Comparative Study on Seismic Analysis of RC Framed Building with Fluid Viscous Dampers and X-Bracings

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Abstract — **This study investigates the seismic behaviour of adjacent RC framed buildings with and without supplemental damping systems—Fluid Viscous Dampers (FVDs) and X-bracings—under severe earthquake loading. Using ETABS modelling and IS 1893:2016 guidelines, three building configurations—a bare frame, an FVD-connected frame, and an X-braced frame—were analysed in seismic Zone V over medium soil conditions. Key performance indicators such as time period, base shear, storey drift, and displacement were evaluated. The bare frame showed the highest vulnerability to pounding effects, with significant displacement and drift. FVDs improved energy dissipation and reduced drift without major stiffness enhancement, making them suitable for retrofitting. X-bracing significantly improved stiffness, minimized displacement and drift, and offered superior control of base shear. Results confirm that X-bracing is the most effective for enhancing seismic resilience in adjacent high-rise buildings with limited separation, while FVDs offer flexibility for diverse applications.**

Keywords — **Seismic Pounding, Fluid Viscous Dampers, X-Bracing, ETABS, RC Buildings, Storey Drift, Base Shear, Seismic Retrofitting, Earthquake-Resistant Design, Adjacent Buildings.**

I. INTRODUCTION

A. General

Studies of past and recent earthquakes reveal that buildings are highly vulnerable to severe damage or collapse under moderate to strong ground motion. Earthquake-resistant design aims to ensure sufficient strength and ductility to protect life. One major concern is pounding between adjacent buildings with different dynamic characteristics, which vibrate out of phase. If separation gaps are inadequate or energy dissipation systems are absent, this can lead to serious damage. While providing adequate seismic separation is the most straightforward solution, it is often limited by high land costs and construction constraints. As an alternative, pounding effects can be reduced by minimizing lateral motion. This can be achieved by strategically connecting adjacent structures at key points to synchronize movement or by enhancing damping through passive control systems like fluid viscous dampers. Seismic retrofitting is also an effective method to improve energy dissipation and reduce impact forces, offering safer and more resilient structural performance.

The focus of this study is the development of an analytical model and methodology for the formulation of the adjacent building-pounding problem based on the classical impact theory, an investigation through parametric study to identify the most important parameters is carried out. A realistic pounding model is used for studying the response of structural system under the condition of structural pounding during earthquakes for medium soil condition at seismic zone V. Two adjacent multi-story buildings are considered as a representative structure for potential pounding problem.

B. Seismic Pounding Effect Between Buildings

Seismic pounding (also known as earthquake-induced pounding) is a phenomenon that occurs as a result of collisions between two adjacent buildings which occurs due to earthquake, difference in dynamic characteristics, adjacent building vibrates out of phase and also when there is insufficient separation between them. Due to different dynamic properties (natural frequencies, mass distribution, and stiffness), both buildings oscillate at different rates during the earthquake. The taller Building A sways more, while the shorter Building B moves at a different frequency. Hence, it was strongly felt that there is a necessity of making structural engineers and builders accountable for the safety and serviceability of the structures under earthquake loading.

C. Fluid Viscous Damper (FVD)

A Fluid Viscous Damper (FVD) is a device that dissipates energy in structures, reducing vibrations from earthquakes, wind, or machinery. It works by forcing a viscous fluid (like silicone oil) through orifices as a piston moves within a cylinder, creating resistance proportional to velocity. This process absorbs kinetic energy and controls motion. FVDs help reduce impact forces and relative movement between adjacent buildings, improving safety and structural resilience. Their adaptability makes them suitable for both new construction and seismic retrofitting to mitigate pounding effects.

D. X Bracing

X-bracing is a type of lateral load-resisting system commonly used in steel structures to enhance their stiffness and strength against horizontal forces, including seismic loads. It consists of two diagonal members that cross each other, forming an "X" shape within a bay of the structural frame.

The effective application of X-bracing in mitigating seismic pounding necessitates careful consideration of stiffness compatibility, structural strength, deformation control, energy dissipation capacity, holistic integration within the structural system, and the detailing of robust connections. Although not a replacement for sufficient building separation, well-engineered X-bracing can substantially enhance a structure's dynamic performance and reduce the likelihood and severity of earthquake-induced impacts, making it a valuable component in comprehensive seismic design strategies.

II. REVIEW OF LITERATURE

Mujeeb et al. (2019) makes a useful contribution by systematically comparing different FVD placement strategies in a common building type. It clearly demonstrates the significant benefits of using FVDs (particularly in corner locations) for reducing seismic demand (displacements, shears) and enhancing stiffness. The comparison between Pushover and Time History analysis results also provides context for engineers choosing appropriate analysis methods. The findings reinforce the value of FVDs as an effective passive control device for improving the seismic performance of RCC structures.

Sudheer S. and Shyam Chamberlin. K (2018) conducted study on the response modelling of RC frames with various bracing systems on an eight-story building. They discovered that X-bracing efficiently reduced storey drift, displacement, and increased the building's rigidity.

Shehata E Abdel Raheem (2006) carried a parametric study on buildings pounding response as well as proper seismic hazard mitigation practice for adjacent buildings. For input, three different types of recorded seismic excitation are adopted. The effect of impact is examined using both linear and nonlinear contact force models for different separation distances, and the results are compared with a nominal model that does not account for pounding. At different stories level, pounding results in acceleration and shear that are higher than those seen in the no pounding situation, while the input excitation characteristics determine the peak drift. In addition, expanding the gap width is probably going to work best when the distance is practically large enough to prevent contact.

III. OBJECTIVES AND METHODOLOGY

A. *Objective of the Project*

1. To determine the suitability of the beams & columns sections for the buildings in the ETABS software.
2. To assess and compare the seismic performance of the RC framed buildings incorporating with fluid viscous dampers & X bracings using equivalent static method, response spectrum method.
3. To check the variations in parameters including base shear, storey drift, lateral displacements, and natural frequencies.

B. *Steps Involved in Earthquake Resistant Design*

- Assess site seismicity, ground motion, and nearby structures.
- Define acceptable damage, focusing on preventing impact between buildings.
- Plan layouts with seismic joints or strong connections for movement.
- Use ductile, impact-resistant materials with sufficient strength.
- Analyse earthquake forces and relative displacements between structures.
- Design members and joints for strength, ductility, and impact loads.

- Ensure foundation stability considering soil and differential settlement.
- Secure non-structural elements to reduce collapse and debris risk.
- Follow codes, especially on seismic separation provisions.
- Get independent review and regulatory approval for pounding mitigation.
- Ensure accurate construction of seismic joints to specified widths.
- Retrofit vulnerable buildings with joints, links, or impact zone reinforcements.

IV. STRUCTURAL MODELING AND ANALYSIS

For the purpose of evaluating the seismic response of different lateral force resisting systems, the present study analyses, using ETABS, three distinct building configurations: two adjacent bare frame buildings, one G+10 and one G+15, a frame structure incorporating fluid viscous dampers, and a frame structure reinforced with X-bracings.

Figure 1: Plan of Fifteen Storey (G+15) and Ten Storey (G+10) Adjacent Building
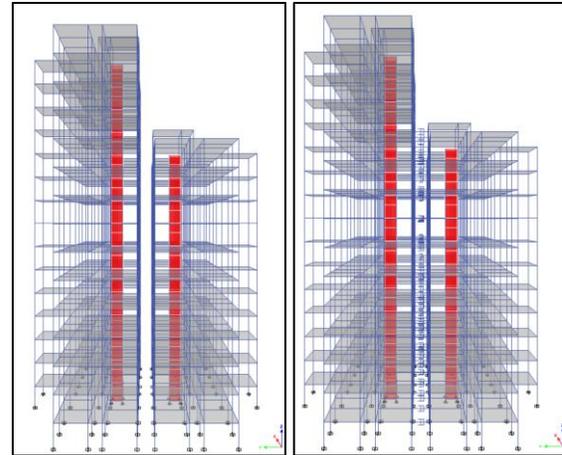

Figure 2: 3D view of G+15 and G+10 adjacent Bare Building (Left Side) and Building connected with Fluid Viscous Damper (Right Side)
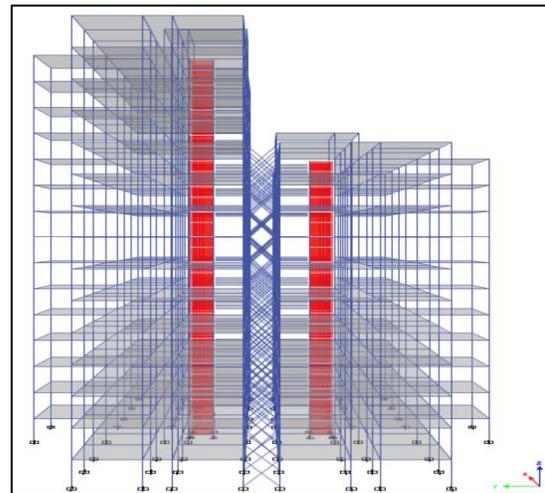

Figure 3: 3D view of G+15 and G+10 adjacent Bare Building connected with X Bracings

A. *Structural Details of Model*

- Number of Stories – 10 and 15 (Two separate buildings)
- Storey Height – 3.60 m
- Seismic Zone Factor, Z – V (0.36)
- Structure Type – RC buildings with special moment-resisting frame (SMRF)
- Response Reduction Factor, R – 5.0
- Importance Factor, I – 1.5

- Soil Type   –   II - Medium or Stiff Soils

B. Material Properties

The material used in the structure is concrete for beam and column members and slab respectively. Fe500 grade of steel and M30 grade of concrete are used for all the models used in this study. Parameters considered for this study is given below.

C. Sectional Properties

The structural elements of the building are specified with the following dimensions: The slab has a thickness of 150 mm. Beams are provided in two sizes—300 mm x 600 mm and 450 mm x 750 mm. Columns come in four different sizes: 900 mm x 900 mm, 750 mm x 750 mm, 600 mm x 600 mm, and 450 mm x 450 mm. The walls have a uniform thickness of 230 mm.

D. Gravity Loads

The self-weight of the structural elements such as beams, columns, and slabs are automatically computed by the software used for analysis and design. Additional loads, such as wall loads, have been calculated separately and assigned as uniformly distributed loads on the beams. The wall load applied on all the floors is 14.50 kN/m², while the wall load on the roof is considered as 3.60 kN/m.

E. Live Loads

Live loads, as defined by IS: 875 (Part 2) – 1987, are dynamic vertical forces from occupancy and use, including people, furniture, and equipment. For this project, classified under business and office buildings, live loads are applied as uniform area loads on slabs. The loads considered are: 2 kN/m² for water closets, 2.5 kN/m² for the EE chamber, 3.5 kN/m² for the computer room, 4 kN/m² for canopy, account room, passage, and technical room, 5 kN/m² for store and record rooms, and 1.5 kN/m² for accessible flat roofs with slopes up to 10 degrees.

F. Load Combination

The load combinations shall be considered as specified in respective standards due to all load effects mentioned therein IS: 875 (Part 5) – 1987. In addition, those specified in the IS 1893 (Part 1): 2016 code shall be applicable, which include earthquake effects.

V. RESULTS AND DISCUSSIONS

A. Variation of Time Period for Different Building Models

The natural period (T_a) of a structure is a critical factor in its seismic behaviour. The natural period of a structure reflects its dynamic characteristics, specifically how long it takes to complete one full cycle of vibration during seismic activity. A shorter period typically indicates a stiffer structure, while a longer period suggests a more flexible one. In this case, the manually calculated time period is 1.556 seconds, which serves as the benchmark for expected stiffness and dynamic performance. When comparing this to the three analytical models:

- Bare Model: Time period of 1.964 s, higher than manual value, indicates high flexibility and larger seismic displacements.
- FVD Model: Time period of 1.958 s, similar to bare model, shows effective energy dissipation but minimal stiffness increase.
- X-Bracing Model: Time period of 1.618 s, closest to manual value, reflects improved lateral stiffness and better seismic control.

Therefore, the X-Bracing model is the best option, as it closely matches the manually calculated period and provides enhanced seismic resistance through increased stiffness.
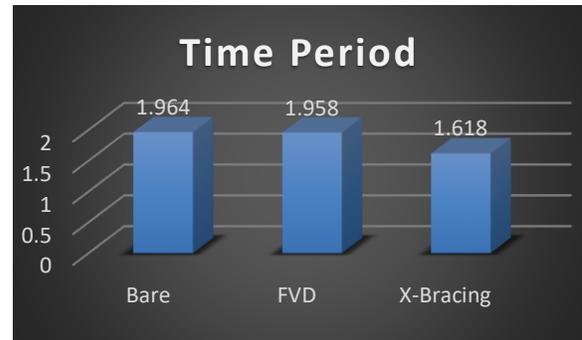

Figure 4: Comparison of Time Period of Different Models w.r.t Equivalent Static Analysis

B. Variation of Base Shear for Different Building Models

The analysis of base shear values in the X and Y directions under different structural configurations – Bare Frame, FVD (Frame with Viscous Dampers), and X – Bracing reveals key insights into the performance of each system under seismic loading.

In the X-direction, the FVD system provides the highest base shear (9985.95 kN), which indicates superior lateral resistance due to the energy-dissipating properties of the viscous dampers. This system is ideal for areas with significant seismic

activity, where reducing displacement and controlling the forces is critical.

In the Y-direction, X-Bracing shows the highest base shear (8877.20 kN), slightly outperforming the FVD system, which registers 8706.17 kN. This suggests that X-bracing provides more efficient lateral force resistance in this direction, likely due to its direct transfer of forces through the bracing members.

Overall, the FVD system is the most effective in terms of base shear in the X-direction, while X-Bracing performs better in the Y-direction. The choice between these systems depends on the specific design needs and seismic load conditions. FVD is recommended where energy dissipation and control of lateral movements are prioritized, while X-bracing might be more suitable in applications where cost-efficiency and performance in the Y-direction are crucial.
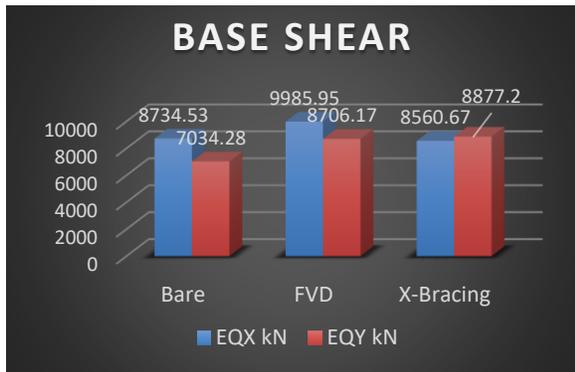

Figure 5: Comparison of Base Shear of Different Models w.r.t Equivalent Static Analysis along X & Y Direction

C. *Variation of Displacement for Different Building Models*

The analysis is conducted in the FEM software ETABS. The displacement was measured for both cases of Equivalent static forces and Response spectrum forces along both X and Y direction.

The Displacement was observed to be maximum for Bare Framed Building reduced for Framed Building with fluid viscous dampers further reduced for Framed Building with X – Bracings condition, this pattern is observed because the bracings is providing the desired stiffening effect and mitigating the pounding effect between the G+15 and G+10 structures. To strengthen the lateral stiffness of the building, bracing systems are primarily used in structural design. This results in reduced lateral displacements and improved overall structural performance, including reduced pounding

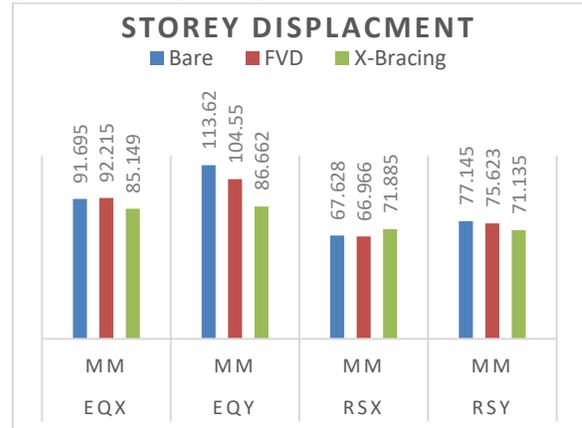effects. Displacement for Equivalent static force is greater than response spectrum.

Figure 6: Comparison of Maximum Displacment of Different Models w.r.t Seismic Analysis along X & Y Direction

D. *Variation of Storey Drift for Different Building Models*

Story drift is the lateral displacement between floors during seismic or wind events. Excessive drift can damage non-structural elements and affect stability. The X-Bracing model shows the least drift, indicating better stiffness and improved performance under lateral loads.
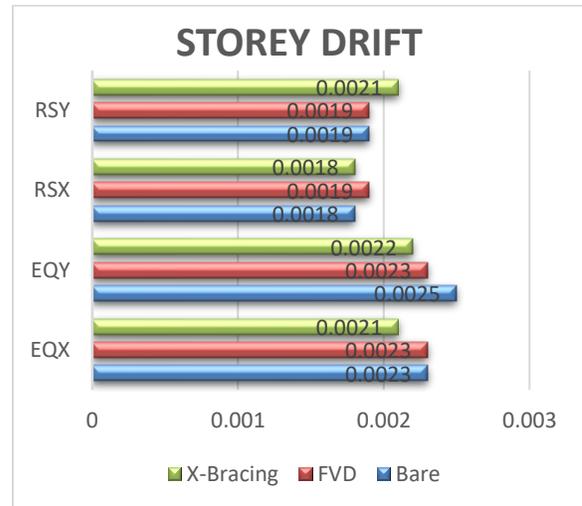

Figure 7: Comparison of Maximum Storey Drift of Different Models w.r.t Seismic Analysis along X & Y Direction

1. EQX and EQY (likely lateral forces in X and Y directions):
- The "Bare" model has slightly higher values, indicating more displacement under lateral forces.
- "FVD" reduces these values a bit, showing improved stability compared to "Bare."

- "X-Bracing" has the lowest EQX and EQY values, which suggests that it's the most effective in controlling lateral displacements.

2. RSX and RSY (possibly related to lateral shear or stress in X and Y directions):

- "Bare" and "FVD" models show similar RSX and RSY values.
- "X-Bracing" has slightly increased RSY compared to others, which might be due to the bracing transferring forces more effectively in one direction while slightly increasing stress in another.

The X-Bracing model shows the greatest reduction in lateral displacements (EQX and EQY), highlighting its superior stability compared to the Bare and FVD models. While RSY in X-Bracing is slightly higher, this is likely due to the bracing effectively transferring forces. Overall, the X-Bracing model improves lateral stiffness, making it the most effective among the three.

Additionally, story drift, which measures the relative lateral displacement between consecutive floors, is a critical consideration in structural engineering. Excessive drift can damage non-structural components and compromise the structure's stability. The reduced displacements in the X-Bracing model suggest that it also minimizes story drift, enhancing safety and resilience under dynamic forces.

VII. CONCLUSION

This study analyzed the seismic performance of adjacent RC framed buildings with and without supplemental systems like Fluid Viscous Dampers (FVDs) and X-bracings. Using ETABS and following IS 1893:2016, three models—bare frames, FVD-connected frames, and X-braced frames—were evaluated for dynamic behavior, displacement, base shear, and inter-storey drift.

- Bare Frame: Showed highest storey displacement and drift, highlighting its vulnerability in dense areas with limited separation gaps.
- FVD System: Improved performance by dissipating seismic energy, reducing drift without greatly increasing stiffness—ideal for retrofitting.
- X-Bracing: Best at controlling displacements and base shear due to added stiffness, reducing dynamic motion between buildings.
- Displacement Trends: Bare frames had highest top-floor displacement; FVDs reduced it moderately; X-bracing minimized sway effectively.
- Drift Control: Both FVD and X-bracing kept drift within code limits, reducing non-structural damage risk.
- Base Shear: More evenly distributed in FVD and X-braced models, lowering chances of local damage or collapse.
- Modal Analysis: Dampers and braces lowered the natural period, enhancing stiffness and dynamic stability.
- RSA Results: FVDs provided smoother displacement curves, confirming energy dissipation effectiveness.
- Practical Use: FVDs suit new/retrofit projects due to flexibility; X-bracing is ideal for high-rises needing stiffness and control.

In summary, while both FVDs and X-bracings are effective in mitigating seismic effects, X-bracings are recommended for buildings requiring higher stiffness and displacement control, particularly in high-rise structures. They offer superior performance in limiting storey displacement and base shear, making them the more efficient option for enhancing seismic resilience in adjacent buildings.

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