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Structural Performance of Vertical Energy Dissipator on Braced Special Moment Resisting Frame

Anix Samuel N[1], Ardra P Nair[2]

[1]M.Tech Student, Department of Civil Engineering, Vidya Academy of Science and Technology, Thrissur, Kerala
[2]Assistant Professor, Department of Civil Engineering, Vidya Academy of Science and Technology, Thrissur, Kerala

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Abstract - *This study focused on end-reinforced steel pipe dampers (ESPDs), specifically the ESPD-70, fabricated from commonly utilized pipes with reinforced ends. These reinforcements, consisting of two inner short pipes connected by welding or mechanically attached steel plates, enhance load-bearing capacity and durability at connection points. The ESPD-70 employs a tension brace mechanism to dissipate energy and provide resistance. Initially, the study examined the effects of the ESPD-70 in a single chevron braced frame using static non-linear pushover analysis with ANSYS Software. The optimal section was identified and subjected to cyclic loading to evaluate its energy dissipation performance against other models. This optimized section was then incorporated into a two-bay multistory frame and subjected to time history analysis with real-time earthquake data. The results demonstrated that using pipe dampers reduces seismic demand on structures. ESPDs are cost-effective, easy to install, and replace.*

***Key Words*: ESPD-70, Cyclic analysis, pushover analysis, chevron Brace Frame, ANSYS, Hysteresis, Time History Analysis**

1.INTRODUCTION

Passive dampers play a crucial role in structural engineering, effectively reducing the impact of dynamic forces on buildings, bridges, and various infrastructures. Unlike active dampers that depend on external energy and intricate control systems, passive dampers function independently, efficiently reacting to vibrations and seismic activity. End-reinforced steel pipes represent an advanced solution in structural engineering. These pipes feature reinforced ends, typically through welding or the mechanical attachment of additional steel plates, to enhance their load-bearing capacity and durability at connection points. The reinforcement mitigates stress concentrations, preventing failure modes such as buckling, deformation, or rupture, especially in high-pressure fluid transportation, underground conduits, or structural support systems. By placing these ESPD dampers on special moment resisting frames, it can reduces the seismic activity acting on the structures.

1.1 Scope and Objective of the study

The study aims to develop a new multi-segmental vertical energy dissipator within a two-bay, multi-story steel special moment-resisting frame (SMRF) featuring a chevron-braced configuration.

At First the performance and effectiveness of a vertical energy dissipator and develop a single-story portal frame with a Chevron-braced configuration, both with and without a damper. Then assessing the hysteresis performance and energy dissipation capacity of an effective steel damper in both braced and unbraced systems by conducting cyclic analysis. Finally time history analysis using real earthquake ground motion data on a multi-story frame to evaluate storey displacement, storey drift, base shear, and acceleration is studied.

1.2 Method of Analysis

To determine the optimal size of the damper, a pushover analysis is conducted, where lateral loading is applied at the top of the frame while keeping the supports fixed. The optimized damper section is then installed on a chevron-braced frame to assess its hysteresis performance, which is compared to that of a standard chevron-braced frame. Finally, earthquake data is applied, and a time history analysis is performed to evaluate the seismic performance of the structure.

2. STRUCTURAL CONFIGURATION AND WORKING MECHANISM OF ESPD ON BRACED SMRF

The configuration of ESPD is simple, consisting of two reinforced steel pipes located on the upper and lower end, one energy-dissipating steel pipe, and two connecting plates, as shown in Figure 1. There is no gap between the reinforced steel pipe and the energy-dissipating steel pipe, thereby reinforced steel pipe can provide support to the energy-dissipating steel pipe. This configuration can delay the cracking of the end of the energy-dissipating steel pipe and prevent the ESPD from losing its bearing capacity due to premature cracking.

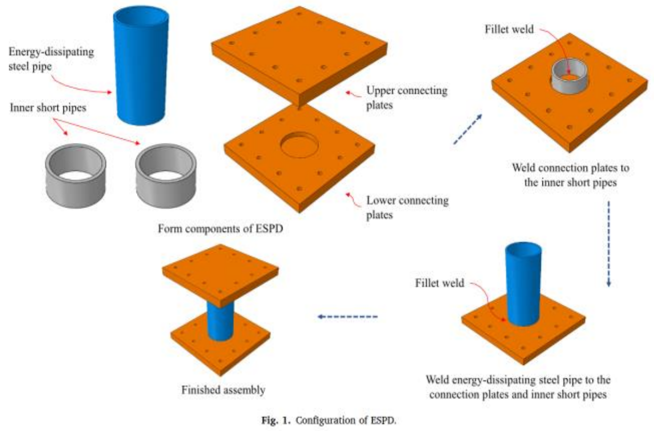


Fig -1: Configuration of ESPD

2.1 Geometrical and Material Properties of ESPD

The ESPD-70 is given structural steel as the material in ANSYS , as its yield strength is 300 MPa,Young's Modulus is 2.06×10^5 and poisson's ratio is 0.3. ESPD-70 Model was modelled using ANSYS 2024 Software.

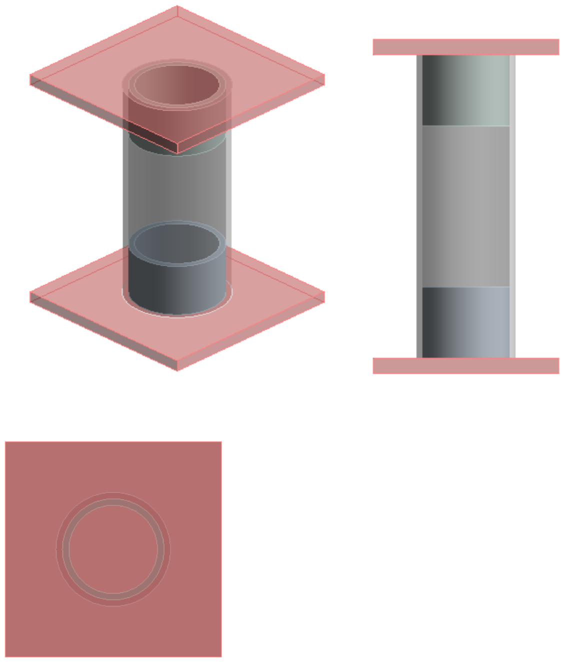


Fig -2: Different views of ESPD-70

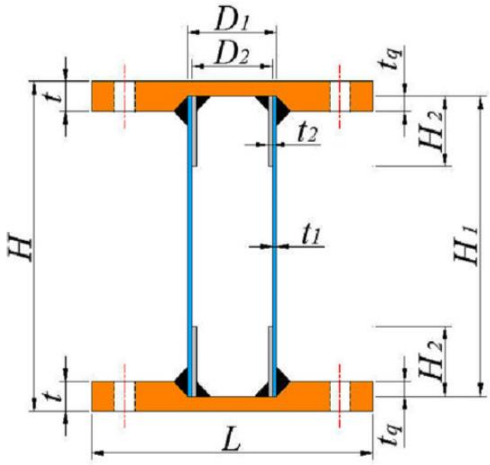


Fig -3: Geometrical definition of ESPD-70

Table -1: Geometric parameters of test specimens

Specimen No:	ESPD-70 (mm)
L	300
H	330
H1	300
H2	70
D1	108
D2	94
t1	6
t2	6

2.2 Material Properties of Chevron braced frame with damper

Table -2: Engineering Data sections of chevron brace frame with damper

Material number	Material	Material properties	
		Isotropic Elasticity	
		EX	20,2000 Mpa
1	Beam and Column	PRXY	0.3
		Bilinear Isotropic Hardening	
		Yield Strength	345 Mpa

		Tangent Modulus	0 Mpa
2	Brace		
		Isotropic Elasticity	
		EX	20,2000 Mpa
		PRXY	0.3
		Bilinear Isotropic Hardening	
		Yield Strength	317 Mpa
		Tangent Modulus	0 Mpa
3	Damper	**Isotropic Elasticity**	
		EX	20,2000 Mpa
		PRXY	0.3
		Bilinear Isotropic Hardening	
		Yield Strength	300 Mpa
		Tangent Modulus	0 Mpa

2.3 Modelling and analysis of optimised section

The ESPD-70 when connected with chevron braced frame it fails considerably and cannot take a load greater than required value. So, the optimization of this damper is required and by changing the different parameters of the section such as diameter,thickness etc we can find more effective and optimized one for the seismic performance. The most optimised ESPD-70 is found to be ESPD-70 with 300-12-300 2 NOS as it denotes the diameter-thickness-height of two dampers.

Table -3: Results obtained from pushover analysis

Model	Ultimate Load (kN)	Ultimate deflection (mm)	ductility (μ)
Chevron Brace Frame	4355.2	16.43	4.1
108-6-300	1621.6	81.03	20.25
150-6-300	1753.4	80.04	20
200-6-300	1872.8	81.03	80.96
250-6-300	2014	92.08	23
300-6-300	2132.4	85.09	84.79
300-10-300	2563.8	99.68	66.07
300-15-300	3068.4	94.09	15.59
300-20-300	3634.9	128.62	31.72
300-25-300	3972.8	93.13	22.95
108-6-300 2 NOS	1824.2	76.03	18.96
150-6-300 2 NOS	2080.5	80.04	19.85
200-6-300 2 NOS	2324.1	82.21	77.87
250-6-300 2 NOS	2596.4	86.33	80.40
300-6-300 2 NOS	2844.5	86.82	80
300-10-300 2 NOS	3852.4	108.65	24.69
300-12-300 2 NOS	4360.3	121.19	27.18
108-6-300 3 NOS	2019.1	90.9	14.7
150-6-300 3 NOS	2419.5	83.36	50.73
200-6-300 3 NOS	2800.2	74.52	45.55
250-6-300 3 NOS	3225.8	90.35	14.08
300-6-300 3 NOS	3537.6	87.04	82.75
300-8-300 3 NOS	4387.2	90.9	87.15
300-9-300 3 NOS	4777.1	132	127.12

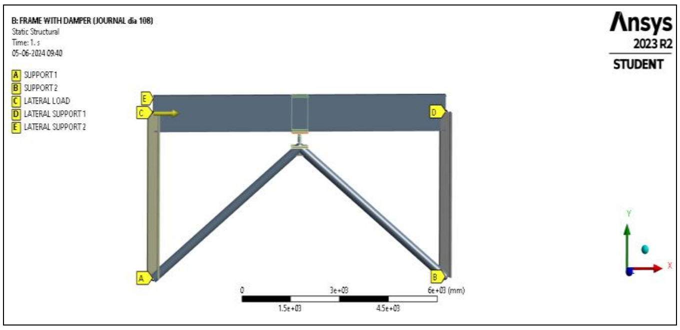


Fig -4: Modelling of ESPD-70 with chevron brace frame

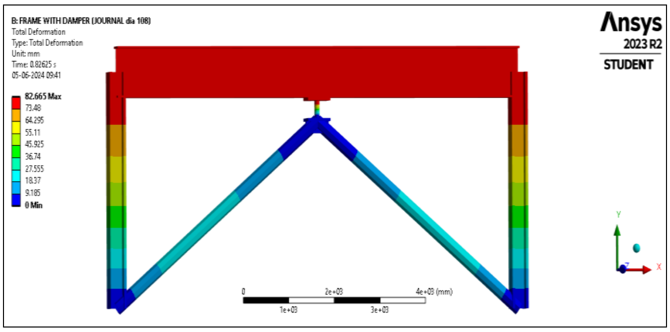


Fig -5: Total deformation of ESPD-70 with chevron brace frame

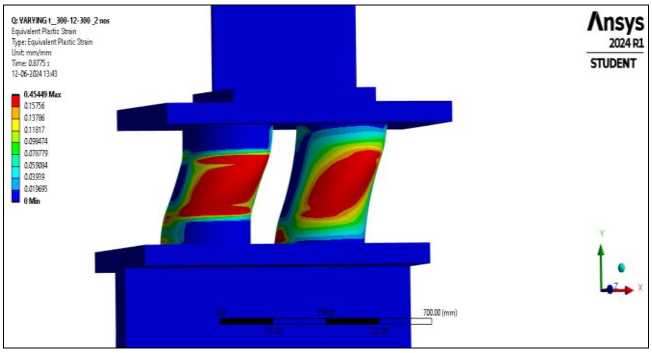


Fig -6: Failure pattern of Optimised damper section

Chart -1: Load comparison chart

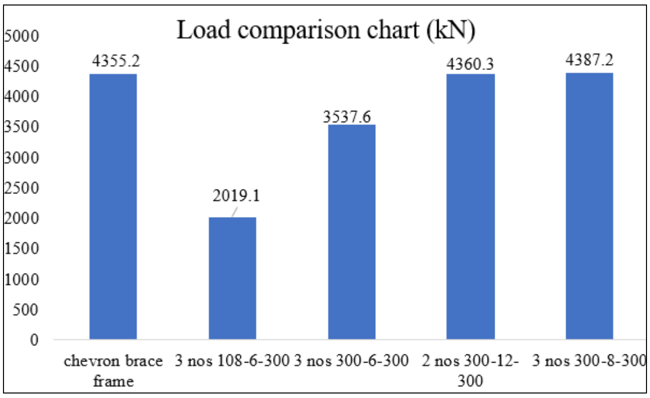
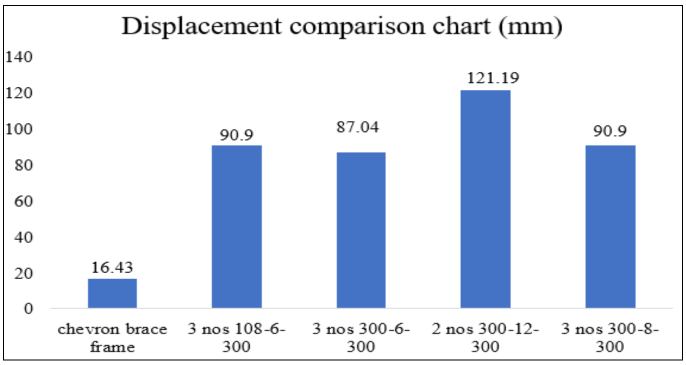


Chart -2: Displacement comparison chart



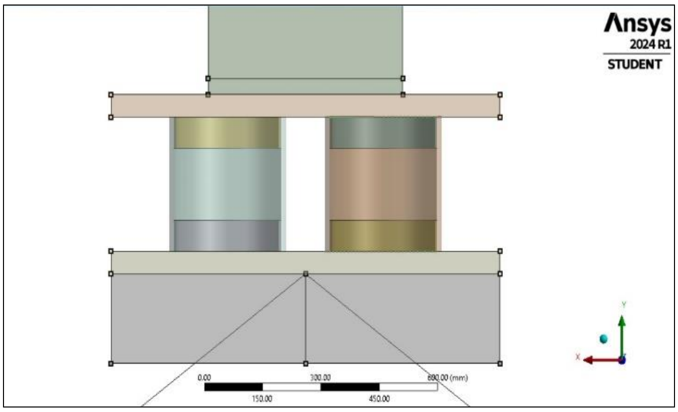


Fig -7: Optimised Damper section

2.4 Cyclic Analysis

Cyclic analysis of Chevron-braced frames is crucial for evaluating their behaviour under repeated loading conditions, which is essential for understanding their performance during seismic events. FEA is commonly used to model the complex behaviour of Chevron-braced frames under cyclic loads. It allows for detailed simulation of material properties, geometric nonlinearities, and interaction effects.

A detailed model of the Chevron-braced frame is created, incorporating the geometry, material properties, and boundary conditions. The frame is subjected to a predefined cyclic loading protocol, typically involving increasing displacement levels as shown in the figure.

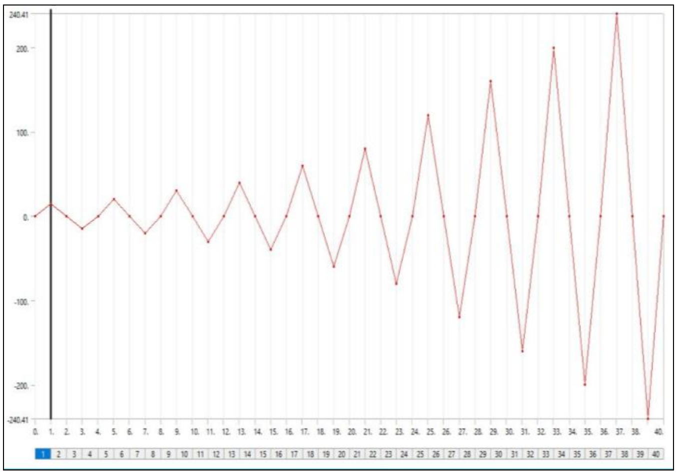


Fig -8: cyclic loading in ANSYS

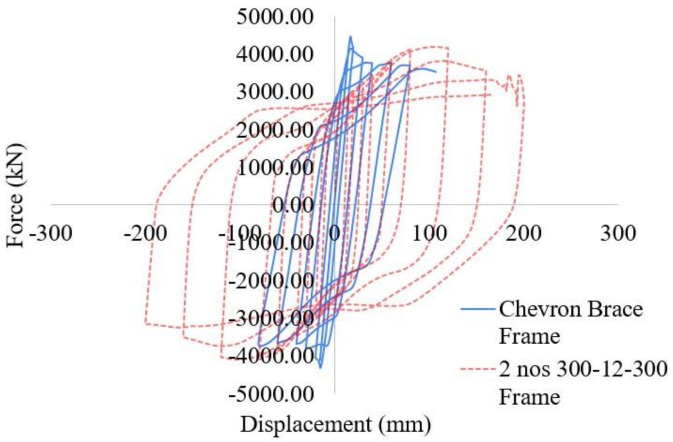


Fig -9: Comparison of Hysteresis performance

2.5 Time history analysis

Unlike simpler static analyses, which consider only steady-state loading conditions, time history analysis accounts for the dynamic response of structures to transient or time-varying loads. The El Centro earthquake of 1940, which occurred near the town of El Centro, California, is an event of great significance in the field of structural design for earthquake engineering. With a magnitude of 7.1 on the Richter scale, the earthquake caused substantial damage to structures in the surrounding areas, and its parameters are now widely used as a reference for seismic analysis of structures. One of the primary reasons why the El Centro earthquake is used as a reference earthquake is that it was one of the first earthquakes for which strong motion data was recorded in detail. This data was used to develop design codes and guidelines for seismic-resistant structures, such as ASCE 7 and NEHRP, which are still in use today.

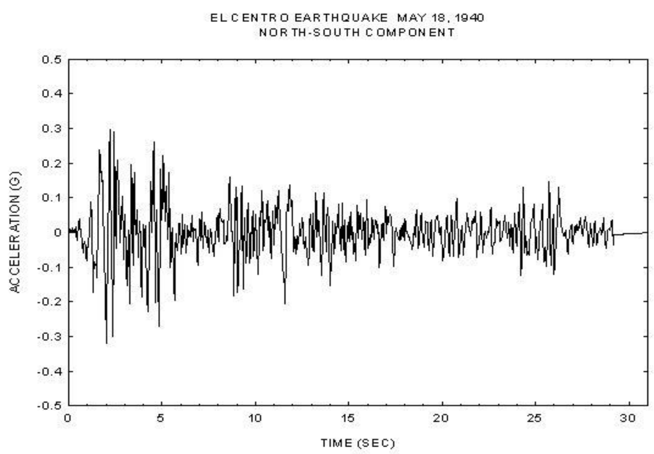


Fig -10: Ground acceleration Data- El Centro Earthquake

The lessons learned from the El Centro earthquake have led to the development of design codes and guidelines that ensure that structures remain stable during earthquakes, with the concept of ductility being a key consideration in earthquake-resistant design. Its ground motion record continues to be used to test and refine seismic analysis tools and software, ensuring that structures are designed to be safe and resilient during seismic events.

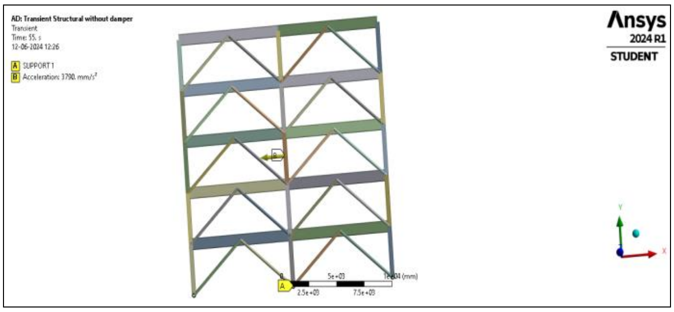


Fig -11: Modelling of multistoried frame

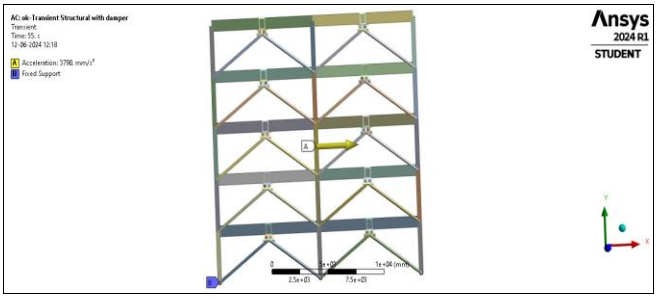


Fig -12: Modelling of multistoried frame with optimized damper

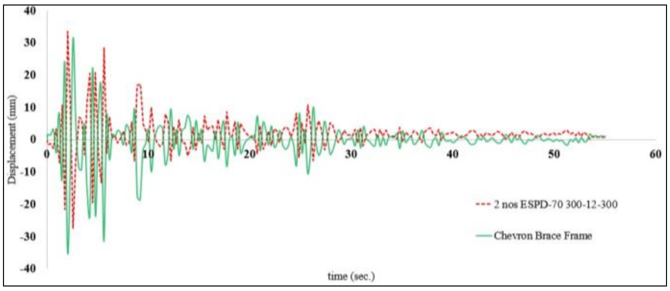


Fig -13: Time history analysis results of Displacement response

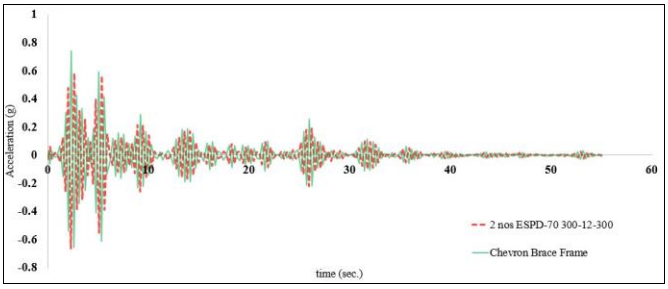


Fig -14: Acceleration time history response curve

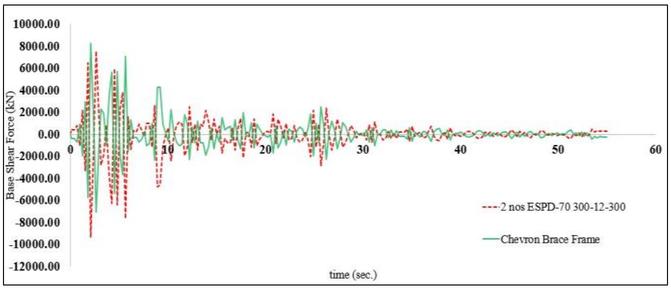


Fig -15: Shear Force Time history curve

3. CONCLUSIONS

On the basis of Non-linear Analysis Results, the following conclusions can be drawn:

- Failure pattern comparison of ESPD-70 of experimental data and the analytical data is verified and found both sbows exact failure plastic patterns.
- From the hysteresis performance the maximum load of both shows a percentage error of 6.93%.
- Single Chevron-braced frame when subjected to a pushover analysis of displacement 100 mm take a load upto 4355 kN,, then fails and deformed to 16.338 mm.
- Single chevron brace frame with ESPD-70 can only take load upto 1637 kN and deformed to 82 mm.
- Optimised section ESPD 300-12-300 2 NOS, when placed in a Chevron-braced frame produce better results when compared to the single Chevron-braced frame and can take a load of 4360 kN which is greater than chevron frame and deformed to 121 mm.
- Ductility of the structure, when placed with ESPD 300-12-300 2 NOS, increased compared to the single chevron frame.
- Yield stiffness of the structure increased to 47 % from 274000 N/mm to 522000 N/mm.
- By conducting cyclic analysis it is found that ESPD 300-12-300 2 NOS damper failure region can be seen in the centre of the pipe.
- Leaf-like hysteresis loop of the frame with ESPD 300-12-300 2 NOS shows that the energy dissipation is done and it is a nonlinear solution.
- Energy dissipation capacity of the chevron brace frame with ESPD 300-12-300 2 NOS increased from 38 kJs to 173 kJs.
- By modal analysis the frequency of both storied buildings is found to be 10.52 Hz in the chevron brace frame and 11.87 Hz in the ESPD inbuilt building.
- By Time history analysis it is found out that the storey acceleration was decreased to 20.85 % in the ESPD frame and storey displacement, Base shear increased to 6.63% and 12.74 %.

4. RECOMMENDATIONS FOR FUTURE WORK

For future research, several potential avenues can be explored:

1. **Parameter Variation Studies**:
    - While this project altered only the diameter and thickness of the steel pipe damper, future studies could expand to include other parameters such as material properties, length of inner pipes, and placement angles. This can help in understanding the broader performance spectrum of the ESPD under various conditions.
2. **Alternative Installation Schemes**:
    - The current study utilized chevron-braced frames. Future research can investigate the effectiveness of ESPDs in other bracing configurations, such as X-bracing, V-bracing, or knee-bracing. This will provide a comprehensive understanding of the optimal installation methods for different structural requirements.
3. **Storey Drift Improvement**:
    - Additional studies could focus on the impact of ESPDs on improving storey drift in multi-storey buildings. By experimenting with different damper placements and configurations, researchers can identify strategies to minimize inter-storey displacements during seismic events.
4. **Energy Dissipation Capacity**:
    - Further analysis can be conducted to evaluate the energy dissipation capacity of ESPDs under various bracing conditions. This involves testing and comparing the performance of ESPDs in different structural systems to identify the most efficient configurations for energy absorption.

5. **Real-time Application and Analysis**:
    - Application studies and simulations on real-time multi-storey buildings are essential for validating the effectiveness of ESPDs in practical scenarios. These studies can include the assessment of the damper's performance under actual seismic events, wind loads, and other dynamic forces experienced by tall buildings.

By addressing these future research directions, the understanding of steel pipe dampers can be significantly enhanced, leading to better implementation strategies and more resilient structural designs.

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