Earthquake Resistance, Structural Performance.

I. INTRODUCTION

Rapid urbanization and limited land availability have resulted in the rise of high-rise reinforced concrete (RC) structures. However, irregular buildings, due to unsymmetrical distribution of stiffness and mass, are highly vulnerable to seismic and wind-induced lateral forces. Traditional strengthening techniques such as shear walls enhance stiffness but also increase base shear, leading to higher design demands.

Advanced structural control systems, including viscous dampers and base isolators, have emerged as effective alternatives. This research focuses on evaluating the comparative performance of different structural control systems for irregular buildings.

II. LITERATURE REVIEW

Atmaca et al. [1] (2018) investigated the effect of shear wall placement on the seismic performance of concrete structures by analysing models with both symmetric and asymmetric configurations. The study revealed that symmetrically positioned shear walls provide superior performance by reducing lateral displacements, stabilizing axial and shear forces, and limiting vibration periods, making this arrangement highly effective for buildings in seismic zones. Mehrabi et al. [2] (2021) examined the seismic performance of highway bridges by applying a hybrid system of viscous dampers and laminated rubber bearing pads (LRBPs). Numerical modelling under near-field and far-field earthquake scenarios showed that the combined use of viscous dampers and LRBPs significantly reduces seismic-induced displacements and residual deformations, enhancing seismic resilience.

Ganesh et al. [3] (2016) investigated the effect of shear wall location on structural performance using ETABS non-linear analysis, focusing on drift and displacement in both X and Y directions. Structures with shear walls experienced significantly reduced displacement and drift, with L-shaped shear walls proving most effective against lateral stresses. Nagendra et al. [4] analysed the impact of shear wall placement on traditional buildings by evaluating storey displacement, storey drift, and overturning moments. The study concluded that positioning shear walls at the centre or corners substantially improves stability by reducing displacements, drifts, and overturning effects, with central and corner placements proving most effective against lateral forces. B. Naresh and J. Omprakash [5] (2019) carried out a study on the seismic design of multi-storey RCC buildings with dampers using ETABS, comparing a 20-storey residential building with and without viscous dampers under different seismic zones and soil conditions. The results revealed that viscous dampers were highly effective, reducing displacement by up to 50% across all soil conditions, with greater reduction in the upper storeys. The inclusion of dampers also improved structural stiffness and reduced storey shear, particularly at higher elevations.

Hernandez Morales [6] (2020) presented a study on modelling Lead-Rubber Seismic Isolation Bearings (LRBs) using Unified Mechanics Theory (UMT), a physics-based approach that eliminates dependency on empirical curve fitting while capturing force-displacement behaviour and material degradation. The UMT-based model successfully predicted the force-displacement characteristics and degradation behaviour of LRBs, offering a reliable alternative to traditional empirical techniques. Islam, Jameel, and Jumaat [7] (2011) reviewed the behaviour of structures and installation techniques of seismic isolation systems, evaluating damping, displacement capacity, material yielding, cost-effectiveness, durability, and ease of installation. The findings revealed that seismic isolation effectively concentrates displacement and energy dissipation at the isolator level, allowing the superstructure to behave nearly rigidly during seismic events.

Besharatian et al. [8] (2024) proposed a practical optimization method for friction tuned mass dampers (FTMDs) in multi-storey buildings using a Particle Swarm Optimization (PSO) algorithm to fine-tune frequency and friction ratios. The optimization process, tested on structural frames subjected to real earthquake ground motion records, significantly reduced lateral drifts, confirming PSO as a practical approach for enhancing FTMD performance. Syed Aatif Hussain, & Gajendra H. [9] (2023) This study evaluates the seismic behaviour of a G+10 RCC building with mass and geometric irregularities, with and without shear walls, using ETABS software. Time History Analysis was performed to assess the structural response under earthquake loading. Key parameters such as storey displacement, storey drift, and base shear were compared. The results highlight the impact of irregularities on seismic performance and demonstrate the effectiveness of shear walls in improving the earthquake resistance of buildings.

III. METHODOLOGY

Building Data and Analysis

The following flow chart represents the methodology adopted for the analysis of plan and vertical irregularity in the building using ETABS software. Four different models—Irregular building, Irregular building with shear wall, Irregular building with dampers, and Irregular building with dampers + isolators—were modelled in ETABS and analysed using the linear analysis method.

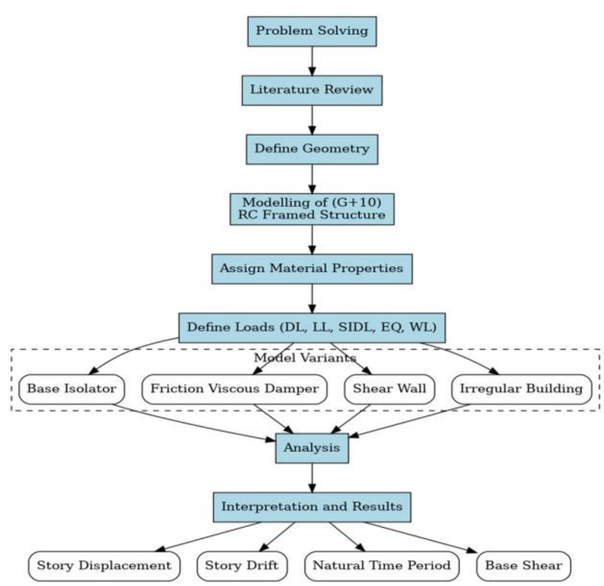


Fig. 3.1: Dampers and Isolators Analysis Steps

Table 3.1: Fluid Viscous Dampers Capacity Chart

FORCE (kN)	Taylor Devices Model No.	Spherical Bearing Bore Dia. (mm)	Mid-Stroke Length (mm)	Stroke (mm)	Clevis Thickness (mm)	Max Clevis Width (mm)	Clevis Depth (mm)	Bearing Thickness (mm)	Max Cylinder Dia. (mm)	Weight (kg)
250	17120	38.1	787	±75	43	100	83	33	114	44
500	17130	50.8	997	±100	55	127	102	44	150	98
750	17140	57.15	1016	±100	59	155	129	50	184	168
1000	17150	69.85	1048	±100	71	185	150	61	210	254
1500	17160	76.2	1105	±100	77	205	162	67	241	306
2000	17170	88.9	1346	±125	91	230	191	78	286	500
3000	17180	101.6	1441	±125	117	290	203	89	350	800
4000	17190	127	1645	±125	142	325	273	111	425	1088
6500	17200	152.4	1752	±125	154	350	305	121	515	1930
8000	17210	177.8	1867	±125	178	415	317	135	565	2625

Lead Rubber Bearing (LRB) Isolator Properties

The properties of the Lead Rubber Bearing (LRB) isolators used in the ETABS model were derived from the seismic base shear and building characteristics. The total seismic base shear considered was 8,731 kN, corresponding to 5% of the total seismic weight of 174,639.45 kN. A total of 15 LRB isolators were provided, resulting in a lateral force demand of 582.06 kN per isolator. The design lateral displacement of each isolator was taken as 0.716 mm, while the vertical design compression on each isolator was 11,642.63 kN, with an assumed vertical settlement of 3 mm. Based on these values, the effective horizontal stiffness (Ke) was calculated as 819,802 kN/m, and the vertical stiffness (Kv) was obtained as 3.88×10^6 kN/m. The yield strength of each isolator was taken as 10% of the applied lateral force, giving 59 kN. For ETABS input, the horizontal spring stiffness in both X and Y directions was derived as 83,098 kN/m using the relation Kh = Fy/Δ, while the vertical spring stiffness (U3) was maintained at 3.88×10^6 kN/m. Rotational degrees of freedom about all axes were either fixed at zero or assumed very large, depending on modelling preference. The damping ratio was taken as 30%, within the typical range of 5–30% for LRBs, and the post-yield stiffness ratio (α) was assumed as 0.05, consistent with the typical range of 0.05–0.10. These calculated values form the spring properties and nonlinear link parameters necessary to represent the isolators in the structural analysis software.

Table 3.2: Geometric Data, Seismic Data, and Session Properties

Parameter	Details
Structure type	Multi-storey RCC (Irregular), G+10
Total height	~48 m (3.5 m GF, 3.0 m typical)
Structural system	Moment-resisting frame (Bare, Shear Wall, Dampers, Dampers + Isolators)
Seismic code	IS 1893 (Part 1): 2016

Parameter	Details
Wind code	IS 875 (Part 3): 2015
Zone & Soil type	Zone III, Medium soil (Type II)
Importance factor (I)	1.0
Response reduction (R)	5 (SMRF)
Damping ratio	5%
Loads	LL: 3.0 kN/m² (floors), 1.5 kN/m² (roof); Wall load: 12 kN/m (ext.), 6 kN/m (int.); Floor finish: 1.5 kN/m²
Materials	M35 Concrete, Fe 500 Steel
Beam sizes	230×450 mm, 300×600 mm
Column sizes	300×600 mm, 450×900 mm
Slab thickness	150 mm
Shear wall thickness	200 mm
Control systems	Viscous Dampers, Lead Rubber Bearings (LRBs)
Software used	ETABS 2018

IV. RESULTS AND DISCUSSION

Story Displacement

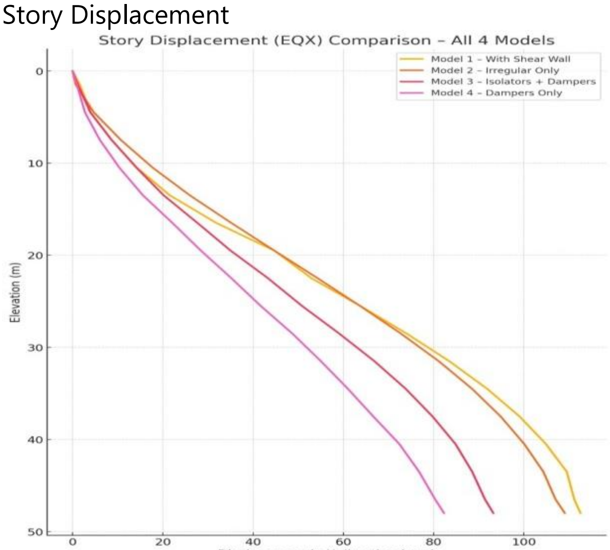


Fig. 4.1: Story Displacement in X Direction Subjected to Seismic Force

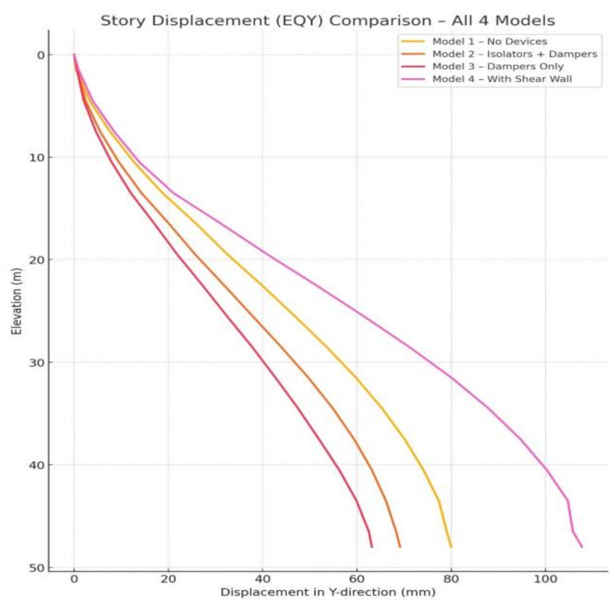
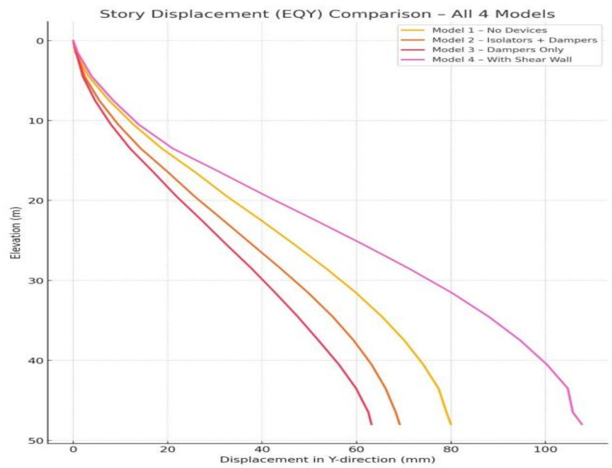


Fig. 4.2: Story Displacement in Y Direction Subjected to Seismic Force



Permissible displacement limit = 96 mm

Figures 4.1 and 4.2 show the variation of story displacement for different irregular building configurations subjected to earthquake loading. It is observed that the irregular building with a shear wall exhibits the maximum displacement in both directions (112.51 mm in EQX and 107.74 mm in EQY), exceeding the permissible limit of 96 mm, due to stiffness irregularity and torsional effects induced by the uneven distribution of shear walls, which concentrate forces and result in higher lateral movements. This indicates that the irregular building with shear wall is not suitable. The original irregular building also shows high displacements (109.04 mm in EQX), confirming its unsuitability.

In contrast, the damper-only configuration achieves the minimum displacement (82.28 mm in EQX and 63.16 mm in EQY), well within the permissible limit, as dampers effectively absorb and dissipate seismic energy, reducing lateral vibrations and enhancing structural stability.

The isolators-with-dampers configuration also improves performance (93.21 mm in EQX), but due to the flexibility of isolators, the displacement remains slightly higher than the damper-only case. Hence, the irregular building with dampers only is justified as the most suitable configuration, providing optimum seismic performance, controlled displacements, and better load distribution compared to the other irregular building systems.

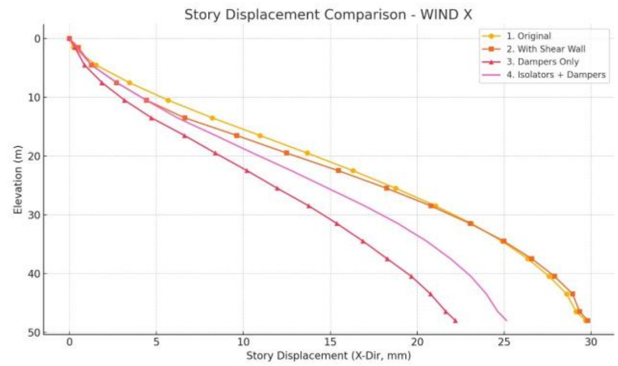


Fig. 4.3: Story Displacement in X Direction Subjected to Wind Force

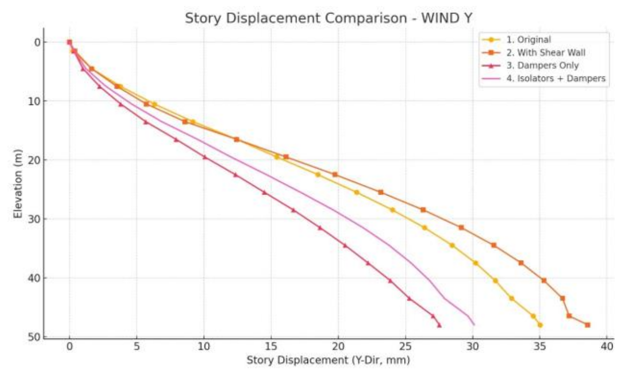


Fig. 4.4: Story Displacement in Y Direction Subjected to Wind Force

Permissible displacement limit = 96 mm

Figures 4.3 and 4.4 depict the variation of story displacement for different irregular building configurations subjected to wind loading. The shear wall model shows the maximum displacement in both directions (29.81 mm in WIND X and 38.56 mm in WIND Y) due to stiffness irregularity and concentration of lateral forces along specific planes, leading to amplified lateral sway. In contrast, the damper-only configuration records the minimum displacement in both directions (22.19 mm in WIND X and 27.52 mm in WIND Y), as dampers effectively dissipate wind-induced vibrations and control oscillations. The isolator-plus-damper model also reduces displacement (25.13 mm in WIND X and 30.12 mm in WIND Y), with performance lying between the shear wall and damper-only systems due to the additional flexibility introduced by isolators.

Importantly, all models remain within the permissible displacement limit of 96 mm as per IS

1893, confirming their safety under wind loads. Among all configurations, the irregular building with dampers only proves to be the most efficient, achieving the lowest displacements, enhancing stiffness, and ensuring more uniform load distribution.

Observation: Shear wall models recorded the highest displacements, exceeding permissible limits in the seismic case, while dampers-only models showed the minimum values, with up to a 41% reduction.

Story Drift

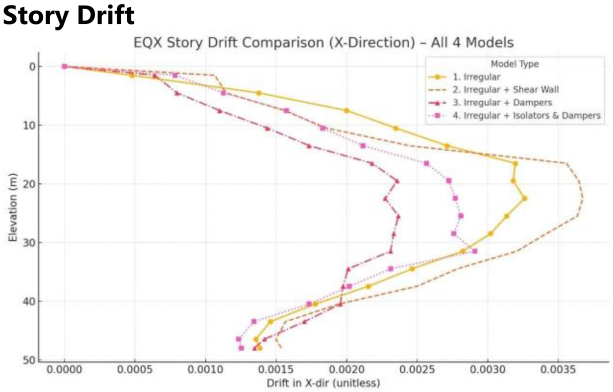


Fig. 4.5: Story Drift in X Direction Subjected to Seismic Force

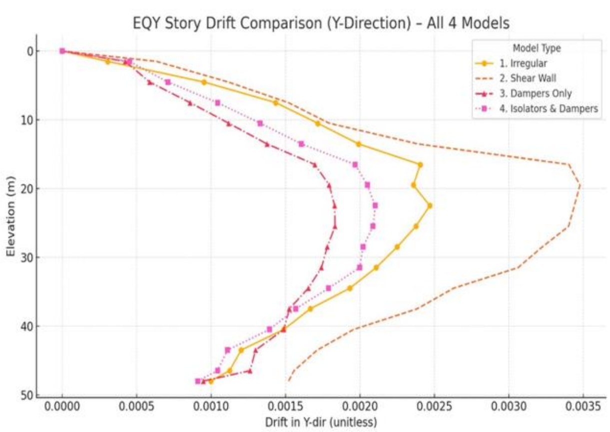


Fig. 4.6: Story Drift in Y Direction Subjected to Seismic Force

Drift limit = 0.004 as per IS 1893

Figures 4.5 and 4.6 show the variation of story drift with respect to story level for different irregular building configurations subjected to earthquake loading. The shear wall model exhibits the maximum drift values in both directions (0.0036 in EQX and 0.0034 in EQY) due to stiffness irregularity and uneven force distribution caused by the placement of shear walls in an irregular structural system. In contrast, the damper-only configuration shows the minimum drift values in both directions (0.0023 in EQX and 0.0018 in EQY), as dampers effectively absorb and dissipate seismic energy and minimize inter-storey deformation.

The isolators-with-dampers configuration also reduces drift (0.0029 in EQX and 0.0021 in EQY), with performance lying between the shear wall and damper-only models due to the added flexibility of isolators. Importantly, all models remain within permissible drift limits specified by IS 1893, but the damper-only configuration clearly provides the best performance by minimizing drift, enhancing stiffness, and ensuring better uniform load distribution. Both graphical and tabular results confirm that the irregular building with dampers only is the most suitable system compared to the other irregular building systems.

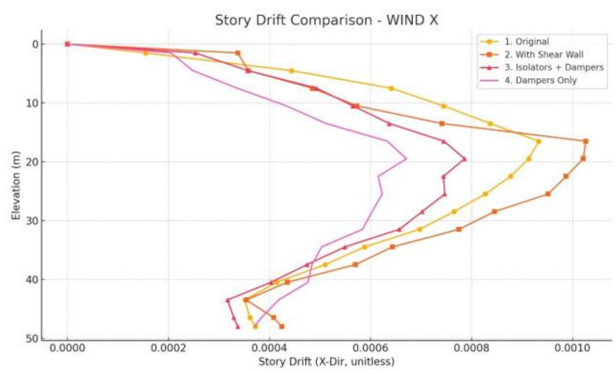


Fig. 4.7: Story Drift in X Direction Subjected to Wind Force

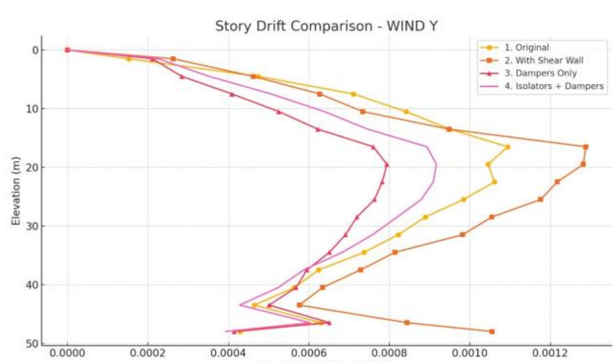


Fig. 4.8: Story Drift in Y Direction Subjected to Wind Force

Drift limit = 0.004 as per IS 1893

Figures 4.7 and 4.8 show the variation of story drift for different irregular building models under wind loading. The shear wall model records the maximum drift values in both directions (0.00102 in WIND X and 0.00129 in WIND Y) due to stiffness irregularity and concentration of forces that amplify lateral deformation. In contrast, the damper-only model achieves the minimum drift in both directions (0.00067 in WIND X and 0.00079 in WIND Y), as dampers efficiently dissipate wind-induced energy and restrict inter-storey movements. The isolator-plus-damper configuration also reduces drift (0.00078 in WIND X and 0.00091 in WIND Y), though its performance remains slightly less effective than dampers alone due to added flexibility from isolators.

All configurations remain within the IS 1893 drift limit of 0.004, confirming their safety under wind loads. However, the damper-only system proves to be the most efficient solution, providing minimum and uniform drift control, improved stiffness, and better load distribution compared to the other irregular building models.

Observation: Dampers significantly reduced drift within permissible IS limits, whereas shear walls increased drift.

Axial Load (Base Reactions)

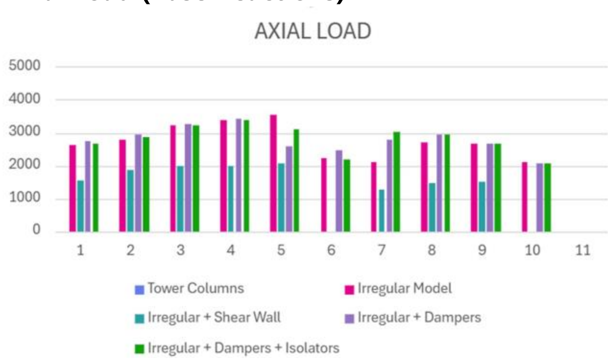


Fig. 4.9: Axial Loads Graph

Figure 4.9 shows the comparison of axial loads in tower columns for different structural configurations. For the irregular model, axial loads range between 2,600 kN and 3,500 kN, with the highest load observed in Column C44 (≈ 3,387 kN). With the addition of shear walls, the column forces reduce significantly, ranging between 1,500 kN and 2,000 kN, showing nearly 35–45% reduction compared to the irregular model. When dampers are introduced, the axial loads rise slightly in certain columns (e.g., C45 reaching ≈ 6,787 kN), indicating localized transfer of forces, but remain within the overall stable range for most columns (≈ 2,000–3,500 kN).

In the case of combined dampers and isolators, the axial load distribution becomes more uniform, with most values between 2,000 kN and 3,200 kN; however, a significant peak is observed at Column C45 (≈ 81,033 kN) due to concentration of isolator forces. Overall, the results indicate that shear walls are effective in reducing axial loads; dampers help in energy dissipation but may introduce local peaks, while dampers with isolators provide improved distribution but require careful detailing to avoid excessive concentration at critical columns.

Observation: Shear walls reduced column base reactions, dampers redistributed loads, and the damper-isolator model introduced irregular spikes (e.g., Column C45).

Base Shear

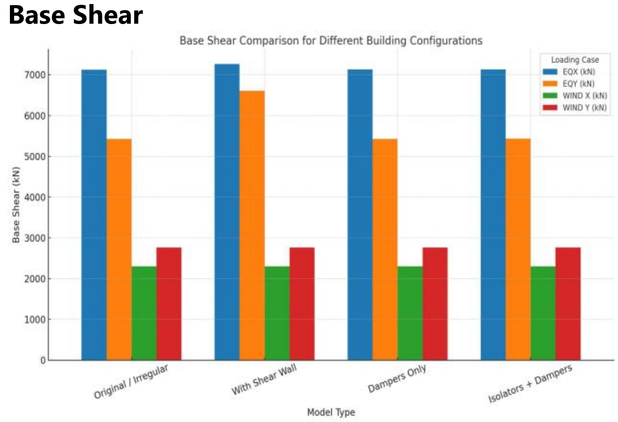


Fig. 4.10: Base Shear Graph

Figure 4.10 presents the comparison of base shear values for different irregular building models subjected to earthquake and wind loading. The irregular building with a shear wall configuration exhibits the maximum base shear under seismic loading, with values of 7,264.20 kN in the EQX direction and 6,607.50 kN in the EQY direction. In contrast, the original irregular model, the damper-only model, and the isolator + damper model show nearly identical base shear values under both EQX and EQY directions, indicating that the addition of dampers and isolators does not significantly increase the seismic base shear demand.

Under wind loading (WIND X and WIND Y), all models display almost the same base shear values, with negligible variation between configurations, indicating that lateral wind forces are not considerably affected by the introduction of shear walls, dampers, or isolators. Overall, the results suggest that the shear wall model attracts higher seismic forces due to increased stiffness, whereas the damper-based systems are effective in controlling lateral displacement without significantly altering the base shear demand.
Observation: Shear wall models experienced maximum base shear, while dampers and isolators had minimal effect.

V. CONCLUSION

The Following conclusions are drawn based on results and discussions

- Dampers significantly reduce story displacements and drifts, ensuring compliance with IS code limits while maintaining uniform load distribution and structural stability.
- Shear walls, though beneficial in reducing axial loads, result in excessive displacements, higher base shear, and drift irregularities, making them less suitable for irregular layouts.
- The combined damper–isolator system improves overall performance but introduces localized axial load concentrations, which may compromise column safety if not carefully detailed.
- Viscous dampers are recommended as the optimal structural control system for retrofitting and designing irregular buildings, offering the best balance of performance, safety, and practicality.

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