Seismic Performance Evaluation of a Multi-Story Steel Frame with Rotational Steel Rod Damper

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Abstract - *This study investigates the seismic performance of a multi-story (G+2) steel frame equipped with a Rotational Steel Rod Damper (RSRD) subjected to El-Centro earthquake excitation through nonlinear finite element analysis using ANSYS. The primary objective of the research is to evaluate the effectiveness of the RSRD implemented at beam–column connections in reducing seismic response parameters such as base shear, story displacement, acceleration, and stress concentration in structural members. The steel frame consists of three stories with a total height of 9 m and a span length of 6m. Two structural configurations were investigated: a conventional bare steel frame and a steel frame integrated with an optimized RSRD system. The bottom of the frame was considered fixed, while lateral acceleration corresponding to the El-Centro ground motion record was applied as dynamic excitation. The results indicate that the introduction of the RSRD significantly improves the seismic response of the structure. The damped frame exhibited reductions in base shear, acceleration, and stress demand compared with the bare frame. A substantial reduction in stress concentration was observed in beam and column members due to the energy dissipation capability of the low-yield steel rods. The study demonstrates that the RSRD effectively enhances structural stability, vibration control, and seismic resilience of steel moment-resisting frames under dynamic earthquake loading*

Key Words: Rotational Steel Rod Damper; Time History Analysis; Seismic Performance; Steel Frame; Finite Element Analysis; ANSYS; Energy Dissipation; El-Centro Earthquake; Passive Control System

1. INTRODUCTION

Steel moment-resisting frames are commonly used in seismic regions due to their ductility, strength, and construction efficiency. However, under strong earthquake excitation, these structures may experience excessive lateral displacement, stress concentration at beam–column joints, and dynamic amplification, leading to structural damage and stiffness degradation. To improve seismic performance, supplemental damping systems are increasingly used in earthquake engineering.

Among passive energy dissipation devices, Rotational Steel Rod Dampers (RSRDs) are effective because they dissipate seismic energy through controlled rotational deformation at beam–column connections. The use of low-yield-point steel rods enables stable hysteretic behavior and significant inelastic deformation, reducing stress on primary structural members.

This study evaluates the seismic behaviour of a G+2 steel frame with and without an RSRD system using ANSYS finite element analysis. The El-Centro earthquake record was applied, and responses such as base shear, storey displacement, acceleration, and member stress were compared to assess the effectiveness of the damper system.

1.1 Literature Review

Recent studies have highlighted the importance of passive energy dissipation systems in improving seismic performance of steel structures. Zhou et al. [1] developed a novel rotational metallic damper and experimentally demonstrated its excellent hysteretic behaviour, energy dissipation capacity, and vibration control under cyclic loading. Chopra [2] established the fundamentals of structural dynamics and emphasized the importance of damping in reducing displacement and acceleration response during earthquakes. Uang and Bertero [3] reported that hysteretic energy dissipation significantly improves seismic resistance of steel frames. Mazzolani [4] investigated passive dampers and observed improved vibration control and reduced stiffness degradation. Constantinou and Symans [5] studied passive control systems and concluded that dampers effectively reduce seismic force demand. Kasai and Takeuchi [6] demonstrated stable cyclic performance of low-yield steel dampers with enhanced ductility. Whittaker et al. [7], Nakashima [8], Sabelli and Mahin [9], and Kelly [10] further reported that supplemental damping systems improve structural stability and seismic resilience.

However, most previous studies focused mainly on experimental behaviour or generalized damping systems without detailed nonlinear finite element evaluation of Rotational Steel Rod Dampers (RSRD) in multi-storey steel frames. Limited research exists on ANSYS-based time-history analysis under El-Centro earthquake loading, particularly regarding stress redistribution, acceleration reduction, and optimized RSRD implementation at beam–column connections.

1.2. The objectives of the study

1.To develop finite element models of a bare steel frame and an RSRD-equipped steel frame.
2.To perform nonlinear time-history analysis under El-Centro earthquake loading.
3.To investigate the influence of the RSRD on seismic response parameters.
4.To evaluate the effectiveness of the damper in improving seismic energy dissipation and structural stability

2. NUMERICAL MODELING AND METHODOLOGY

2.1 Rotational Steel Rod Damper (RSRD)

The Rotational Steel Rod Damper (RSRD) used in the present study consists of low-yield steel rods connected with steel plates and pin mechanisms to provide rotational flexibility and seismic energy dissipation at beam–column joints. The rods were fabricated using LYP160 steel having a yield strength of 147 MPa, ultimate strength of 269 MPa, and elongation of 47.9%, enabling stable cyclic yielding under earthquake loading. The plates and pin components were made of Q355 steel with a yield strength of 315 MPa and ultimate strength of 461 MPa to ensure sufficient strength and rigidity. The high ductility of LYP160 steel enhances hysteretic energy dissipation capacity during seismic excitation. Zhou et al. [1]

2.2 Optimized Geometrical Parameters of RSRD

Table 1- Optimized Dimensions of RSRD

Parameter	Value
Steel Rod Diameter	60 mm
Outer Plate Thickness	50 mm
Inner Plate Thickness	50 mm
Overall Plate Length	570 mm
Plate Height	500 mm

2.3 Modelling and Meshing of RSRD

The Rotational Steel Rod Damper (RSRD) was modelled in ANSYS 2024 R2 using detailed three-dimensional finite element modelling to capture nonlinear rotational behavior and stress distribution under seismic loading. The damper assembly consisted of outer plates, inner plates, steel rods, and pin connections. SOLID186 higher-order structural solid elements were used due to their capability to simulate material and geometric nonlinearities accurately. A structured hexahedral mesh with an element size of 10 mm was adopted. Mesh refinement was provided near rod–plate interfaces and connection regions to accurately capture stress concentration, deformation behavior, and energy dissipation characteristics during time-history analysis.

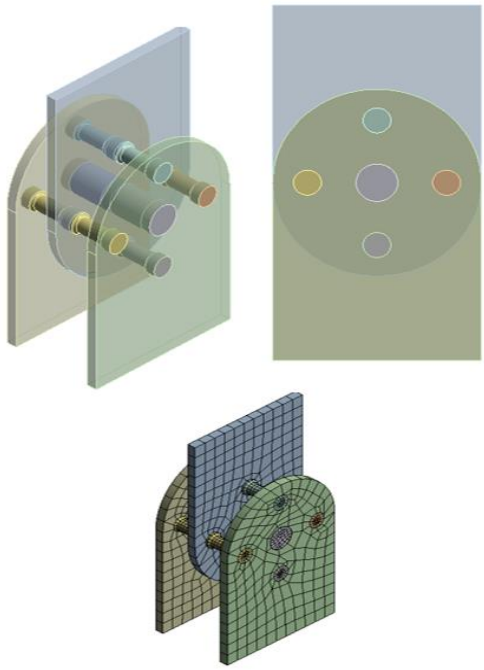

Fig -1 : Rotational Steel Rod Damper (RSRD)

2.4 Structural Configuration

The structure considered in this investigation is a G+2 steel moment-resisting frame with a total height of 9 m. Each storey has a height of 3 m, while the span length of the frame is 6 m. The finite element model was developed in ANSYS to simulate the nonlinear dynamic behaviour of the structure under earthquake loading.

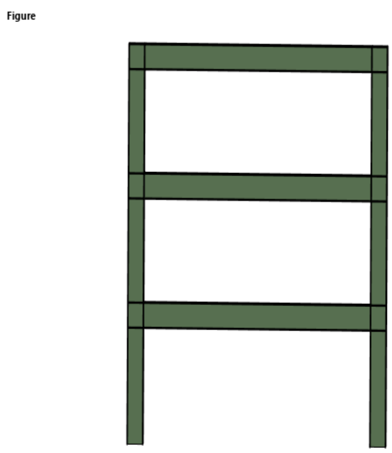

Fig -2: Bare Frame

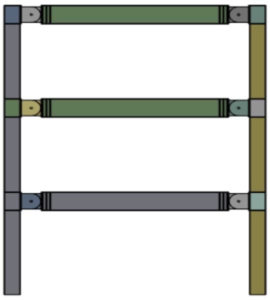

Fig -3: Frame with RSRD

2.5 Beam and Column Properties

The steel frame was modelled using standard rolled steel beam and column sections to ensure adequate stiffness and seismic resistance. The beam section adopted was NPB 600 × 220 × 107.56 with a mass of 107.56 kg/m, cross-sectional area of 137.0 cm^2, depth of 597 mm, and flange width of 220 mm. The column section used was WPB 450 × 300 × 99.74 having a mass of 99.74 kg/m, area of 127.1 cm^2, depth of 425 mm, and flange width of 300 mm. Appropriate web thickness, flange thickness, and root radius values were provided to improve strength, stiffness, and stress distribution under seismic loading conditions.

2.6 Boundary Conditions and Loading

The bottom ends of the columns were modelled as fully fixed supports, restraining all translational and rotational degrees of freedom.
Earthquake excitation was applied in the lateral direction in the form of acceleration time-history loading corresponding to the El-Centro earthquake record.
The dynamic analysis was performed to evaluate the transient structural response during the complete duration of the earthquake excitation.

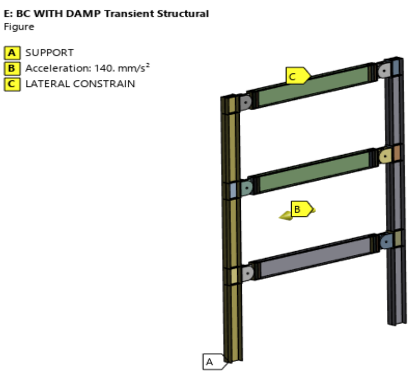

Fig -4: Boundary Condition

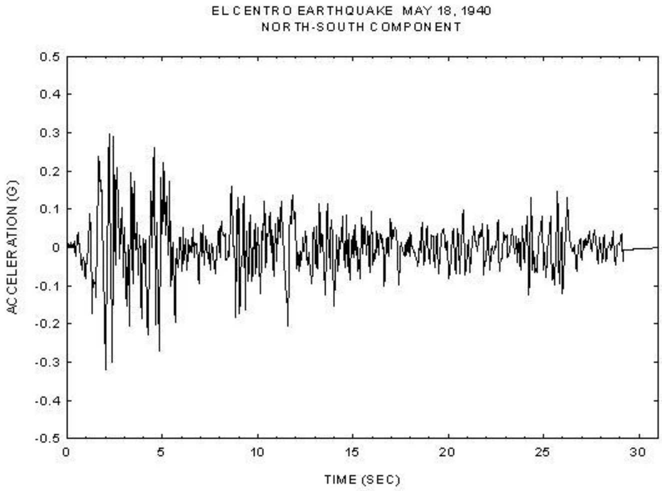

Fig -5: Loading Protocol -ELCENTRO PGA

3. RESULTS AND DISCUSSION

Table 2- Comparison of Seismic Response Parameters

Model	Max Displacement (mm)	Max Base Shear (kN)	Max Acceleration (mm/s^2)	Max. Stress (MPa)
Bare Frame	18.78	207	8233.4	211.7
Frame with RSRD	18.20	187	7983	126.25

3.1 Storey Displacement Response

- Storey displacement is an important parameter in evaluating the seismic stability of framed structures. Excessive lateral displacement can lead to instability, non-structural damage, and amplification of secondary moments.
- The bare frame recorded a peak displacement of 18.78 mm, whereas the RSRD-equipped frame showed a reduced displacement of 18.20 mm. Although the reduction appears moderate, the displacement profile of the damped frame exhibited more stable and controlled deformation characteristics.
- The RSRD improved displacement compatibility between storeys by controlling rotational deformation at beam–column joints. This behavior reduced the possibility of soft-storey formation and minimized localized deformation concentration.
- The reduction in lateral displacement demonstrates the ability of the damper to improve serviceability performance during seismic excitation.

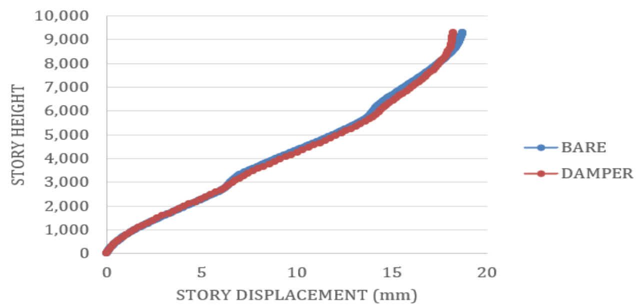

Fig -6 : Story Displacement comparison

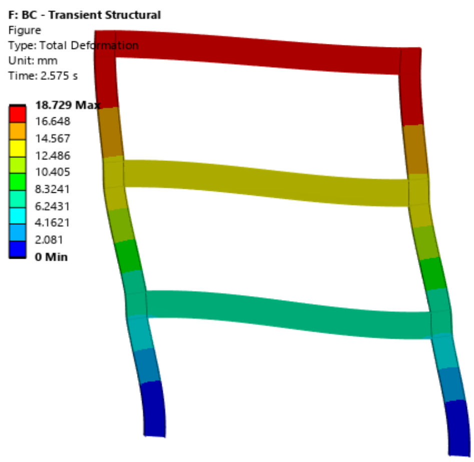

Fig -7 : Total deformation – Bare frame

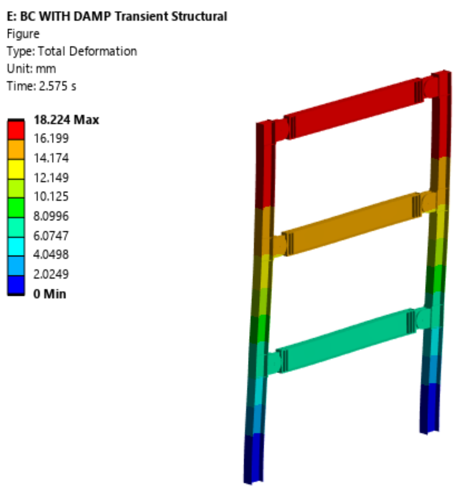

Fig -8 : Total deformation –frame with RSRD

3.2 Acceleration Response

- The acceleration response of the structure significantly influences inertia force generation and vibration transmission throughout the frame.
- The bare frame developed a peak acceleration of 8233.4 mm/s², while the frame with RSRD recorded a lower acceleration of 7983 mm/s². The reduction in acceleration confirms the effectiveness of the RSRD in suppressing structural vibrations.
- The rotational damper dissipated a substantial amount of kinetic energy through hysteretic deformation of the low-yield steel rods. Consequently, the transmission of seismic energy to the primary structural system was reduced.
- Lower acceleration response is advantageous because it minimizes fatigue damage, connection distress, and dynamic force amplification in structural and non-structural components.

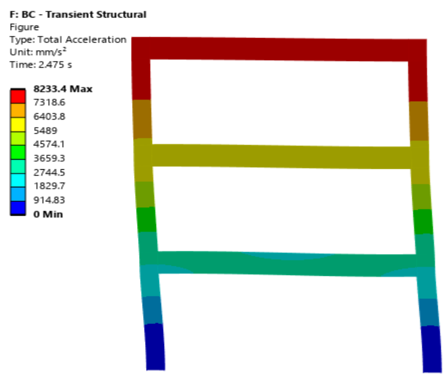

Fig -9 : Total Acceleration – Bare frame

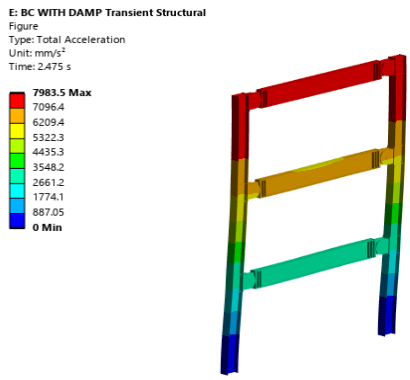

Fig -10: Total Acceleration –frame with RSRD

3.3 Base Shear Response

The base shear time-history response illustrates the influence of the RSRD on seismic force reduction. The bare frame exhibited significant oscillatory fluctuations throughout the loading duration, indicating high inertia force transfer to the foundation.

The maximum base shear developed in the bare frame reached 207 kN. Large oscillations were observed during the initial phase of seismic excitation, where the earthquake intensity was dominant.

In contrast, the frame equipped with RSRD showed a smoother response with lower oscillation amplitude. The maximum base shear reduced to 187 kN due to the supplemental damping introduced by the rotational steel rod mechanism.

The reduction in base shear can be attributed to:

- Increased equivalent damping,
- Hysteretic energy dissipation,
- Reduced dynamic amplification,
- Controlled rotational deformation at beam–column joints.

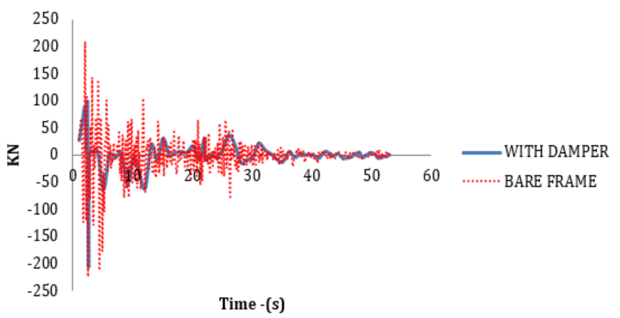

Fig -11 : Base shear comparison

3.4 Stress Distribution in Beam and Column

The implementation of the Rotational Steel Rod Damper (RSRD) significantly reduced stress in the beam and column members during earthquake loading. The bare frame developed a maximum stress of 211.7 MPa due to high moment transfer and cyclic deformation at the beam–column connections. After installing the RSRD, the maximum stress decreased to 126.25 MPa.

This reduction occurred because the damper absorbed and dissipated seismic energy through controlled rotational deformation and yielding of the steel rods. The RSRD also reduced stress concentration and improved force distribution within the structure. Lower stress levels indicate improved structural safety, stability, and better post-earthquake performance of the steel frame.

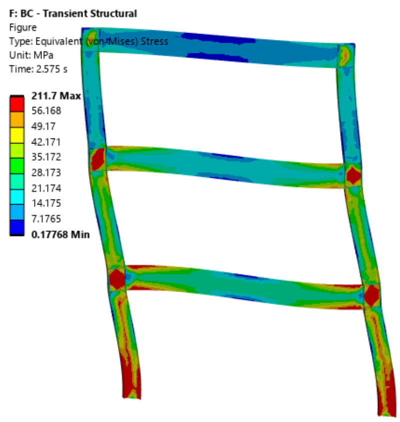

Fig -12 : Stress distribution – Bare frame

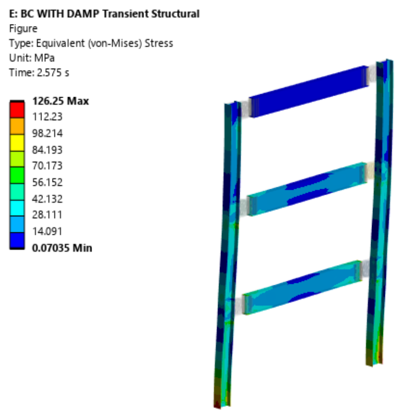

Fig -13 : Stress distribution – Frame with RSRD

4. CONCLUSION

A nonlinear time-history analysis was performed on a G+2 steel frame with and without a Rotational Steel Rod Damper using ANSYS under El-Centro earthquake excitation. Based on the analytical investigation, the following conclusions are drawn:

1.The implementation of the RSRD significantly improved the seismic behavior of the steel frame under dynamic loading conditions.

2.The peak base shear reduced from 207 kN to 187 kN due to the supplemental damping introduced by the rotational damper system.

3.The maximum storey displacement decreased from 18.78 mm to 18.20 mm, indicating improved lateral deformation control.

4.Structural acceleration reduced from 8233.4 mm/s^2 to 7983 mm/s^2, demonstrating effective vibration suppression capability.

5.The maximum stress in beam and column members reduced substantially from 211.7 MPa to 126.25 MPa because of improved energy dissipation and force redistribution.

6.The low-yield steel rods effectively absorbed seismic energy through stable hysteretic yielding and protected the primary structural members from severe plastic deformation.

7.The RSRD improved the overall seismic resilience, dynamic stability, and post-earthquake performance of the steel frame.

The study concludes that the Rotational Steel Rod Damper is an efficient passive control device for enhancing the seismic performance of multi-storey steel moment-resisting frames subjected to earthquake loading.

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