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Seismic Response Mitigation in G+4 Reinforced Concrete Buildings through Viscoelastic Damping Systems

Amy Thomas[1], Aryan Kumar Singh[2], Ashutosh Kumar Singh[3], Devansh Misra[4], Raghav Gangrade[5], Rohit Sahu[6]
[1, 2, 3, 4, 5]*UG Student,* [6]*Assistant Professor*
[1,2,3,]*Department of Civil Engineering, Oriental Institute of Science & Technology, Bhopal, Madhya Pradesh, India*

Abstract: ***Earthquake-induced ground motions impose significant lateral forces on structures, leading to potential damage at critical sections such as beam-column connections. Conventional structural systems often rely on increasing member stiffness or cross-sectional area to cope with seismic demands, an approach that can be both materially intensive and economically burdensome. Supplemental energy dissipation devices, particularly passive dampers, have emerged as a structurally efficient alternative that redirects input energy away from the primary load-bearing elements. This study presents a comparative numerical investigation of seismic response parameters for a five-storey (G+4) reinforced concrete (RC) framed building, modelled both with and without viscoelastic (VE) dampers. The structure is designed in accordance with the Indian seismic design standard IS 1893:2002, located in Seismic Zone II with medium soil conditions. Finite element modelling and nonlinear time history analysis were carried out using the commercially available structural analysis software SAP2000. The 1994 Northridge earthquake ground motion record (Mw 6.7) was employed as the seismic input to capture realistic dynamic demands. Critical beam sections exhibiting the highest bending moment demand were identified and selected as optimal locations for damper placement. Viscoelastic dampers were incorporated at all four exterior sides of the frame, extending throughout the building height. Key response metrics evaluated include peak top-floor displacement, inter-storey drift at each floor level, and base shear. Results demonstrate that the incorporation of VE dampers reduces peak top displacement by approximately 17.08% while significantly increasing effective base shear resistance by about 65.21%, confirming the dual benefit of energy absorption and enhanced lateral stiffness. The findings validate the practicality and effectiveness of VE dampers as a retrofit and new-construction strategy for earthquake-resistant RC buildings.***

Keywords: Viscoelastic Dampers, SAP2000, Seismic Analysis, Time History Analysis, G+4 RC Frame, Earthquake Engineering, IS 1893:2002, Inter-storey Drift, Base Shear.

I. INTRODUCTION

A. Background and Seismic Hazard in India

Earthquakes are among the most devastating natural hazards, capable of causing wide spread structural collapse and economic losses within seconds of onset. India's seismic vulnerability is well documented: approximately 54% of the country's land area lies within moderate to high seismic zones. The IS 1893 (Part 1): 2002 zonation map partitions India into four zones (II–V), with Zone V carrying the highest hazard factor of 0.36 g and Zone II the lowest at 0.10 g. The photo graph below illustrates the scale of destruction that can be inflicted by a major earthquake, underscoring the urgent need for robust seismic mitigation strategies in structural design.

Fig.1.1–Structural devastation from the 2015 Nepal Earthquake (Mw7.8), illustrating the vulnerability of unreinforced and poorly detailed RC construction.

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B. Problem Statement

Conventional design philosophy relies on ductility and controlled plastic hinging at beam-column joints to dissipate seismic energy. While effective in preventing collapse, this approach leads to costly post-earthquake repairs and can compromise structural serviceability. Supplemental passive damping devices address this limitation by providing an alternate energy-absorption pathway that preserves the primary structural frame. Among passive devices, viscoelastic dampers are particularly well suited for simultaneous wind and seismic mitigation owing to their combined stiffness and viscous damping characteristics.

C. Objectives

The study aims to:

- Develop a calibrated 3DSAP2000 model of aG+4 RC building per IS1893:2002.
- Identify critical sections from bending moment and shear force envelopes.
- Install and optimize VE dampers at identified critical locations.
- Perform non linear direct-integration time history analysis using the1994 North ridge record.
- Quantitatively compare peak displacement, inter-storey drift, and base shear between b are an damped frames.

II. LITERATURE REVIEW

A substantial body of research supports the use of passive dampers for seismic response control. Zahrai and Mortezaei (2009) demonstrated thatVEdamperssignificantlyreducedisplacementandaccelerationdemandsinRC buildings under near-field ground motions, while noting temperature and frequency sensitivity of damper performance. Muley, Kazi, and Barbude (2015) reported up to 50% displacement reduction in multi-storey buildings fitted with VE dampers in Zones II and V.

Eramma and Pulakeshitha (2015) found that X-braced friction dampers increase effective base shear and reduce storey displacement across G+5 to G+15 frames. Naresh and Omprakash (2018) extended this work to ETABS- based studies, confirming that storey-level placement of viscous dampers consistently reduces deflection. More, Patil,and Takkalaki(2019)reportedinter-storeydriftreductionsofupto78%withfluidviscousdampersinazigzag arrangement, and a 40% reduction in fundamental period. These findings collectively motivate the present comparative investigation on a low-rise G+4 building in Zone II using real recorded ground motion.

III. STRUCTURAL MODELLING

A. Building Geometry

The structure is a G+4 moment-resisting RC frame with a symmetric35m×35m plan and a uniform inter-storey height of 3.5 m (total height 17.5 m). Seven bays of 5 m span are provided in each direction. Key geometry parameters are tabulated below.

Table3.1–Structural Geometry Parameters

Parameter	Value
Number of Stories	G+4 (5 storeys)
Storey Height	3.5 m
Number of Bays X&Y	7 ×7
Bay Width	5 m(both directions)
Column Size	0.4 m×0.4 m
Beam Section	0.3 m×0.3 m
Slab Thickness	0.12 m
Seismic Zone	Zone II(IS 1893:2002)
Soil Type	Medium Soil
Total Height	17.5 m
Plan Area	35 ×35 m

B. Floor Plan and Column Layout

The architectural floor plan, consistent across all five storey, accommodates residential accommodation including bedrooms, living halls, kitchen, toilets, and a pooja room. The column layout follows a regular 7×7 grid at 5 m centers in both directions. Plans are presented in Figures 3.1 and 3.2.

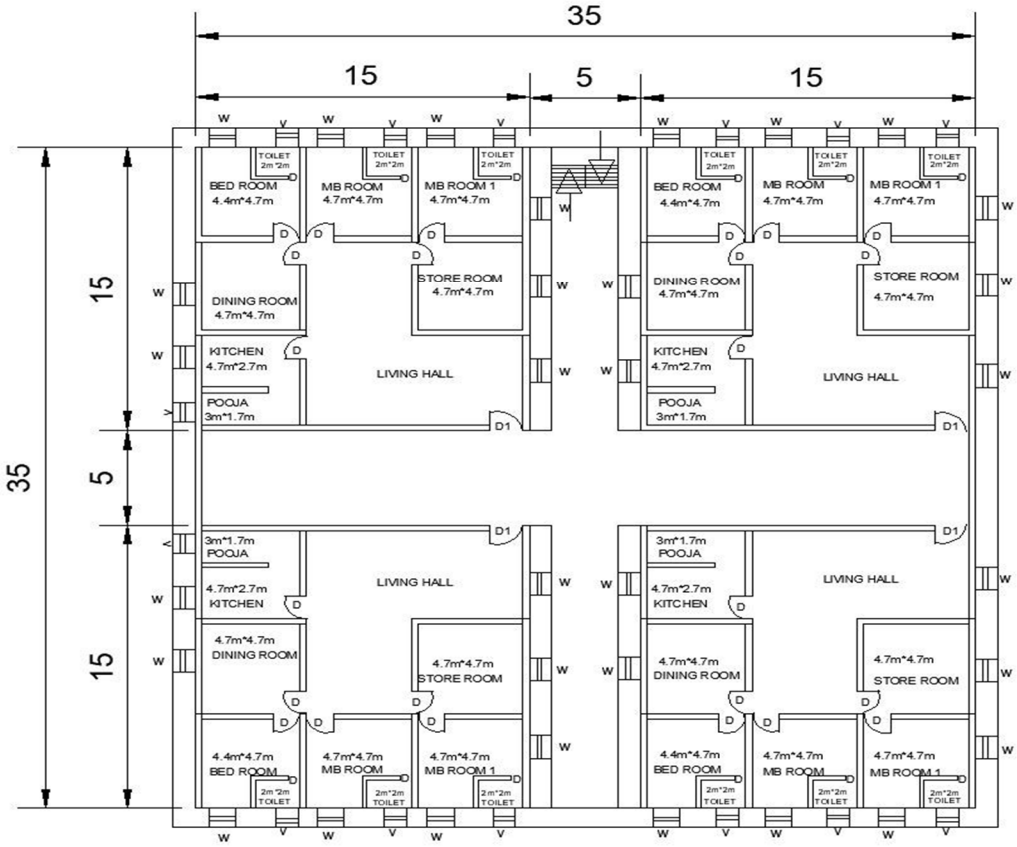

Fig.3.1– Architectural floor plan for the 5-storey RC frame buildings (35m×35m; plan identical for all storey's).

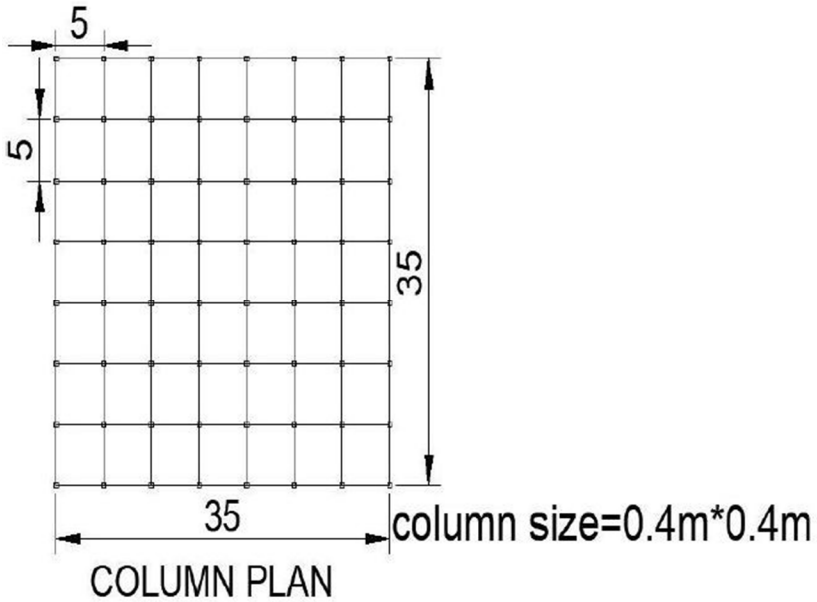

Fig.3.2–Column plan showing the regular 7×7grid layout; column size=0.4m×0.4m;bay width=5m.

C. SAP 2000 Finite Element Model

The three-dimensional model was constructed in SAP2000 using frame elements for beams and columns, and shell area elements for floor slabs. Fixed boundary conditions were applied at column bases. The extruded 3D view of the bare RC frame is shown in Figure 3.3.

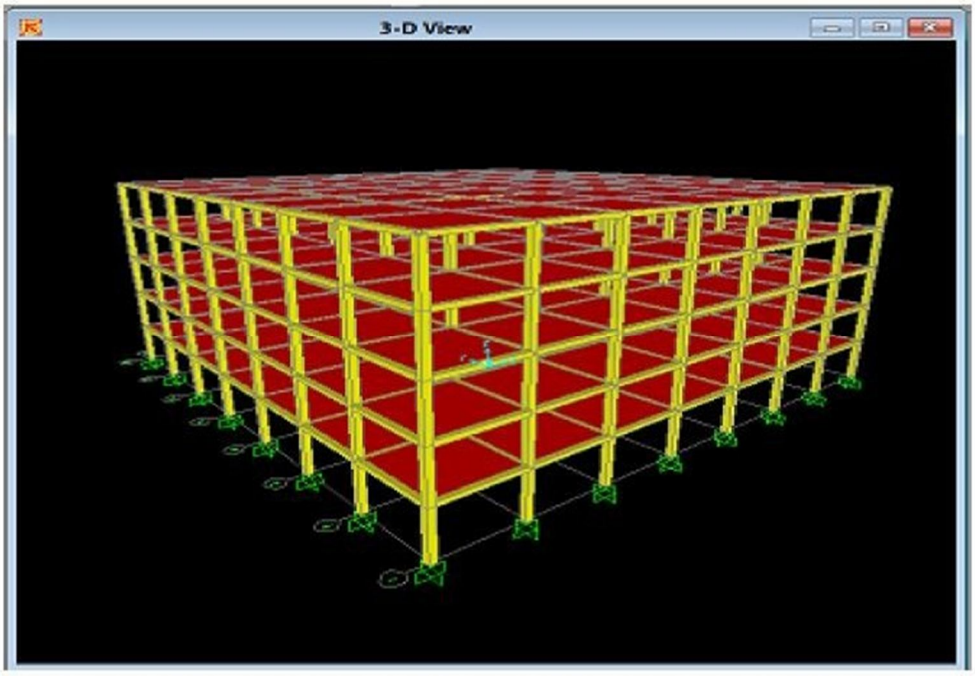

Fig.3.3–Three-dimensional extruded view of the G+4 RC frame model in SAP2000, showing the7×7 bay configuration and five-storey elevation.

D. Material Properties

M25 grade concrete and Fe415 reinforcing steel were adopted throughout. Material properties were input as shown in the SAP2000 Material Property Data dialog (Figure 3.4) and summarized in Table 3.2.

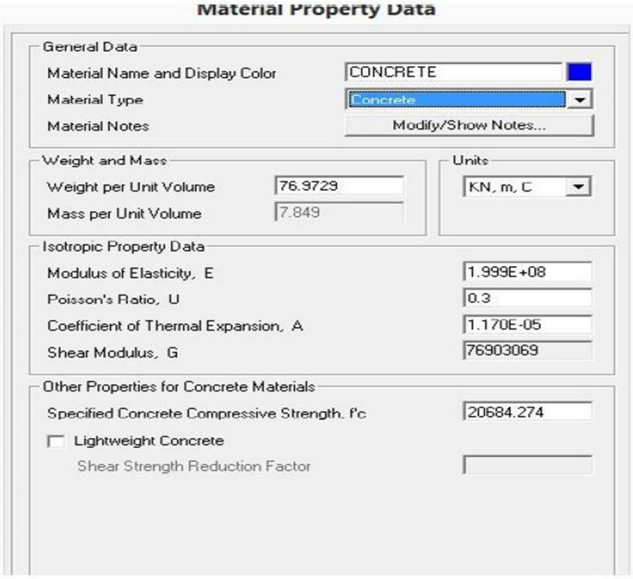

Fig.3.4–SAP2000 Material Property Data dialog showing M25 concrete parameters ($E=1.999\times10^8 kN/m^2$, $\nu=0.3$, $f'c=20{,}684\ kN/m^2$).

Table3.2–MaterialPropertySummary

Property	Concrete (M25)	Steel(Fe415)
Modulus of Elasticity	1.999×10⁸kN/mZ	2.0×10⁸kN/mZ
Poisson's Ratio	0.3	0.3
Weight/Unit Volume	76.97 kN/m3	77.0 kN/m3
Compressive Strength	20,684 kN/mZ	—
Damping Ratio	0.05	0.05
Shear Modulus G	76,903,069	—

IV. VISCOELASTIC DAMPERS

A. Working Principle

Viscoelastic dampers consist of elastomeric polymer layers bonded between steel plates. Under lateral storey drift, the polymer undergoes cyclic shear deformation, converting mechanical energy into heat. Their restoring force combines an elastic stiffness component (storage modulus G')and a viscous damping component(loss modulus G''), making Them effective against both wind and seismic excitation. The schematic cross-section is shown in Figure4.1.

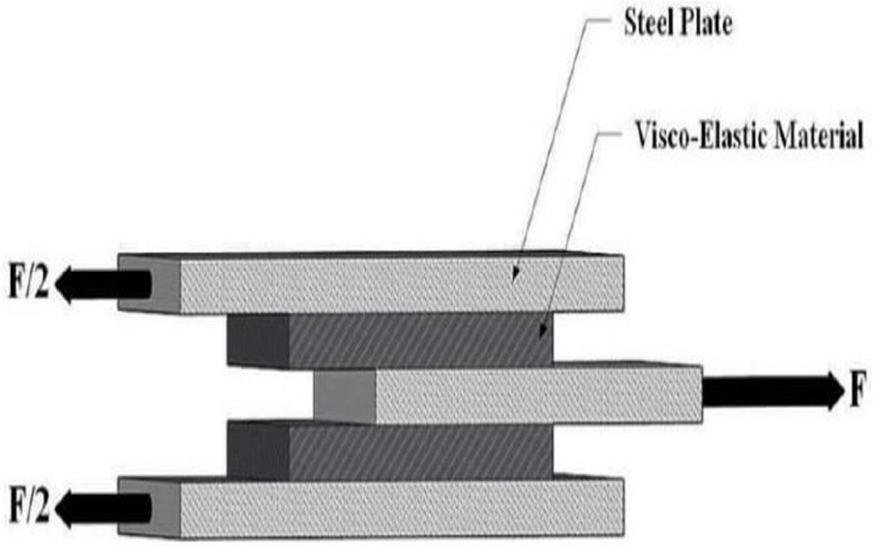

Fig.4.1–Schematic of a Viscoelastic damper: steel plates and wichisco-elastic polymer layers; sheared formation of the polymer dissipates energy as heat.

B. Advantages

- Protects structural integrity and prevents plastic hinging at beam-column connections.
- Reduces structural damage and repair costs following seismic events.
- Effective for both wind-induced vibration and earthquake excitation.
- Applicable tone construction and retrofit of existing buildings.
- Minimal increase in structural mass avoid simplification of seismic inertia loads.

V. CRITICAL SECTION IDENTIFICATION

A static analysis under the factored gravity combination (1.5 DL + 1.5 LL) was first performed on the bare frame. Axial load, bending moment, and shear force envelopes were examined across all members. The governing critical section—the exterior beam at the base storey level—was identified from the maximum bending moment demand. Figures 5.1, 5.2, and 5.3 illustrate the identified critical positions and the corresponding force diagrams extracted from SAP2000.

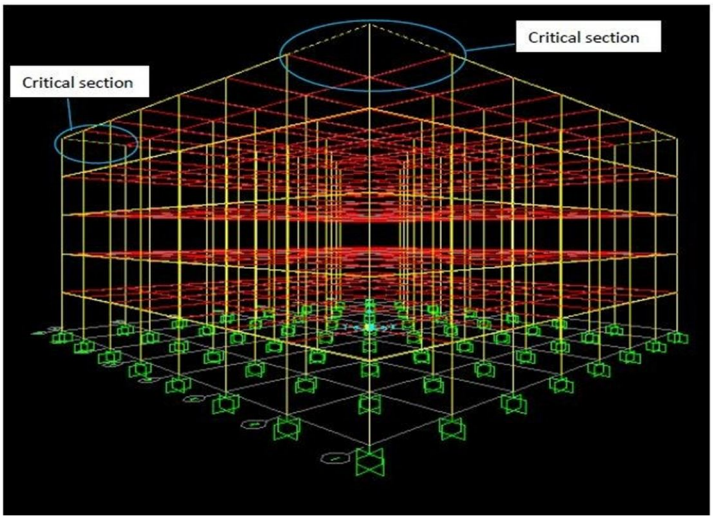

Fig.5.1–Critical section locations (highlighted with blue ellipses) at the exterior top corners of the G+4 RC frame, identified from maximum bending moment distribution.

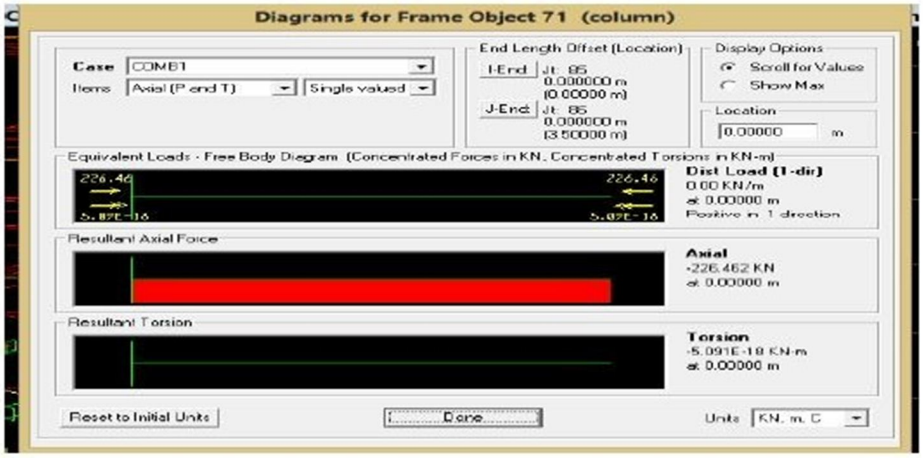

Fig.5.2–Axial load diagram for critical column (Frame Object 71): resultant axial force=−226.462kN at the base storey.

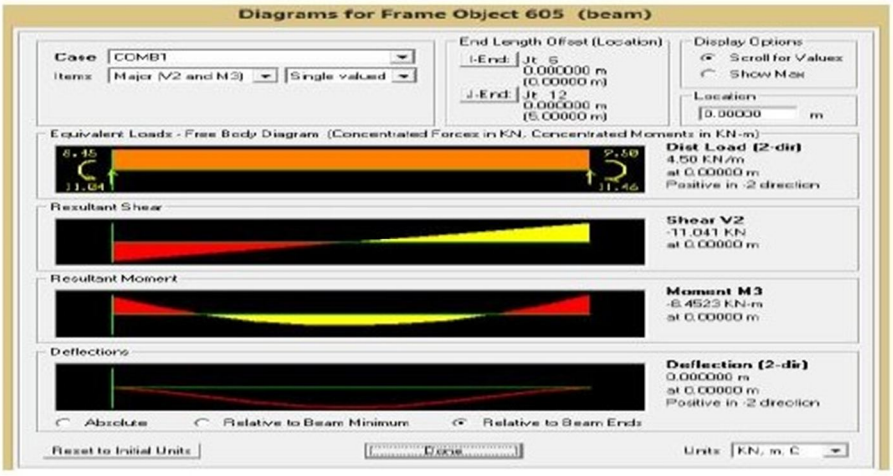

Fig.5.3–Bending moment and shear force diagram for critical beam (Frame Object 605): Shear V2=11.041kN; Moment M3 =6.4522 kN·m.

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VI. OPTIMIZATION AND MODELLING OF DAMPERS

Based on the critical section analysis, VE dampers were placed diagonally within the exterior bays on all four faces of the building, spanning the full height from ground to fifth floor. A trial-and-error optimization approach was used to determine the most effective configuration. Figures 6.1 and 6.2 shows the damper positions and the final modeled configuration in SAP2000.

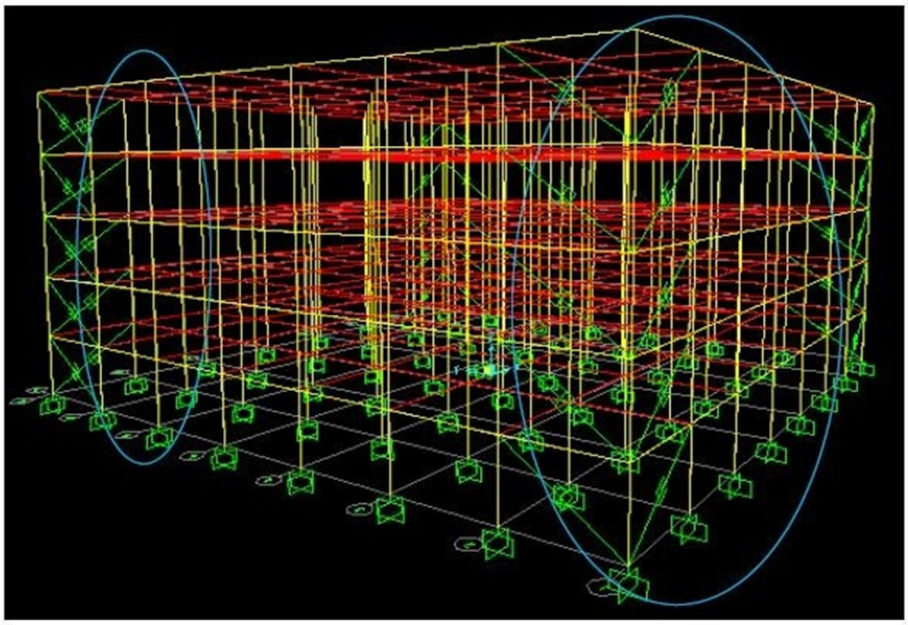

Fig.6.1–Optimal damper positions (blue ellipses) for the5-storey RC frame: dampers placed at exterior perimeter bays along all four sides, extending through the full building height.

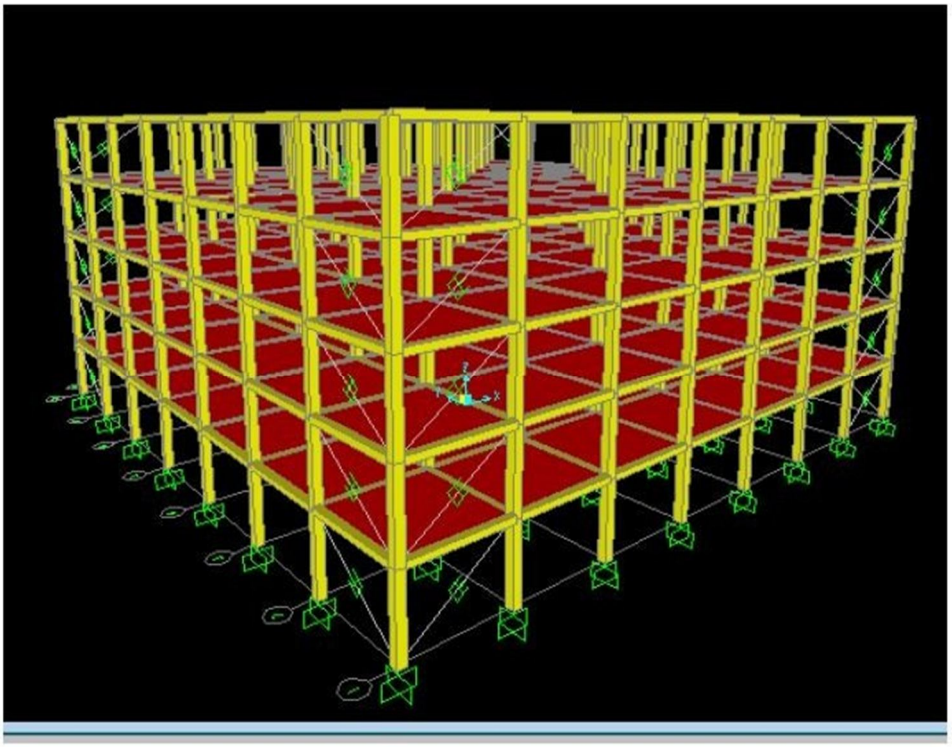

Fig.6.2–SAP2000 model of the G+4RC frame with VE dampers installed (diagonal link elements visible at exterior bays on all four faces of the structure).

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VII. TIME HISTORY ANALYSIS

A. *Ground Motion Record*

The 1994 North ridge earthquake (Mw6.7, January 17, 1994, San Fernando Valley, California) was selected as the seismic input. With an epicenter distance of 26.8km and a PGA of 0.165g, the event represents a realistic near-field ground motion demand. Its total duration of approximately 1020 seconds provides adequate time for the structure to fully respond and dissipate energy. Table 7.1 summarizes the record parameters.

Table7.1–Northridge Ground Motion Record Parameters

Sl. No.	Earthquake	Year	Magnitude(Mw)	Epicentral Dist. (km)
1	Northridge	1994	6.7	26.8

The acceleration time series imported into SAP2000 is shown in Figure7.1.

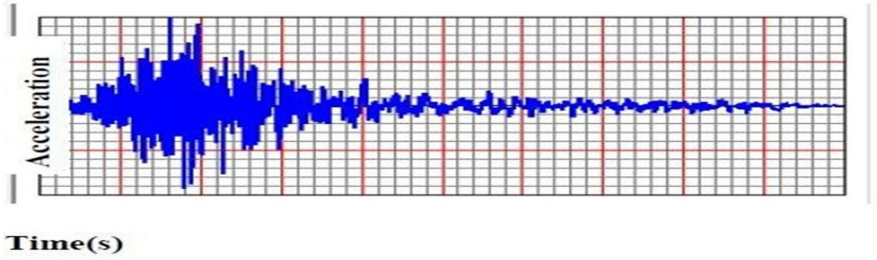

Fig.7.1–Northridge (1994) acceleration vs .time record used as the seismic input for time history analysis ;PGA=0.165g; duration ≈ 1020 s.

B. *Analysis Configuration*

The non linear direct-integration time history load case was configured with-delta geometric non linearity, a scale factor of 9.81 to convert g to m/s Z, and a time step of 0.02 s. Both the bare frame and the damper-equipped frame were analyzed under identical conditions. Response parameters extracted were peak top-floor displacement, inter- storey drift at each level, and total base shear.

VIII. RESULTS AND DISCUSSION

A. *Peak Top-Floor Displacement*

The bare RC frame exhibited a peak top-floor displacement of 0.1206 m under the Northridge record. With VE dampers installed, this reduced to 0.10 m—a 17.08% improvement. This reduction indicates that the dampers successfully absorb a significant portion of the input seismic energy beforeittranslatesintolateral movement of the superstructure.

Table8.1–Comparative Seismic Response Summary

Parameter	Without Damper	With Damper	Change(%)
Top Displacement(m)	0.1206	0.10	−17.08%
Base Shear(kN)	~35,000	~100,000	+65.21%
Inter-storey Drift	Higher tall floors	Lower tall floors	Significant Reduction

B. *Inter-Storey Drift*

The inter-storey drift (ISD) profiles for both configurations are compared in Figure 8.1. Drift values decrease consistently at all floor levels when dampers are present, with the most significant absolute reduction at the upper storeys where lateral flexibility is greatest. The damped frame maintains drift within safer bounds at every level, directly reducing both structural and non-structural damage risk.

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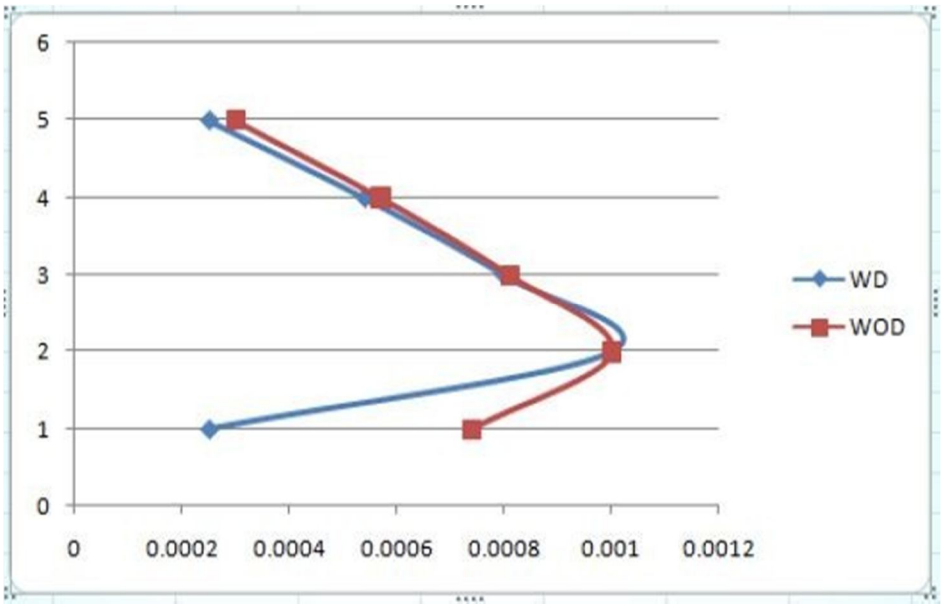

Fig.8.1–Inter-storey drift comparison: With Dampers (WD, blue)vs. Without Dampers (WOD, red)under the Northridge earthquake. Dampers reduce drift at all five storey levels.

C. Base Shear

The VE damper configuration increases base shear by approximately 65.21% compared to the bare frame (Figure 8.2).Thisincreasereflectstheaddedlateralstiffnesscontributedbythedampers'elasticcomponent,whichshiftsthe effective fundamental frequency and enables the structure to attract and redistribute forces through a more controlledloadpath.Theelevatedbaseshearismanagedthroughtheenergy-dissipatingpolymerlayers,preventing localized plastic damage at critical joints.

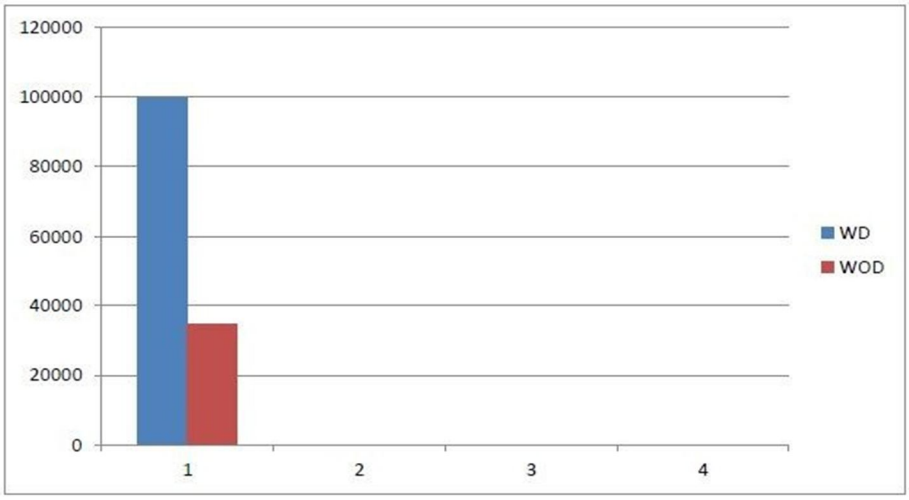

Fig.8.2–Base shear comparison: With Dampers (WD, blue) ≈ 100,000kN vs. .Without Dampers (WOD, red) ≈35,000kN.The 65.21% increase indicates enhanced lateral stiffness and controlled force redistribution.

IX. CONCLUSIONS

1) The overall seismic performance of the G+4 RC frame improves substantially with peripheral VE dampers spanning the full building height.
2) Peak top-floor displacement is reduced by 17.08 % (from 0.1206 m to 0.10 m) under the 1994 Northridge ground motion, confirming effective energy absorption by the dampers.

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3) Inter-storey drift decreases at every storey level, with the largest absolute reductions at the upper floors, reducing the risk of both structural and non-structural damage.

4) Base shear increases by 65.21%, reflecting the stiffness contribution of the VE dampers and indicating a stiffer, more controlled lateral load-resisting mechanism.

5) Critical sections at base-level exterior beams—identified from bending moment envelopes—are confirmed as optimal damper locations; peripheral placement across all storey's is effective.

6) VE dampers are suitable for both new construction and seismic retrofit of RC buildings in India, particularly in low-to-medium seismic zones.

7) Future work should investigate Zone III–V buildings, taller structures (G+10 and above),multiple ground motion records, and parametric variations in damper mechanical properties.

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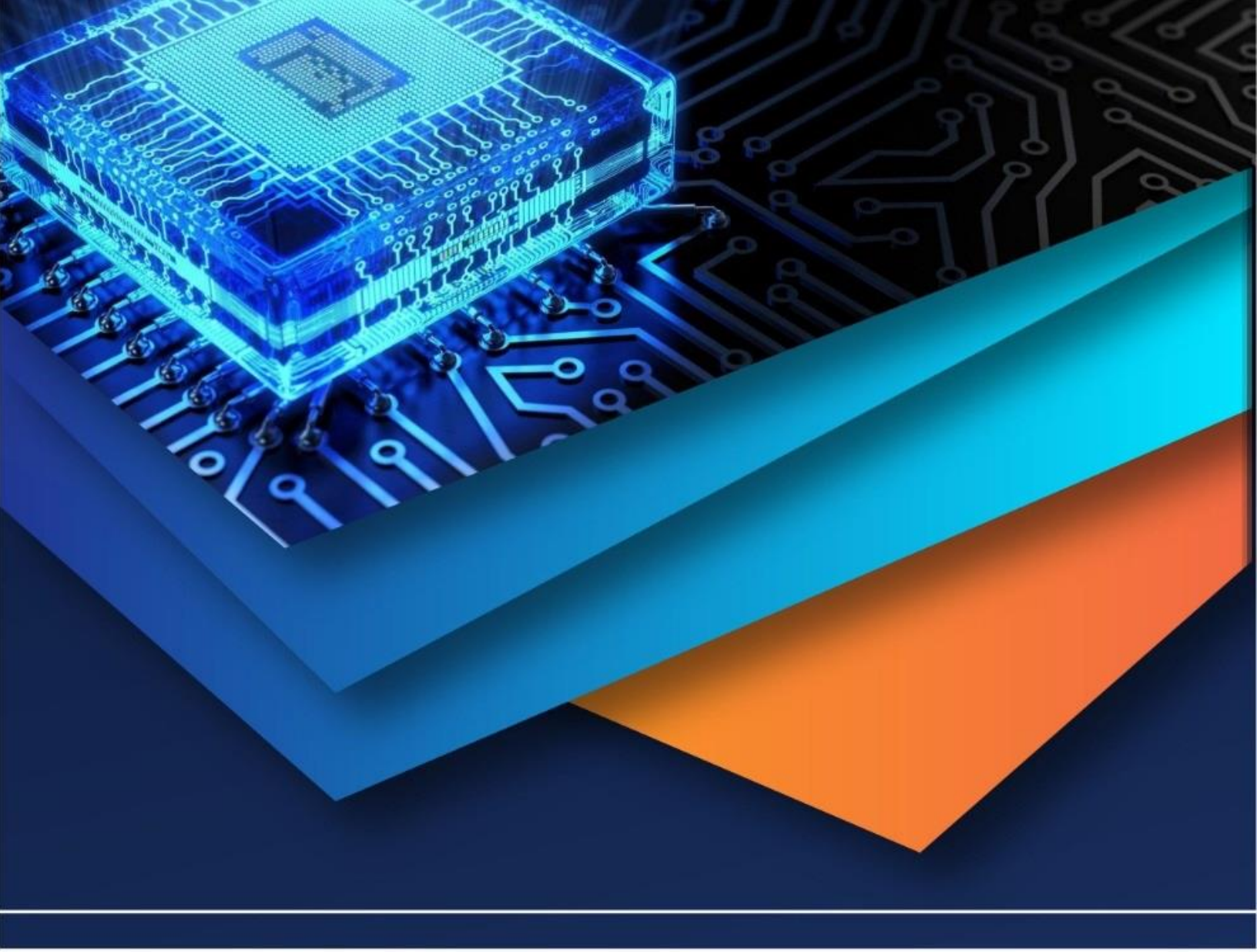

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