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Comprehensive Review of Effectiveness of Friction Damper in High Rise Building

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Abstract—

The rapid growth of urbanization and increasing demand for high-rise buildings in seismic-prone regions have made structural safety under dynamic loading a critical concern, as conventional systems such as moment-resisting frames and shear walls, although widely used to resist lateral forces, often lack sufficient energy dissipation capacity, leading to excessive inter-storey drift, large displacements, and potential structural damage during earthquakes; to overcome these limitations, friction dampers have been extensively studied as passive energy dissipation devices, and this review summarizes findings from five key studies focusing on their effectiveness, configuration, placement, optimization, and comparative performance. The studies consistently show that friction dampers significantly enhance seismic performance by reducing base shear, storey displacement, and inter-storey drift compared to conventional systems, while providing additional damping without substantially increasing stiffness or mass, making them an economical and efficient solution. The configuration of dampers is an important factor, with X-braced systems proving more effective than inverted V-braced arrangements in controlling drift and forces, while damper placement is identified as a critical parameter, as distributing dampers along the full height of the structure provides maximum reduction in displacement, drift, and acceleration, particularly in upper storeys, ensuring more uniform energy dissipation. Optimization studies further highlight that proper selection of damper location and friction force, including parameters such as slip load and stiffness, can achieve significant improvements with a minimal number of devices, enhancing both efficiency and cost-effectiveness. Comparative analyses also indicate that friction dampers perform better in higher seismic zones, especially when combined with systems such as friction pendulum bearings, whereas other damping systems may be more suitable for lower seismic regions. Overall, friction dampers offer several advantages, including simplicity, ease of installation, reusability, and cost-effectiveness, making them suitable for both new construction and retrofitting of existing buildings, while also improving force distribution, reducing structural damage, and enhancing post-earthquake functionality and resilience; however, their effectiveness largely depends on proper configuration, placement, and parameter optimization, requiring careful engineering design, and thus they are considered a reliable and practical solution for improving the seismic performance of high-rise structures.

- **Key words**: Tall Buildings; Friction Dampers; Seismic Response; Passive Energy Dissipation; ETABS; Structural Systems; Optimization in slip load and stiffness; Storey displacement; Drift

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1. INTRODUCTION

Seismic safety in tall buildings has become a pressing concern due to rapid urbanization and the increasing frequency of high-intensity earthquakes. Conventional structural systems, including moment-resisting frames and shear walls, though widely used, often fail to dissipate seismic energy effectively. Friction dampers, as passive energy dissipation devices, have been identified as a practical and economical solution to enhance resilience against seismic loading. This literature review critically examines five research papers,[1,2,3,4] each contributing to the understanding of friction damper applications in structural engineering and also the optimization for numbers and location of friction damper. The studies cover comparative performance against shear walls,[1] bracing arrangements,[2] bundled-tube high-rises,[3] optimization strategies,[4] and seismic provisions in steel and composite buildings[5].

1.1 About the friction damper

A **friction damper** is a type of passive energy dissipation device used in buildings and other structures to control vibrations, particularly during earthquakes and strong wind loads. Its basic principle is to convert the kinetic energy generated by structural motion into heat energy through the mechanism of sliding friction. A friction damper generally consists of metallic plates, often clamped together with high-strength bolts and lined with friction materials such as brass, steel, or composite pads. When the structure is subjected to lateral forces, the relative motion between connected members causes these plates to slide against each other. The sliding action develops frictional resistance, which absorbs and dissipates a significant portion of the input energy, thereby reducing the amount of energy transmitted to the main structural components.

The **working principle** of a friction damper is similar to that of a mechanical brake system. When lateral displacements occur due to dynamic loads, the damper resists the motion by engaging friction forces at the interfaces of the clamped plates. The force level at which sliding begins can be adjusted by varying the clamping force of the bolts, which makes the device tunable for different performance requirements. Unlike viscous dampers that rely on fluid properties, friction dampers are not affected by temperature variations or aging of materials to the same extent, and they provide stable hysteresis loops with nearly constant energy dissipation capacity. The dissipated energy reduces structural vibrations, enhances damping ratio, and minimizes damage to both structural and non-structural elements. Overall, friction dampers are a cost-effective, reliable, and reusable solution to improve the seismic performance and resilience of buildings and infrastructure.

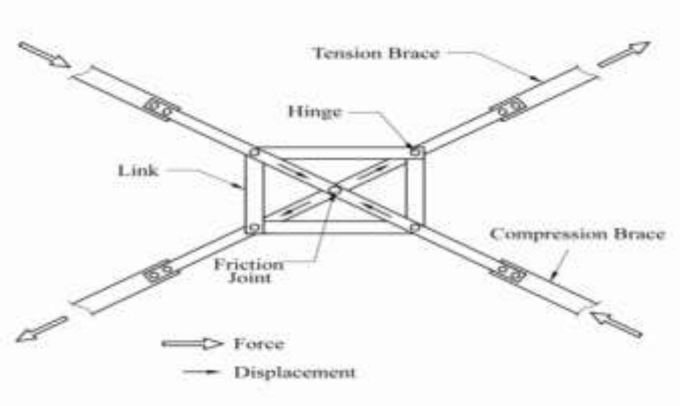
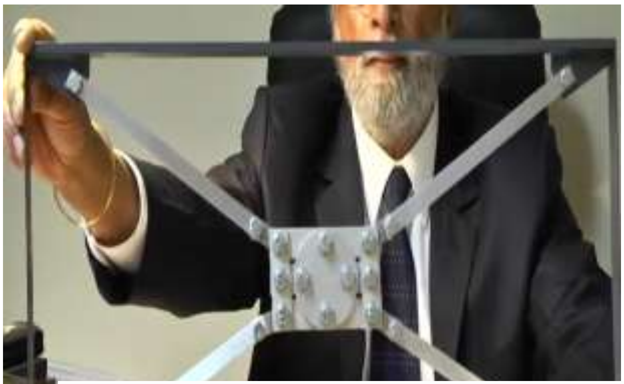


Fig.1: working of friction damper



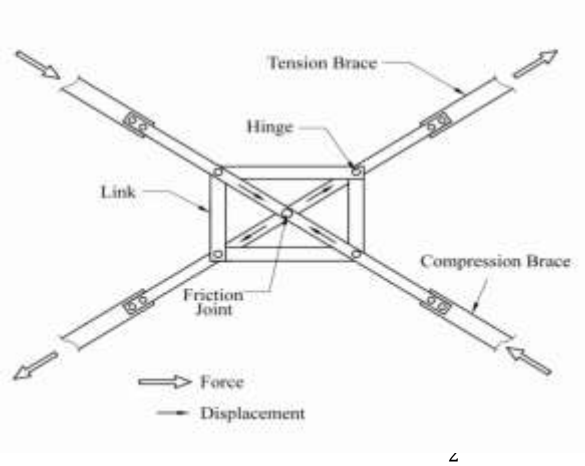


Fig.3:Diagonal friction damper

The **advantages** of friction dampers include their simplicity, robustness, and cost-effectiveness compared to other damping devices. They do not require external power supply or complex maintenance, making them reliable during seismic events. Unlike fluid-based dampers, their performance is not significantly influenced by temperature variations, and they remain effective over long service periods. They are also reusable, meaning that after an earthquake, the structure may not need complete replacement of dampers, only inspection and tightening of bolts. Furthermore, friction dampers are highly effective in reducing structural drift, controlling inter-storey displacements, and protecting both structural and non-structural components from damage.

Fig.4:Friction damper in frame

2. LITERATURE REVIEW

2.1 Majd Armaly et. al[1] motivates using friction dampers as cost-effective passive dissipation devices suitable for tall, flexible buildings located in high seismic risk zones. Majd Armaly et. al[1] note that population growth in developing countries drives demand for taller, lighter structures that must still resist earthquakes; traditional shear-wall solutions increase stiffness but can be heavy or reduce usable floor area. Friction dampers, which dissipate seismic energy through sliding friction, provide supplemental damping without altering intrinsic structural stiffness and can be relatively inexpensive and easy to install. The article situates its contribution in prior work on energy-dissipation devices and optimization of damper slip loads, and emphasizes that the originality here is a detailed seismic study of an asymmetric 40-storey reinforced concrete (RC) building under real earthquake records to compare a friction-damper strategy with a conventional shear-wall system.

2.2 Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] frames the seismic vulnerability of buildings and motivates passive energy dissipation devices as practical solutions to reduce structural damage from earthquake excitation. The authors review passive systems (viscous and friction dampers) and note friction dampers' advantages ,simplicity, reusability, velocity-independent behavior and high energy dissipation. Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] focus on comparing two friction-damper configurations X-braced and inverted V-braced in reinforced concrete (RC) moment-resisting frames. The central research question is whether and how the bracing configuration affects seismic performance (story drift, base shear) of a 7-storey RC building under multiple earthquake records, and whether X-braced arrangements outperform inverted V configurations.

2.3 Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] discusses the threats posed by earthquake and wind to high-rise buildings and frames friction dampers as an economical, easy-installed, reusable option to mitigate lateral loads. Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] focus on a **bundled-tube high-rise structural system** a configuration of interconnected tubes offering high lateral stiffness and explore how the **type** (X-type vs diagonal) and **location** (bottom, middle, top thirds, or throughout height) of friction dampers affect building response. The motivation is to determine whether damper arrangement or damper type is more influential on performance, and to identify effective damper placements to minimize response at higher stories.

2.4 Leandro Fleck Fadel Miguel et. al.[4] & Rafael Holdorf Lopez et. al[4] addresses the challenging mixed discrete–continuous optimization problem of placing friction dampers and choosing their friction forces simultaneously to minimize seismic response. While many optimization studies have targeted tuned mass dampers or viscous devices, friction dampers pose specific difficulties (non-smooth Coulomb behavior, discontinuities in forces), and there is comparatively little literature optimizing both placement (discrete) and force (continuous). Leandro Fleck Fadel Miguel et. al.[4] & Rafael Holdorf Lopez et. al[4] propose using a heuristic global optimizer the Backtracking Search Optimization Algorithm (BSA) well suited to mixed-variable, non-convex problems, and argue the method's potential practical benefits for cost-effective damper design. Two illustrative structural examples (a six-storey shear building and a transmission line tower) serve to validate the methodology.

2.5 Aishwarya Yogesh Patil et. al[5] and R. D. Patil et. al.[5] studies seismic provisions and their effects on steel and composite slab buildings with an eye to selecting appropriate damping/isolation strategies for multi-storey steel framed buildings. The authors position base isolation and dampers (viscous and friction) as key approaches for seismic mitigation and highlight that base isolation often provides superior drift reduction but that dampers can be easier to retrofit. Aishwarya Yogesh Patil et. al[5] and R. D. Patil et. al.[5] aims to evaluate G+10 steel framed buildings with various seismic provisions (including friction dampers and different isolation bearings) across seismic zones II–V using ETABS to compare responses (storey drift, displacement, base shear) and identify optimal damper/isolation combinations.

3. METHODOLOGY AND ANALYSIS

3.1 Majd Armaly et. al[1] model a 40-storey RC building (123 m height, irregular plan) and develop two structural schemes: (1) a conventional shear-wall system (fixed base) and (2) a frame system incorporating friction dampers distributed through the height with a limited number of shear walls kept for elevator cores. Majd Armaly et. al[1] used nonlinear modal time-history procedures in ETABS with the El Centro record; nonlinear hinges for frame elements and a rigid diaphragm assumption are applied. Friction dampers are idealized with rectangular hysteresis; the paper discusses computing equivalent stiffness and damping, and adopts a practical slip-load design strategy inspired by manufacturer guidance and prior studies — grouping stories into four shear-force bands and allocating damper slip loads as a portion of story shear. Several damper distribution patterns are tested (six dampers per storey, alternating patterns every two storeys) and damper properties are chosen across four types to match estimated slip forces. Majd Armaly et. al[1] compares storey accelerations, displacements, base shear, hysteretic behavior and energy dissipation between the damper-equipped frames and the shear-wall baseline.

3.2 Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] design and model three structural configurations in SAP2000: ordinary moment-resisting frames (baseline), frames retrofitted/installed with X-braced friction dampers, and frames with inverted V-braced friction dampers. The building is modeled as a 7-storey RC structure; nonlinear time-history analyses are performed using a variety of earthquake acceleration records applied simultaneously in both orthogonal directions (X and Y). The friction dampers are modeled analytically to capture their Coulomb-type hysteresis, Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] computes peak story drifts and base shear responses for each layout and ground motion. The modeling also compares multi-unit damper behavior (single vs multi-unit) and examines validation against experimental/numerical precedents from the literature.

3.3 Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] models a typical bundled-tube high-rise building and simulates lateral loading using time-history and response spectrum approaches (the methods list response spectrum and time-history among typical tools). Multiple configurations are studied: X-type dampers and diagonal dampers placed in different vertical zones (bottom third, middle third, top third) and a scheme with dampers distributed throughout the building's height. Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] used standard structural analysis software like ETABS are commonly used in the industry and evaluates peak responses such as story drift, displacement, and possibly gust/wind effects (they mention Gust Factor and wind methods in keywords). Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] the performance indicators across configurations to identify which arrangement best reduces lateral response, especially in upper stories.

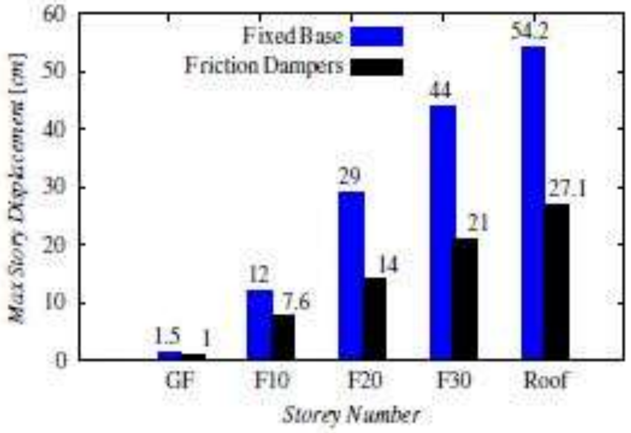
3.4 Leandro Fleck Fadel Miguel et. al.[4] & Rafael Holdorf Lopez et. al[4] formulate the equation of motion for MDOF systems with Coulomb friction damper forces and adopt a continuous regularization of the discontinuous sign function (they use tanh with a very large coefficient per previous work) to enable numerical integration. Seismic input is simulated via a Kanai Tajimi filtered white noise process for the examples. The optimization problem's design variables are damper positions (binary/discrete vector) and friction forces (continuous bounds). The BSA is used to search the mixed space: population initialization, mutation, crossover and selection operators are applied; constraints include number of available positions and allowable friction force ranges. Leandro Fleck Fadel Miguel et. al.[4] & Rafael Holdorf Lopez et. al[4] implement explicit time-integration (finite difference) of the equations of motion inside the optimization loop and evaluate objective functions that minimize maximum interstorey drift or maximum top displacement .Numerical parameters (population size, generations, integration timestep) and multiple independent runs assess robustness.

3.5 Aishwarya Yogesh Patil et. al[5] and R. D. Patil et. al.[5] develop ETABS models of a G+10 multi-storey steel framed building and run comparative analyses for multiple configurations: fixed base (baseline), models with viscous dampers, models with friction dampers, and models with base isolation systems (friction isolation, lead-plug bearings, friction pendulum systems). Seismic input is varied across seismic zones (II–V) and the response spectrum method are used to compute key response metrics. The study defines the plan and bay sizes, storey heights, and typical member details and evaluates seismic behaviors primarily by storey drift, maximum story displacement, base shear and bending moment — compiling results to identify trends across seismic zones and device combinations.

4. RESULTS

4.1 Reduction of structural parameters

4.1.1 The incorporation of friction dampers significantly improved the seismic performance of the 40-storey high-rise building. The maximum base shear reduced from **7890.76 tons** in the conventional shear wall system to **4436.85 tons**, showing a **43.77% decrease**. Roof displacement dropped from **54.2 cm** to **27.1 cm**, achieving a **49.9% reduction**. The maximum inter-storey drift ratio (IDR) decreased from **0.0123** to **0.0043** in the X-direction (**65.04% reduction**) and from **0.0066** to **0.0051** in the Y-direction (**22.73% reduction**), resulting in an overall drift reduction of about **58.53%**, keeping the values well within UBC-97 limits. These results confirm that friction dampers effectively dissipate seismic energy and significantly enhance the stability and safety of high-rise structures during earthquakes.

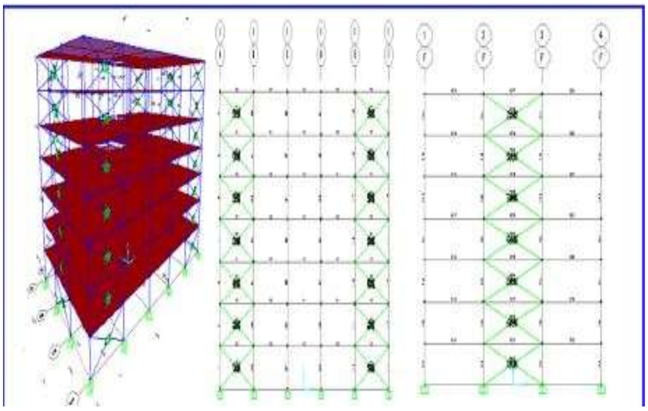


Storey displacement

4.1.2 Majd Armaly et. al[1] conclude that friction dampers, when optimally designed and positioned, can be an effective alternative or complement to conventional shear-wall systems for high-rise RC buildings in seismic regions. They emphasize that dampers reduce displacements, accelerations and interstorey drifts while adding little to the intrinsic structural mass/stiffness and that their installation is economically attractive. Majd Armaly et. al[1] recommends optimization of slip loads and arrangements (noting that sophisticated optimization for tall RC buildings is computationally expensive) and suggests that simple, intuitive grouping methods (as used in the paper) can provide practical designs. Majd Armaly et. al[1] close with directions for further work on optimization algorithms and addressing higher-mode participation in tall structures.

4.2 Performance of X-braced and V-braced friction damper

4.2.1 The study demonstrated that friction dampers greatly reduce seismic response compared to a bare frame without dampers. The **X-braced friction dampers** were found to be more effective than the **inverted V-braced dampers** across all seven earthquake records analyzed. In particular, the X-braced configuration in **Arrangement 1** achieved the **lowest storey drift ratios**, consistently outperforming the inverted V configuration. For instance, during the **Southern California earthquake**, the maximum drift ratio decreased from **0.017** in the uncontrolled structure to **0.007** with the X-braced configuration, representing a **58.8% reduction**. Similarly, the base shear force was also significantly reduced; the structures with X-braced dampers recorded lower base shear values than both the inverted V configuration and the bare frame. In some cases, the inverted V arrangement produced results close to the uncontrolled frame, indicating limited effectiveness. Overall, the use of X-braced friction dampers provided the most reliable seismic mitigation, reducing both story drifts and base shear, thereby enhancing the building's stability and safety during seismic events.

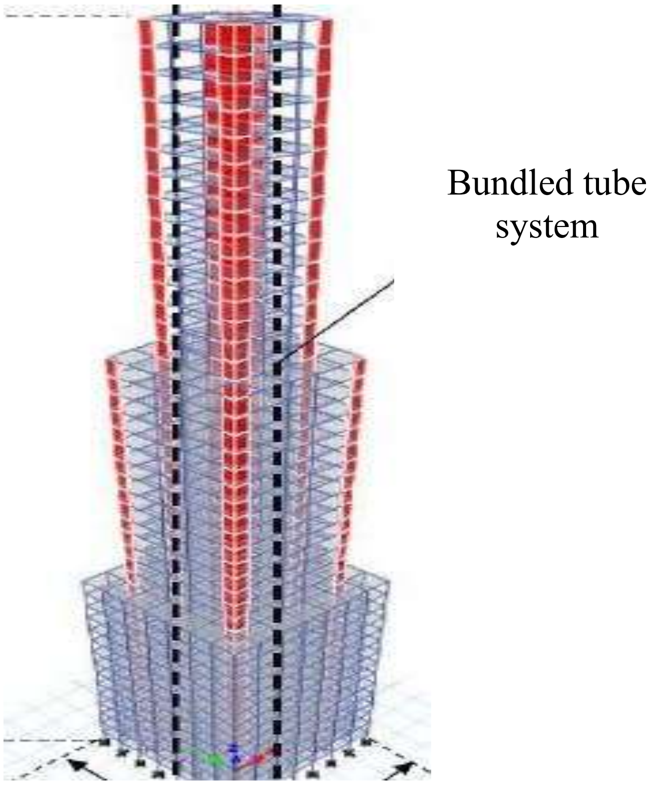


Arrangement-1

4.2.2 Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] concludes that installing friction dampers significantly improves seismic performance of RC buildings and that the specific bracing arrangement matters: X-braced configurations outperform inverted V in the modeled 7-storey case. Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] recommend X-braced friction dampers for enhanced control of drift and base shear in similar RC frames, and note the practicality of friction dampers for retrofit and new construction because of lower cost and simpler installation compared with isolation systems. Lida Afsari et. al.[2] and Hande Gökdemir et. al[2] also suggest further work on parametric studies (damper sizing, location, multi-directional effects) and experimental validation for broader design guidance.

4.3 Best arrangements of the friction damper

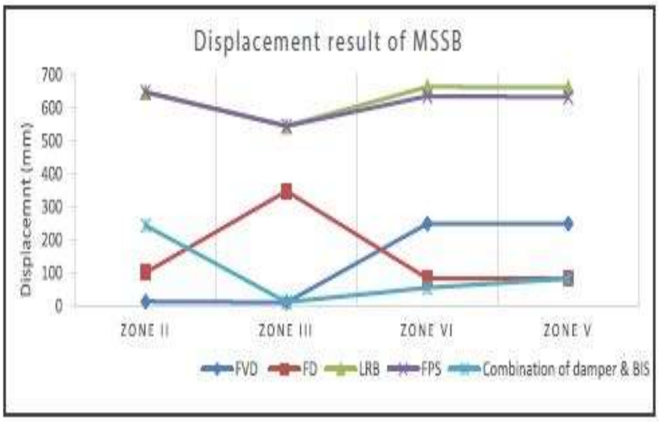
4.3.1 The study found that the **location of friction dampers** had a greater effect on seismic performance than the damper type. Among all configurations, **A6** (X-type friction dampers distributed throughout the building height) showed the best performance. Using response spectrum analysis, the **topmost storey drift** and **displacement** in A6 were **26.96%** and **19.19% lower** than those of the uncontrolled building (A1). Under dynamic gust wind analysis, A6 achieved further reductions, with storey drift and displacement decreased by **20%** and **16%**, respectively. Time-history analysis using El Centro (near-fault) and Kobe (far-fault) earthquake data showed that A6 recorded the lowest joint displacements of **58.94 mm** and **224.91 mm**, which are **33.9%** and **26%** lower than A1. Similarly, the joint accelerations for A6 were reduced to **1.11 m/s²** and **3.7 m/s²**, reflecting decreases of **15.3%** and **12.7%**, respectively, compared to A1. These results confirm that distributing X-type friction dampers across the full building height provides superior control over lateral forces, significantly enhancing stability and reducing seismic demands, especially in the upper stories.



4.3.2 Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] concludes that careful placement of friction dampers in a bundled-tube high-rise system significantly improves seismic/wind performance and that, for the cases studied, an X-type layout spanning the full height is most beneficial for protecting higher stories. Sandeep G S et. al[3] and Arun kumar Y M et. al.[3] recommend prioritizing damper **location** decisions in design and retrofitting of bundled-tube structures, and suggest that distributing dampers throughout the height yields more uniform protection than concentrating them in a single vertical third. They also note that further parametric investigations (varying damper capacity, number, and exact layout) would refine design guidance for practice.

4.5 Friction damper along with base isolation techniques(FPS)

4.5.1 The proposed optimization method significantly improved the seismic performance of both case study structures. For the **six-storey shear building**, the optimal placement and tuning of friction dampers reduced the **maximum inter-storey drift by over 65%** compared to the uncontrolled structure. In the **transmission line tower**, the maximum top displacement decreased from **0.05962 m** (without dampers) to **0.02711 m** with three optimized dampers, representing an **approximately 55% reduction**. Across different nodes, the displacement reductions ranged between **52% and 61%**, demonstrating consistent improvement throughout the structure. Moreover, when dampers were installed randomly with the same total friction force but in non-optimal positions, the maximum displacement rose to **0.04612 m**, which was **70.1% higher** than that achieved with optimized placement. These results confirm that simultaneous optimization of damper location and friction force provides a highly effective strategy for seismic vibration control using a minimal number of dampers.



Max. Displacement

4.5.2 Leandro Fleck Fadel Miguel et. al.[4] & Rafael Holdorf Lopez et. al[4] demonstrates that simultaneous optimization of friction force and placement using BSA is an effective design tool that yields substantial reductions in seismic response with only a few dampers. The method handles the mixed discrete-continuous nature and the nonlinearity of friction devices, producing robust solutions with reasonable computational cost for the sample problems. The authors recommend the methodology for practical design and retrofit tasks, while noting that uncertainty (in structural properties or seismic input) and scaling to very large structures will increase computational demands; they suggest extension to robust or reliability-based formulations as future work.

4.6 Optimized slip load and placements

4.6.1 The analysis of the G+10 multi-storey steel building revealed that seismic provisions significantly improved structural performance across all seismic zones (II–V). Dampers were especially effective, reducing **displacement by 62.45–97%**, while base isolation systems reduced displacement by only **4.65–15.52%**. In Zone II, the maximum story displacement decreased by **87.4%** and the maximum drift by **90.23%** when viscous dampers (VD) were used compared to friction dampers (FD). In Zone III, the reductions were even higher, with story displacement dropping by **85.8%** and drift by **91%**. Combining VD with lead rubber bearings (LRB) achieved displacement and drift reductions of **91%** and **47.3%** in Zone II, and **96.2%** and **97.6%** in Zone III, respectively.

For higher seismic zones, friction dampers performed better. In Zone IV, the combination of friction dampers and friction pendulum systems (FPS) reduced displacement by **91.71%** and drift by **86.89%**, while also increasing base shear by **5.8%**. Similarly, in Zone V, the same combination achieved displacement and drift reductions of **86.56%** and **78.56%**, respectively, with a **5.86%** increase in base shear. Overall, these results confirm that viscous dampers are most effective for low to moderate seismic zones, while friction dampers combined with FPS provide superior performance in higher seismic zones, enhancing both structural stability and load-carrying capacity.

4.6.2 Aishwarya Yogesh Patil et. al[5] and R. D. Patil et. al.[5] conclude that selecting the optimal seismic provision depends on desired outcomes (drift reduction vs base shear control), seismic zone, and retrofit constraints: base isolation generally minimizes drift most effectively, while dampers (friction or viscous) are effective, lower-cost retrofit options and can be preferred when base isolation is impractical. They recommend tailored combinations (e.g., viscous/friction damper plus selective base isolation) as design choices to balance cost, constructability and seismic performance. The paper also calls for further studies comparing device lifecycle cost and occupant safety/functionality under realistic earthquake scenarios.

5. CONCLUSION

- Shear wall and other conventional systems are generally preferable for low to mid rise buildings.
- X-braced friction dampers consistently produced **lower story drifts** than inverted-V.
- **Location is More Important Than Type:** The **placement** of the dampers had a much greater impact on performance than whether they were X-type or Diagonal.
- In Zones II & III (low–moderate seismicity) VD + LRB performed best in reducing both displacement and drift.
- In Zones IV & V (higher seismicity) Friction damper and FD+FPS gave better results in reducing both displacement and drift.
- The paper shows that if we optimize both the **position and the friction** force of dampers together, the building's earthquake response reduces significantly.

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