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*Original Article*

# Dynamic Performance Analysis of Reinforced Concrete Frames with Viscous Dampers Using Finite Element Modeling

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***Abstract*** *- This research evaluates the way that viscous dampers in Reinforced Concrete (RC) frames change the behavior of these structures, using FEA through ANSYS R18.0. The RC frame, configured using given dimensions and reinforcement layouts, was studied during dynamic simulations under earthquakes such as the Bhuj event. It was integrated into the frame using a stainless-steel piston and silicon-based hydraulic fluid to examine how the damper changed the structural behavior. Results from experiments were investigated to check the trustworthiness of the simulation model. Key findings show that a viscous damper cuts down lateral deflection by over 70% compared to a structure without the damper. Higher energy dissipation can be seen in the broader and larger loops shown in the load-displacement plots. Lateral acceleration was more balanced in the damped frame, confirming that it offered better handling and reduced vibrations. With these enhancements, RC frames become safer and more stable, proving again how viscous dampers handle the damaging impacts of shaking. The results emphasize the usefulness of dampers for strengthening and safeguarding RC buildings in earthquake zones.*

***Keywords*** *- Reinforced concrete frame, Viscous damper, Finite Element Analysis, Dynamic response, Seismic resilience.*

## 1. Introduction

Most civil engineers depend on RC frames due to their strength and durability for various projects [1]. RC frames still have issues when earthquakes occur, and the previous solutions have shown their limits. This study seeks to improve on that. Though all these structures do well when faced with steady and evenly distributed loads, their ability to withstand earthquakes, wind, and machine vibration must be considered [2]. Most RC frames can resist basic impacts, yet they end up destroyed by dynamic loads since they cannot control energy and undergo too much deformation [3]. A building's structure may fail so severely that it reduces its life span and sometimes leads to its complete collapse [4]. The reaction of RC frames to different actions is influenced by their stiffness, mass, damping characteristics, and the frequency of their loads [5]. During earthquakes, RC frames develop intricate stress types concentrating on the areas where the columns connect to the beams [6]. Plastic hinges at such spots can determine the structure's stability. Standard RC frames absorb energy through material cracking, steel yield, and friction between connected parts [7]. These damping methods offer limited vibration control but waste energy and weaken the structure over time when exposed to repeated loads [8]. One crucial problem is that RC frames depend mainly on cracking materials and stretching steel to reduce energy, which can cause stiffness to decrease and damage that does not heal under strong shocks. Due to these limits, buildings may collapse or fail if exposed to repeated large loads, such as those from earthquakes or vibrations, in high-seismic zones. Supplemental damping systems represent an essential solution that improves the dynamic response of RC frames. Research shows viscous dampers reduce structural vibrations by converting movement into energy dissipation [9]. Viscous dampers transform motion between internal parts in hydraulic or mechanical systems to produce heat. This system manages energy absorption to minimize building sway and acceleration-related forces [10]. Viscous dampers in RC frames bring multiple benefits to the structure. The system increases the structure's energy absorption capabilities, resulting in better protection against dynamic forces. The system safeguards buildings by decreasing both vibration strength and time duration [11]. Viscous dampers enhance building occupant comfort by reducing vibration effects in high-rise structures located in urban areas. Structures in earthquake regions gain exceptional protection from viscous dampers due to their strong safety features. The experimental setup used in this study is illustrated in Figure 1.

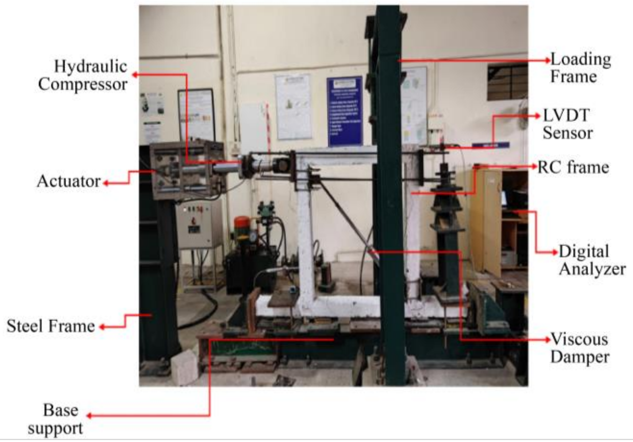


**Fig. 1 Experimental setup [12]**

Advanced analytical tools are needed to design and optimise RC frames with viscous dampers because these tools must track the detailed interactions between the building's components and the damping system. FEA stands as a necessary engineering method for current structural analysis [13]. Through dynamic simulation of materials and damping systems, FEA allows engineers to precisely forecast the behaviour of damped RC frames. It supports engineers in assessing different design solutions and identifying the best positions and features of dampers to accomplish performance targets.

RC frame performance under seismic and dynamic loads remains fundamental to structural engineering practice. [14]. RC frames face challenges with their standard energy dissipation systems, but adding viscous dampers provides a way to improve their performance. Modern design tools help engineers create reinforced concrete frames that work well under dynamic loads, ensuring safety and durability under challenging situations. [15].

In recent years, adding viscous dampers has become an effective way to boost the earthquake resistance of RC buildings. Arjmand et al. did optimal control analysis on frames reinforced with nonlinear viscous dampers and found that damage and displacement were significantly reduced [16]. Using lead viscoelastic dampers in frames made from reinforced concrete increased energy dissipation and reduced inter-storey drift in a sequence of mainshocks and aftershocks, according to Huang et al. [5].

The effectiveness of braces was evaluated in RC frames manufactured in the K-configuration by Li et al. It was discovered that repeated loading of the structure favored viscous damping systems [3]. According to Shin et al., using circular steel rod dampers in non-seismically designed RC frames produced higher damping and improved crack control [17]. Hejazi et al. also created a finite element model for RC frames, including elasto-plastic viscous dampers. They tested their method using experiments and proved that it accurately predicts hysteresis and energy dissipation [18]. These studies confirm the usefulness of viscous dampers, although most fail to check their accuracy with experiments or to simulate actual earthquake records. This study combines ANSYS and experimental testing with data from the Bhuj earthquake to give a detailed overview of how damped RC frames behave in an earthquake.

Structural engineers have tested various damping devices, including friction, viscoelastic, and tuned mass dampers (TMDs). Although friction dampers are low-cost and straightforward, their effectiveness can decrease. They generally behave non-linearly and inconsistently after being used many times. Although viscoelastic dampers help absorb energy well, they are easily affected by temperature and should be installed carefully.

TMDs are only helpful for a particular frequency range and are better for towers with minor structural irregularities. Although these improvements have been made, few studies have directly examined these systems side by side with viscous dampers in RC frame performance using verified computer modelling and real earthquake inputs. This demonstrates an area where more research is needed, which the present study helps to correct by analysing viscous dampers through experiments and FEA and positioning them as feasible and scalable for reducing dynamic loads in RC structures.

Many studies have considered damping systems for better earthquake resistance in RC frames. However, a significant research gap exists in combining tests and detailed computer modelling to check their effectiveness. Most studies use straightforward simulations or single experiments, so it’s rare to link theoretical predictions with actual behaviour during strong earthquakes.

In addition, the flexible response of RC frames using viscous dampers, mainly related to lowering acceleration, dissipating energy, and stress distribution, has not been well studied with actual earthquake information and large-scale computer simulations. Because seismic activity is rising and buildings need to be stronger, making viscous dampers a key solution for seismic protection is necessary and urgent. Their ability to work well in brand-new and retrofitted structures has made them very important for structural engineering in earthquake-prone places.

This research stands out by analysing RC frames with viscous dampers using a combination of computer modelling and laboratory experiments. Using the earthquake data from Bhuj, 2001, and careful material properties and reinforcement descriptions, this study enables a thorough examination of hysteresis, leaning, and acceleration responses. Rather than past studies, this research connects computer simulations with what is observed in practice.

Combining data improves the analysis's reliability and reveals new information about where dampers should be installed, how best to control structure responses, and how the structure can stay safe.

## 2. The Rationale for Using Viscous Dampers and Employing FEA for Analysis

Viscous dampers are added to structural systems to improve the vibration reduction of reinforced concrete (RC) frames under various dynamic loads. Viscous dampers dampen energy by turning the motion of the piston-cylinder assembly into heat. As a result of this mechanism, substantial sideways movement is less likely, vibration is well controlled, and the structure is less prone to damage inflicted by strong or constant loads [19].

Unlike conventional passive methods for releasing stored energy, viscous dampers are very effective and under user control, making RC frames safer and longer-lasting. While these alternative damping systems reduce vibrations in structures differently, they are tough to fit, not adaptable, and tend to change with the environment [20, 21]. Viscous dampers are different in that they give a reliable, flexible, and straightforward option for adding damping to any RC frame. As a consequence of having this benefit, they help increase the resistance to earthquakes.

In buildings exposed to significant side forces in seismic areas, viscous dampers reduce the response's height and speed up its disappearance. Therefore, the total stress from cyclic loading shrinks, making the structure more adaptable and functional. [22, 23]. Since they are easy to add to already-built structures, viscous dampers have a broad appeal and become practical when improving older buildings. FEA helps determine if viscous dampers are effective in improving the seismic performance of RC frames.

FEA makes it possible to compute how elements and damping equipment in a structure interact under changing conditions. Thanks to advanced software such as ANSYS, researchers can design models with nonlinear materials, formulate dynamic settings, and include damping characteristics with great accuracy [26].

FEA allows engineers to fully understand how dampers affect a construction project, allowing them to optimise dampers for effective results. Using viscous dampers with FEA helps guarantee that RC frames remain strong, safe, reliable, and durable during dynamic events. Adding viscous dampers to high-rise buildings and bridges in Japan and the United States reduces the risk of damage during an earthquake and extends their useful lives. Examining these cases helps demonstrate that using viscous dampers inside new or existing reinforced concrete frames is wise for places with significant seismic threats.

### *2.1. Objectives of the Study*

This study aims to boost the dynamic performance of RC frames exposed to dynamic loads by using viscous dampers and checking their results via FEA. RC frames are modelled in ANSYS as they behave dynamically, with viscous dampers added to assess their role in cutting down lateral deflections and unwanted vibrations and the additional ways these dampers help dissipate energy during vibrations. The study checks if the findings from finite element analysis are similar to those obtained with experiments so that the model accuracy is confirmed. It also examines how well viscous dampers increase earthquake resistance by evaluating parameters including peak deflections, hysteresis characteristics, and the response to acceleration. In addition, the research aims to offer practical design tips and recommendations so that viscous dampers are used safely and effectively to improve sacrificial RC frames in earthquake-prone areas.

## 3. Methodology

This chapter demonstrates finite element analysis of an RC frame using cement concrete and reinforcing steel. The overall shape includes a footing of 1600 mm × 550 mm × 100 mm, with two columns of 1000 mm × 75 mm × 75 mm and a 1000 mm × 75 mm × 75 mm beam. The piston, made from stainless steel, and the steel cylinder are joined by a single chamber made from the piston head. A silicon-based compressible hydraulic fluid is used in the damper with a viscosity of 350 $mm^2/s$. The ANSYS R18.0 software was employed to make a detailed dynamic loading analysis of the frame. The simulation results are then summarised and compared to experimental findings for validation and performance assessment. Servos controlled the cyclic loading frame to apply lateral loads in a way controlled by displacement. For this test, the RC frame was fixed to the base, and lateral loading was applied by a hydraulic actuator that was part of the loading frame. The programme was designed to reproduce the effects of seismic shocks using reversed cyclic loading. The system's digital interface and data acquisition software recorded real-time load and displacement information. A monitor was used to oversee the test, and the data, such as load versus displacement, was saved to check later. Before the frames were cast, concrete cubes and steel tensile tests were carried out to check the materials. All data were obtained using the same loading conditions, matching the conditions used in the finite element simulation.

### *3.1. Structural and Geometric Modeling*

The required structural model was designed using Autodesk Revit to achieve geometrical and material representations. The structural model was constructed with the specified dimensions of the 3D solid RC frame. Reinforcement bars were defined by their diameter and length, and the height and width of the structural elements defined stirrups. The frame consists of a footing measuring

1600 mm × 550 mm × 100 mm, two columns with dimensions of 1000 mm × 75 mm × 75 mm, and a beam of the exact dimensions, thus forming a strong structural configuration. The RC footing was designed to incorporate primary reinforcement in longitudinal and transverse directions.

This reinforcement consists of 8 bars with a diameter of 10 mm, spaced at 50 mm in one direction, and 10 bars with a diameter of 10 mm, spaced at 200 mm in the perpendicular direction. It included the provision of a side cover of 20 mm to ensure durability compliance and hooked end elements with a length of 50 mm and a development length of 280 mm for higher strength of bonding and better anchorage in the concrete matrix.

The beam sections were reinforced with four 8 mm diameter TMT bars placed on the neutral axis's tension and compression sides, ensuring adequate resistance to bending moments and deflections under static and dynamic loads. In addition, the beam was reinforced with high-strength wires with a diameter of 3 mm, spaced at 50 mm intervals along its entire length. IS details these reinforcement sections: 1893 (2002) specifications specified enough shear resistance and ductility, especially for seismic situations.

The concrete cover for the beam sections had a minimum thickness of 15 mm to shield the reinforcement against corrosion effects and thermal impacts. Four 8 mm diameter TMT bars were used for longitudinal reinforcement. Thus, a reinforcement percentage of 3.1% is obtained. The column section was designed to take axial load without failure. At appropriate intervals, stirrups were placed for the confinement of concrete. Hence, it increases the ductility and energy dissipation capacity when subjected to lateral loads.

The solid frame model and the reinforcement bars were assembled carefully to form a unified structural system. This integration ensures that the concrete and reinforcement act together to resist applied loads, according to the principles of composite action. The case of frames fitted with a viscous damper includes a stainless-steel piston and a steel cylinder divided into two chambers by the piston head. The cylinder is filled with a silicon-based compressible hydraulic fluid with a viscosity of 350 mm²/s. The damper is strategically integrated into the frame to ensure maximum damping efficiency without compromising the model's structural integrity.

The model was subjected to fixed-end conditions that simulate realistic support conditions. Boundary constraints were defined to represent the structural behaviour under various loading scenarios. The completed model, including the detailed reinforcement layout, is illustrated in Figures 2 and 3, which show the geometrical and material configurations adopted in the study.

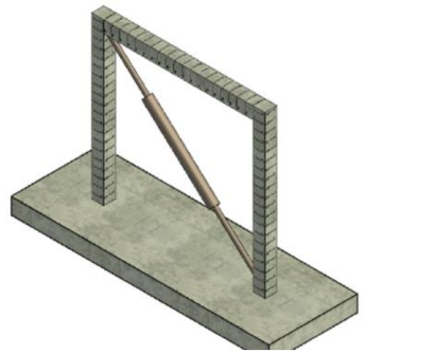

**Fig. 2 Experimental model setup [12]**

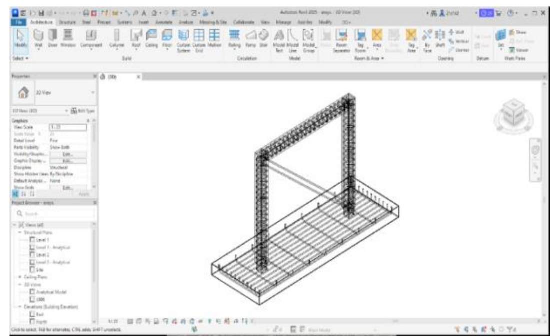

**Fig. 3 Experimental setup view [12]**

### *3.2. Material Properties*

This section imported the concrete, steel, and viscous damper properties into the ANSYS software. Properties such as density, Young's modulus, and Poisson's ratio were imported into the ANSYS software, as shown in Table 1.

**Table 1. Properties of materials**

| S.No | Concrete | Value |
|---|---|---|
| 1 | Compressive strength of Concrete (Fck) | 30.12 |
| 2 | Density of Concrete (kg/m³) | 2400 |
| 3 | Young's Modulus (MPa) | 32000 |
| 4 | Poisson's Ratio(ν) | 0.2 |

Table 2 fully details how the fluid viscous damper and its parts physically and mechanically work. These properties-Young's modulus (200 GPa), Poisson's ratio (0.3), and density (7850 kg/m³)-show that the piston and cylinder are very stiff and strong. It is unnecessary to mention the thermal expansion coefficient directly; however, it dramatically helps judge how thermal stresses influence the structure. Dynamic loads and energy absorption are assisted by the 350 mm²/s dynamic viscosity, 250 MPa bulk modulus, and 980 kg/m³ density within the silicon-based liquid in the damper. The damping capability of the damper comes from its 3250 N·s/mm damping coefficient and its velocity exponent of 1.0. This damper can handle a maximum pressure of 20 MPa, travel a stroke length of 100 mm, and has a piston velocity range of 0.4 m/s. An accurate model of the damper and its results on frame movements is achieved only with these carefully specified properties.

**Table 2. Parameters of the fluid viscous damper**

| Component | Fluid Viscous Damper | Value | Unit |
|---|---|---|---|
| Steel (Cer/ylindPiston) | Young's Modulus (E) | 200 | GPa |
| | Poisson Ratio | 0.3 | - |
| | Density | 7850 | kg/m³ |
| | Thermal Expansion Coefficient | | |
| Silicon-Based Fluid | Dynamic Viscosity | 350 | mm²/s |
| | Density | 980 | kg/m³ |
| | Bulk Modulus (K) | 250 | MPa |
| | Thermal Expansion Coefficient | $4.5 \times 10^{-4}$ | /°C |
| Damping Properties | Damping Coefficient (C) | 3250 | N·s/mm |
| | Velocity Exponent (n) | 1.0 | - |
| | Maximum Working Pressure | 20 | MPa |
| | Maximum Stroke Length | 100 | mm |
| Operating Parameters | Piston Velocity Range | 0.4 | m/s |

### *3.3. Modeling*

The reinforced concrete (RC) frame and the integrated viscous damper were modelled using ANSYS Workbench to accurately represent the structural system, as shown in Figures 4 and 5. The RC frame geometry included a footing (1600 mm × 550 mm × 100 mm), two columns (1000 mm × 75 mm × 75 mm), and a beam (1000 mm × 75 mm × 75 mm). Reinforcements were detailed with 10 mm diameter bars in the footing, 8 mm TMT bars in the beams and columns, and 3 mm wires spaced at 50 mm intervals in the beams. The viscous damper consisted of a steel piston and cylinder filled with silicon-based hydraulic fluid, modelled for its energy dissipation capabilities. The geometry was discretised into finite elements using SOLID65 elements for concrete, LINK180 for reinforcements, and COMBIN39 for the damper. The meshing was refined to capture critical stress and strain distributions, particularly in the beam-column regions. Fixed-end supports were applied to replicate real-world boundary conditions, and seismic loading (Bhuj earthquake, 2001) was simulated to assess dynamic performance, as depicted in Figure 6. In ANSYS Workbench, SOLID65 elements were used to model the nonlinear behaviour of concrete, such as cracking and crushing, in the finite element model. LINK180 elements were used to show reinforcement bars, and COMBIN39 elements were chosen to simulate the viscous damper, with its damping coefficient and velocity exponent set by the user. Sensitivity tests with meshes were run to ensure the elements were appropriately sized, and refined meshes were used at the beam-column joints to show where stress concentrations and hinges could occur accurately.

Initially, the concrete was assumed to be isotropic, and its hardening behaviour followed a multilinear pattern. Cracking was permitted in tension zones using shear transfer coefficients, each set to 0.3. A bilinear kinematic hardening law was given to the steel reinforcement. People thought concrete and steel were ideally suited for each other. Fixed-end supports were fitted at the base of the columns to represent the actual restrictions they would experience. The seismic input for the model used dynamic loading from the Bhuj earthquake of 2001, scaled accordingly. Using a step time of 0.01 s and a total duration of 30 s in the transient structural analysis module allowed us to observe the dynamic behaviour. The solver was set to use automatic time stepping and energy norm convergence checks to maintain stability.

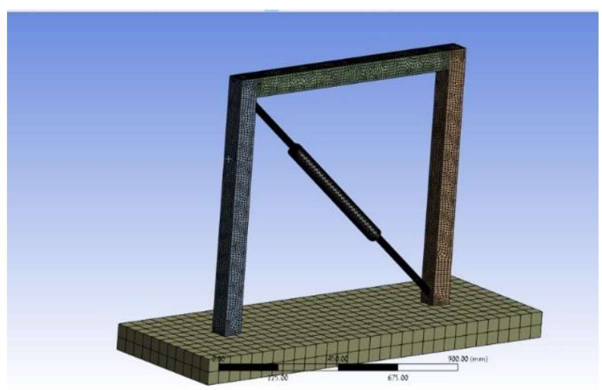

**Fig. 4 Meshing of the developed model**

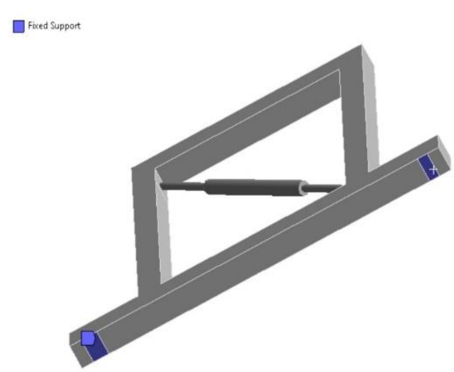


**Fig. 5 Fixed support applied to the simulated model**

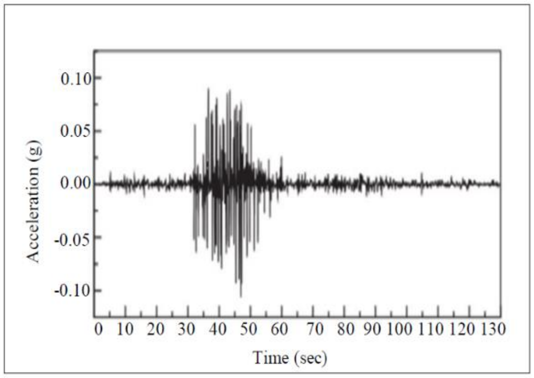


**Fig. 6 Applied loading history, Bhuj earthquake 2001- India**

Material behaviour was simplified for analysis, with concrete treated as isotropic before cracking and orthotropic afterwards and steel modelled isotropically. Perfect bonding between materials was assumed. Shear transfer coefficients were used to model crack behaviour in concrete. These simplifications provided a balance between computational efficiency and accuracy. The finite element model was validated against experimental results, ensuring reliable simulations to predict the dynamic response of the RC frame with and without the viscous damper. The model effectively captured the nonlinear behaviour, stress concentrations, and energy dissipation mechanisms critical to understanding the frame's structural performance under dynamic loads.

## 4. Results and Discussion

This study recorded and observed directional deformation, load vs. displacement behaviour, and time vs. lateral acceleration of the developed models. As can be seen from Figures 7 and 8, the RC frame without a damper displays significant nonlinear behaviour and progressive stiffness degradation. The frame depicts decreasing resistance to deformation with increasing lateral loads, leading to progressively larger displacements per load increment.

The frame's response clearly shows abrupt nonlinearity in its displacement profile and the load-displacement relationship. Such nonlinear behaviour can be attributed to the inherent properties of reinforced concrete, such as concrete cracking, steel reinforcement yielding, and bond-slip interactions between steel and concrete. These mechanisms intensify with increasing loads and lead to continuous stiffness reduction. Figure 8 shows distinct pinching characteristics in the hysteresis loops, corresponding to the concrete's energy dissipation mechanisms. Energy is dissipated due to crack opening and closing during load cycles and friction at cracked surfaces. The bond-slip interaction between reinforcement and concrete also contributes to this effect. These mechanisms prove relatively inefficient and manifest in pinched hysteresis loops that indicate progressive stiffness loss under cyclic loading. The peak loads of approximately ±12 kN occur at maximum displacement of ±12 mm. Due to such asymmetric hysteresis loops, asymmetry in loadings, material property variations, or inbuilt frame imperfections can be suspected. Small peak loads under the large displacements reflect a limited lateral load resistance capacity.

Finite element analysis corroborates these observations, showing significant transverse beam deflections reaching 8.54 mm at the top. This substantial deflection underscores the frame's susceptibility to lateral loading. The analysis identifies intense stress concentrations at beam-column interfaces, marking potential plastic hinge locations. These plastic hinges, representing zones of concentrated plastic deformation, pose risks to structural stability if extensively developed. Without a viscous damper, the frame experiences increased dynamic effects under cyclic loading. Poor energy dissipation capacity increases vibration amplitudes, making the structure particularly vulnerable to sustained and repetitive loads, such as seismic forces.

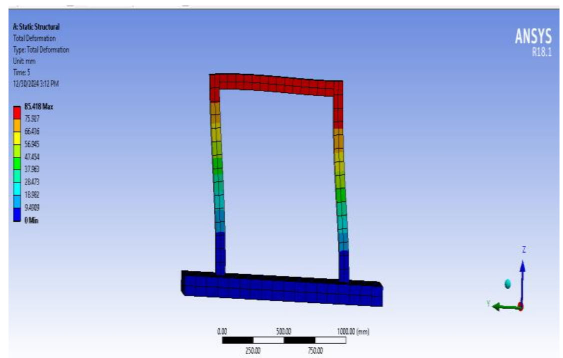


**Fig. 7 Deflection profile without damper**

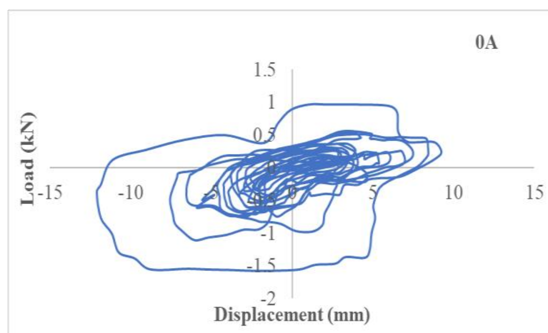


**Fig. 8 Load vs. Displacement curve of the RC frame without a viscous damper, showing pinched hysteresis loops and significant stiffness degradation under cyclic loading**

The effects of adding a viscous damper, depicted in Figures 9 and 10, lead to a complete change in the frame's structural response. The deflection profile in Figure 9 shows a significant reduction in transverse deflections compared to the undamped case. The peak deflection is much smaller, indicating that the damper effectively controls the frame's lateral movement. The deformation pattern is also more controlled, with the damper actively resisting the lateral forces.

Figure 10 presents the load-displacement graph. Compared to the pinched loops of Figure 8, much fuller and broader hysteresis loops are present. It clearly shows an improvement in the capacity for energy dissipation. The viscous damper provides a better energy dissipation mechanism than cracking and friction within the undamped frame. The larger loops indicate that the damper is dissipating energy from the system, reducing the vibrations and, thus, the damage potential. The damper effectively increases the effective damping of the frame, reducing the vibrations and stresses within the frame. This decreases the potential for structural damage by cracking and plastic hinge formation. The viscous damper dissipates the load's cyclic effect and diminishes the amplification effect due to its impact on cyclic loading. Amplitudes in frame vibration are reduced, minimising potential damage due to prolonged and repetitive loadings. Seismic performance, in general, improves as earthquake activity gains a higher capacity to endure during loading.

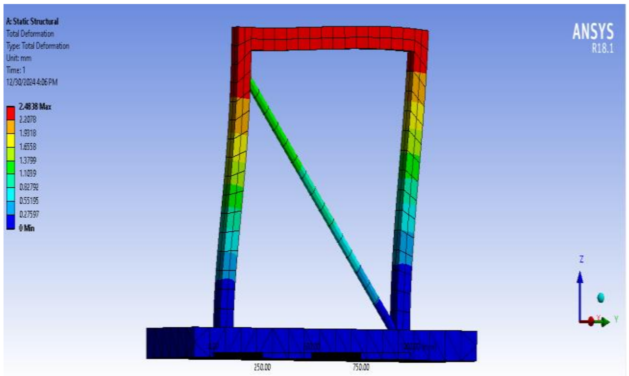


**Fig. 9 Deflection profile with viscous damper**

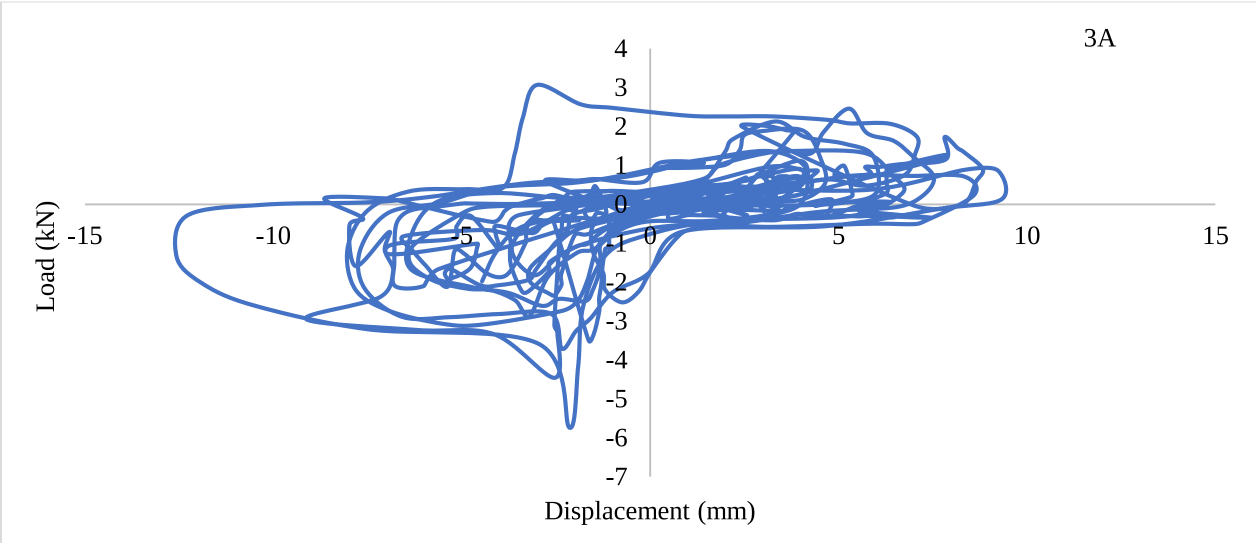


**Fig. 10 Load vs. Displacement curve of the RC frame with viscous damper, exhibiting broader, fuller hysteresis loops and enhanced energy dissipation capacity**

Figure 11 displays the lateral acceleration response of the undamped RC frame for dynamic loading in terms of time. This presents an accelerating pattern as irregular, changing from a negative value to a positive value within short durations. The acceleration response with the characteristics described is typical when a structure undergoes seismic loads since these will introduce fast and periodically varying forces to the structural system. The accelerations observed do not seem to be constant, as they show very significant differences in magnitude and direction related to the complexities of the input motion and also due to the dynamic characteristics of the frame itself. Fluctuation, as observed, signifies vibration in lateral directions, wherein the positive accelerations correspond to movement in opposite directions.

The peak value of acceleration is approximately ±0.3 m/s². Higher accelerations translate to higher inertial forces, which may induce significant stresses and potentially lead to damage inside the frame. These peak accelerations are more or less a good indicator of the severity of dynamic loading and its eventual impact on the frame's structural integrity.

The strong motion, where lateral accelerations are large, lasts approximately 5 to 25 seconds. This time interval is the most severe portion of the seismic loading since the frame suffers the highest acceleration and, thus, the most significant forces. The duration is another critical parameter for seismic design: it affects the total input energy into the structure and its potential for cumulative damage. Figure 11, with its associated characteristics, poses questions about the structural behaviour of the undamped frame. This shows that the acceleration is irregular and oscillatory, and the peak values are relatively high, which indicates that the frame is subjected to considerable dynamic forces. Without a damper, these forces would likely cause large displacements, as shown in Figure 7, and the possibility of structural damage would increase because effective energy dissipation is absent. Since the frame cannot dissipate energy properly, it will continue vibrating longer after the initial excitation, raising the chances of attaining cumulative damage due to repeated loading cycles.

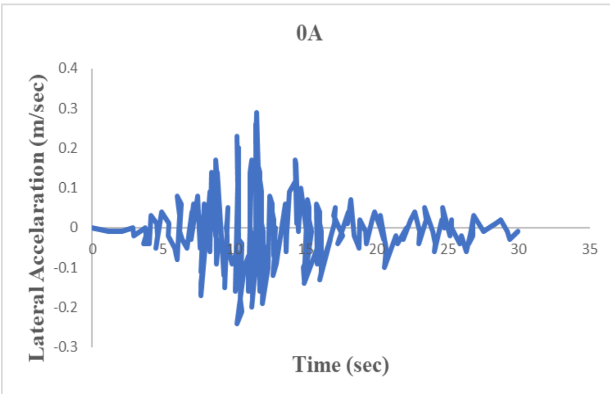


**Fig. 11  Lateral acceleration response of the undamped RC frame under seismic loading, showing high peak values and prolonged oscillation**

Figure 12 presents the lateral acceleration of the RC frame equipped with a viscous damper when subjected to dynamic loading over time. A key observation is the noticeable reduction in peak acceleration values compared to the undamped case (Figure 11). While the undamped frame experienced peak accelerations reaching approximately ±0.3 m/s², the damped frame's accelerations are significantly constrained, generally remaining within a narrower range, approximately ±0.4 m/s². This reduction in peak acceleration is a direct and crucial consequence of the viscous damper's function: absorbing energy from the system. By dissipating energy, the damper effectively limits the magnitude of the frame's acceleration response, which has profound implications for the forces experienced by the structure.

Another prominent feature of Figure 12 is the significantly faster decay of oscillations compared to Figure 11. In the undamped case, the frame oscillated considerably after the initial excitation. However, with the viscous damper in place, the oscillations diminish rapidly, bringing the frame to a state of near-zero acceleration much sooner. This rapid decay indicates the damper's effectiveness in dissipating energy and damping out vibrations. The damper's action effectively shortens the duration of strong shaking experienced by the frame, which is a critical factor in mitigating potential damage from the cumulative effects of repeated loading cycles. Furthermore, the acceleration pattern in Figure 12 appears smoother and less erratic than the jagged, irregular pattern observed in Figure 11. This smoothing effect suggests that the viscous damper reduces the magnitude of accelerations and filters out some of the higher-frequency components in the frame's response. This filtering action results in a more controlled and predictable behaviour, reducing the likelihood of sudden, sharp acceleration spikes that could induce high stresses in the frame. The smoother response indicates a more stable and predictable dynamic behaviour, which is desirable in structural design, particularly in seismic regions.

The reduced peak accelerations, the faster decay of oscillations, and the smoother response observed in Figure 12 all contribute to a significant improvement in the frame's dynamic performance. Lower accelerations directly translate to lower inertial forces, reducing the stresses and strains within the frame's structural members. The faster decay of oscillations minimises the duration of intense vibrations, thus reducing the risk of cumulative damage from repeated loading cycles. The smoother response indicates a more predictable and controlled behaviour, enhancing the frame's stability and resilience under dynamic loading conditions. Compared to the undamped case, the viscous damper substantially improves the frame's ability to withstand dynamic excitations, such as those experienced during earthquakes, as shown in Table 3.

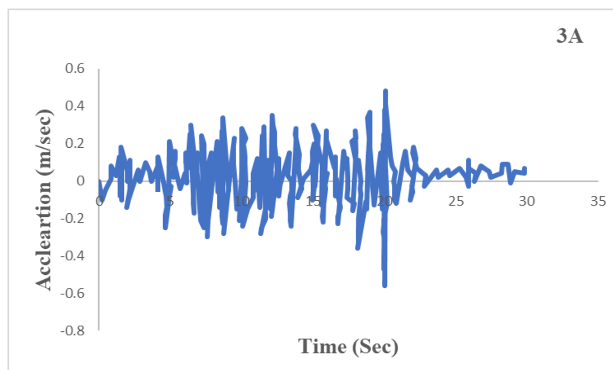


**Fig. 12  Lateral acceleration of the damped frame showing reduced peak acceleration and rapid decay, indicating improved damping effectiveness**

Unlike many earlier studies that looked mainly at simple models or friction and viscoelastic dampers [4, 10, 19], the current research performed much better in different ways. Using a viscous damper reduced lateral deflection by 70%, expanded the hysteresis loops, and decreased the time for lateral acceleration to drop. The better results are due to using ANSYS to model dampers with a velocity-dependent coefficient and actual material properties. In addition, setting the damper in the full-scale RC frame helped the structure absorb dynamic energy without much change to the stiffness path. Traditional methods of dissipating energy by friction or yielding tend to wear out quickly and are unreliable, so viscous dampers were chosen for their dependable and adjustable performance. The similarity between the results from experiments and simulations confirms the model's ability to predict seismic behaviour and proves that combining numerical and physical approaches in the analysis is useful.

**Table 3. Displacement of RC frame under cyclic loading**

| Displacement (mm) without Dampers | | | | | Displacement (mm) with Dampers | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Experiment | | Ansys | | % Difference | Experiment | | Ansys | | % Difference |
| Max Load (kN) | Max Displacement (mm) | Max Load (kN) | Max Displacement (mm) | | Max Load (kN) | Max Displacement (mm) | Max Load (kN) | Max Displacement (mm) | |
| 0.19 | 8.75 | 0.22 | 9.36 | Load =15.79 Displacement = 6.97 | 0.25 | 7.87 | 0.28 | 8.49 | Load = 12.00 Displacement = 7.88 |

The findings indicate that the experimental and ANSYS simulated results for maximum load and displacement differ by no more than 15%, which is acceptable in engineering validation. The steady results indicate that the model works just as it should in the real world. Although there is some variation, mainly in the load values, it is caused by differences in the materials, the assumed boundary conditions, and the small-scale nature of the experiments. The agreement between the two models is strong, which makes the model robust.

## 5. Conclusion

This study investigated the dynamic performance of reinforced concrete (RC) frames equipped with viscous dampers through FEA and experimental validation. Using viscous dampers led to strengthened resistance to shaking under both earthquakes and repeated loads. The model reflected how concrete, reinforcing rods, and the damper behave nonlinearly, allowing us to understand load-deflection trends, how energy is dissipated, and the acceleration response throughout the scenario. Here is the main set of conclusions from the study:

1. A viscous damper allowed the experimental RC frame to remain almost three times stiffer in lateral movements, proving better dynamic control.
2. The hysteresis loops looked more exhaustive and complete for the damped frame, revealing an increased ability to convert mechanical forces into heat.
3. The damped frame produced much smaller peak accelerations, showing how the damper managed to control inertial forces and reduce vibration.
4. FEA outcomes were very close to those from experiments, with errors within what is considered acceptable, proving the reliability of the numerical model used.
5. Thanks to the damper, the application of stresses overtime was reduced by lowering the vibration levels and their duration, which enhanced the seismic performance of the concrete frame.
6. Installing viscous dampers strengthens a building's earthquake resistance, helps save money, and keeps people safe after a quake.

The results confirm that viscous dampers are practical and effective for enhancing RC frames' dynamic behaviour and safety in places where earthquakes are common. The comparison of results, with less than 15% difference between simulation and experiment, demonstrates that the finite element model is reliable and suitable for analysing structures under dynamic stress. It would be valuable for future work to investigate how changing the damper layouts or optimising their placement can improve the behaviour of structural frames. Examining other types of dampers (hybrid, magnetorheological, or viscoelastic systems) using the same FEA-experimental validation approach would help better understand damping performance. Testing large models under dynamic simulation or on shake tables would help us better understand their behaviour. Evaluating the pros and cons of dampers and their entire performance in earthquake-prone areas would be necessary for planning in the field.

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