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Enhancing Seismic Resilience And Efficiency In Braced Frame Structures Using X-Shaped Pipe Dampers

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Abstract: X – shaped Pipe dampers (XPDs) are one such latest low cost innovation, owing to its minimal material usage. They are produced by welding two oppositely positioned pipe halves forming an X-shaped core. This project involves the seismic resilience behavioural analysis of XPDs w.r.t to the frame that it is incorporated on. Initially a bare frame, double XPD installed braced frame of similar dimensions are analysed to study the effects of dimensions and double damper on the seismic resilience behaviour of a frame. A suitable double damper configuration selected after a parametrical study on the damping efficiency of the frames is then further examined to determine the placement of double XPDs at connections of columns, beams and the braces of the frame. The frame configurations are then cyclically analysed for further by cyclic loadings as per Federal Emergency Management Agency (FEMA) standards were adopted. The analysis was carried out with the help of a Finite Element (FE) analysis software, ANSYS Workbench.

Index Terms - **Passive energy dissipation, metallic dampers, Double X-shaped pipe damper, pushover analysis, cyclic analysis**

I. INTRODUCTION

Control systems are used to control earthquake effects on new structures and on rehabilitation of existing structures that possess low lateral strength. In this paper, Double X-shaped pipe damper are one of the most effective passive energy dissipation device. Double XPDS dissipate the input energy inside a superstructure caused by seismic waves and thus controlling the swinging of the building. By proper configuration of the lateral resisting system, the earthquake energy is directed towards these devices located within the lateral resisting elements, to intercept this energy. The earthquake induced mechanical energy in the system is transformed into thermal energy within these devices. These devices enhance the damping characteristics of the structure and consequently the amplitude of the motion of the structure is damped, thereby reducing the forces on structural members.

The outline of this study an experimentally tested Double XPD is analysed for seismic performance in general finite element (FE) software ANSYS. Cyclic analysis on damper-frame configurations. To find the double XPD configuration in a frame, model of a frame is fixed with double-XPDs, XPDs were analysed in ANSYS software. Optimum double-XPDs configuration was find out by using dimensional studies.

II. METHODOLOGY

- Literature Survey
- Study of software: ANSYS Workbench
- Validation of software
- Analyse the effects of dimensions on damping efficiency
- Selection of an optimal damper
- Pushover analysis on placement of damper along a steel frame
- Cyclic analysis of braced frames incorporated with XPDs and double XPDs
- Observation & Conclusions

III. EXPERIMENTAL STUDY

A. VALIDATION

A paper titled "Experimental study of a steel damper with X-shaped welded pipe halves" authored by Guo et al is selected for validating the modelling procedure. The sample with most favourable results.

B. DESCRIPTION OF THE VALIDATED MODEL

The study had reported an XPD with dimensions of 133mm, 40mm and 5mm as the diameter of the pipe, length of the damper and thickness of the pipe plate thickness respectively, which had earned favourable results in terms of ultimate load bearing and ductility.

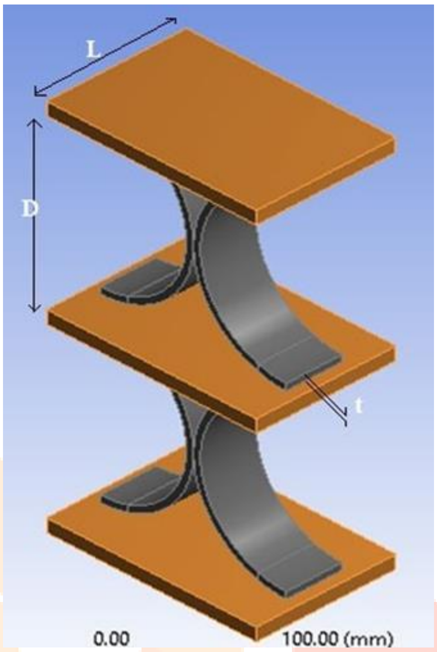

Fig.1 ANSYS Modelled Damper: 133mmx40mmx5mm

Devices are further categorized as hysteresis devices, viscous devices, tuned mass dampers, magnetic negative stiffness devices, resetting passive stiffness devices and viscoelastic dampers. Metallic dampers dissipate energy through the inelastic deformation of their constitutive material while in friction dampers the energy is dissipated through the rubbing of surfaces in friction. The main advantages of metallic dampers over active dampers are stable hysteretic behaviour, rate independence, resistance against ambient temperature and reliability and the fact that practice engineers are familiar with their material behaviour.

Pipe dampers are one of the simple metallic damping devices that could be fabricated through welding of steel pipes. On comparing with other passive metallic dampers, pipe dampers generally possess superior ductility.

X shaped pipe damper (XPD) is a type of pipe damper, that can exert the load bearing and energy dissipation more efficiently while still keeping the simple fabrication advantages

Theoretically, this new XPD possess additional advantages that only the high effective parts in dual-pipe dampers are remained, which can improve the energy dissipation efficiency per steel material usage in the damper.

Although the design concept of the XPD have been analysed in terms of its strength, stiffness, energy dissipation performance and failure modes.

Protection of old and new structures against seismic attacks have always been a challenge in the field of structural engineering. A number of control systems are now being used for the reduction of structural damage and metallic dampers are one of the widely used systems in seismic control. X shaped pipe damper is a recent iteration of such metallic dampers.

An optimum damper-frame configuration that has better impact on the seismic performance of a frame has been identified. Now, studies have found that seismic behaviour of frames are also affected by the placement of dampers on the frames. In the previous section of the thesis, all analyses were carried out at the brace to beam connection.

IV. ANALYSIS ON CONNECTION OF THE FRAME USING ANSYS WORKBENCH SOFTWARE

ANSYS is an engineering simulation software provider founded by software engineer John Swanson. It develops general-purpose finite element analysis and computational fluid dynamics software.

Seismic behaviour of frames are affected by the placement of dampers on the frames. Since damper placement also has an effect on the damping efficiency, to further validate the optimum damper, it is to be tested at other joints under monotonic pushover loading. The connections available on the test frame w.r.t the braces are beam to brace, brace to brace & column to brace connections.

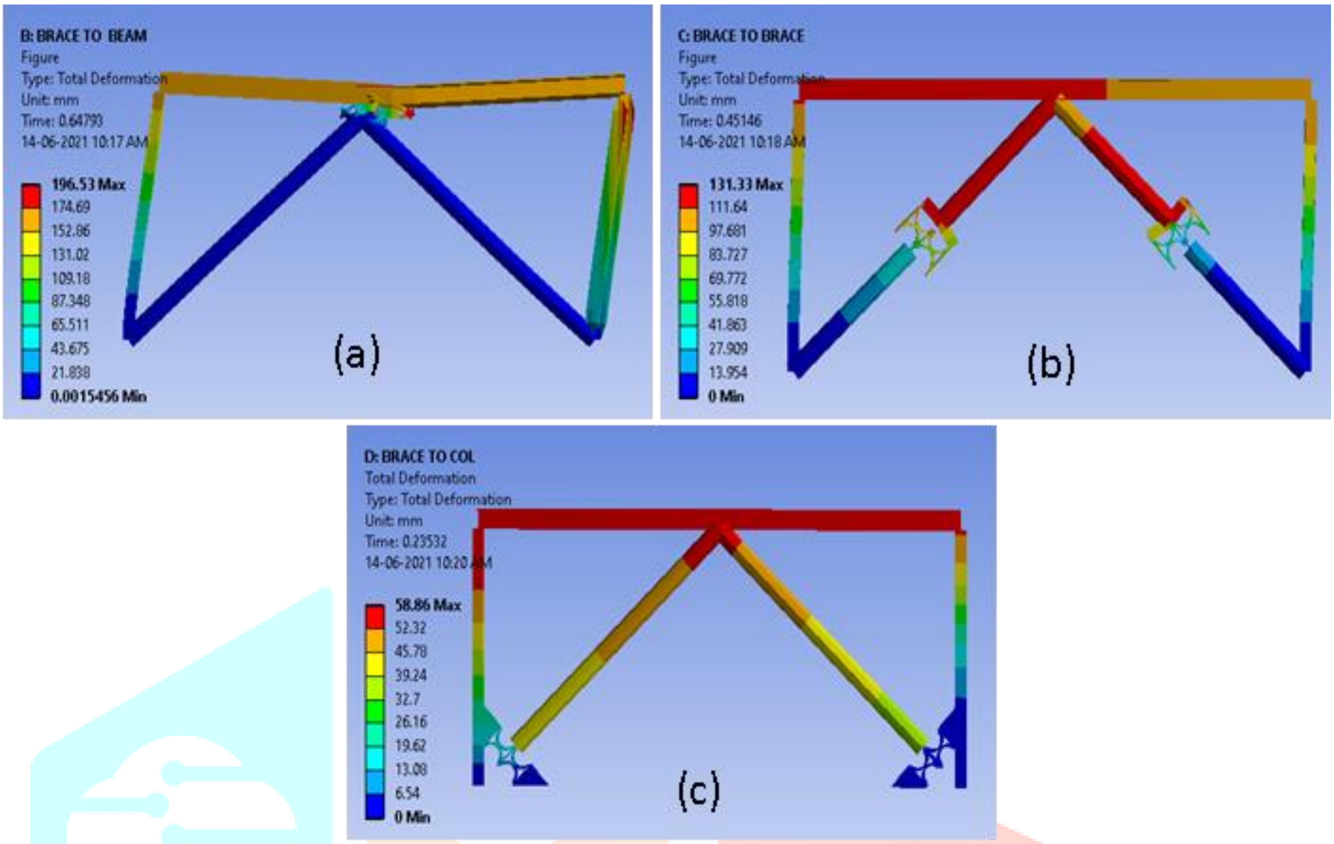

Fig 2. Deflection maps obtained for (a) Brace to beam, (b) Brace to Brace connection and (c) Brace toColumn connection

Result of analysis of XPDs

	Specimen	Δ_y (mm)	Δ_u (mm)	P_u (kN)	µ	% load increase
STUDY ON DAMPER AT CONNECTIONS	Brace To Brace	6.769	131.33	2777.10	19.40	1206.14
	Column To Brace	17.640	58.86	4490.40	3.34	2011.94
	Beam To Brace	**17.639**	**192.84**	**5416.60**	**10.93**	**2447.55**
	Bracing	6.0223	28.45	4084.60	4.72	1821.08
	Bare frame	40.703	74.73	212.62	1.84	-

Table 1 : Result of analysis of XPDs

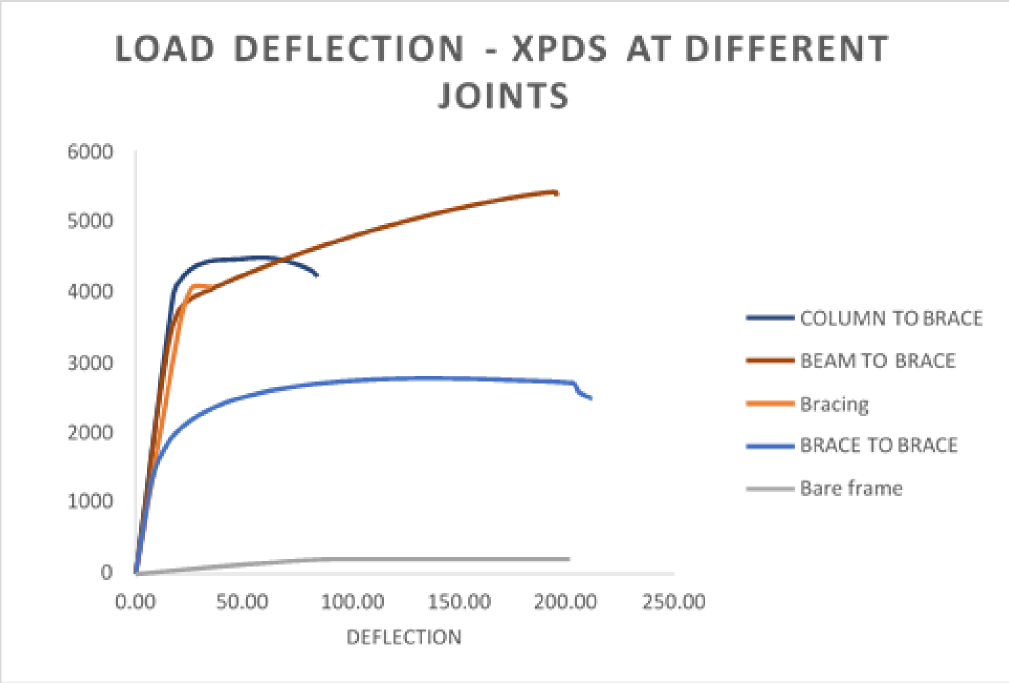

Fig 2 : Deflection Curves for damper placement at joints

Cyclic Analysis On Damper-Frame Configurations

Pushover analysis of these configurations had identified their seismic peak behaviour. A cyclicanalysis is also carried out on these samples for determining the energy dissipation capacitiesand the hysteresis loops. The displacement values of the monotonic analysis can be used as target displacement for the cyclic analyses. Therefore, as per FEMA the loading protocol is calculated based on the height of the frame and the drift percent, as discussed in section 3.5. The target displacement of cyclic analysis was determined based on the resultant displacementvalues of the pushover analysis. Maximum displacement recorded in the whole analysis was 194mm. The target displacement applied was 256mm. It should be noted that failure in cyclicanalyses occurs early than their corresponding displacement in pushover analyses, as residual strain would accumulate in the system after each cycles.

Hysteresis loops were obtained from ANSYS and were analysed using a data analytic software,Origin Lab to derive the energy dissipation capacities. Results are depicted in Table 4.6. The resultant hysteresis loops of the cyclic analyses on the damper-frame configurations are shownin Fig. 4.9 to 4.13. The number of cycles until failure is also shown. It should be noted that thebeam to brace connection model had about 50% more energy dissipation over other placementmodels. Energy difference of the beam to brace model is also shown in table

Specimen	**Cycles**	**Energy (kJ)**	**% Energy difference of beamto brace model**
Brace to Brace	5.151	929.69	67.492
Column to Brace	4.748	1499.24	47.577
Beam to Brace	**6.232**	**2859.88**	**-**
Bracing	2.000	19.72	99.311
Bare frame	6.250	182.67	93.613

Table 3 Results of Cyclic Analysis

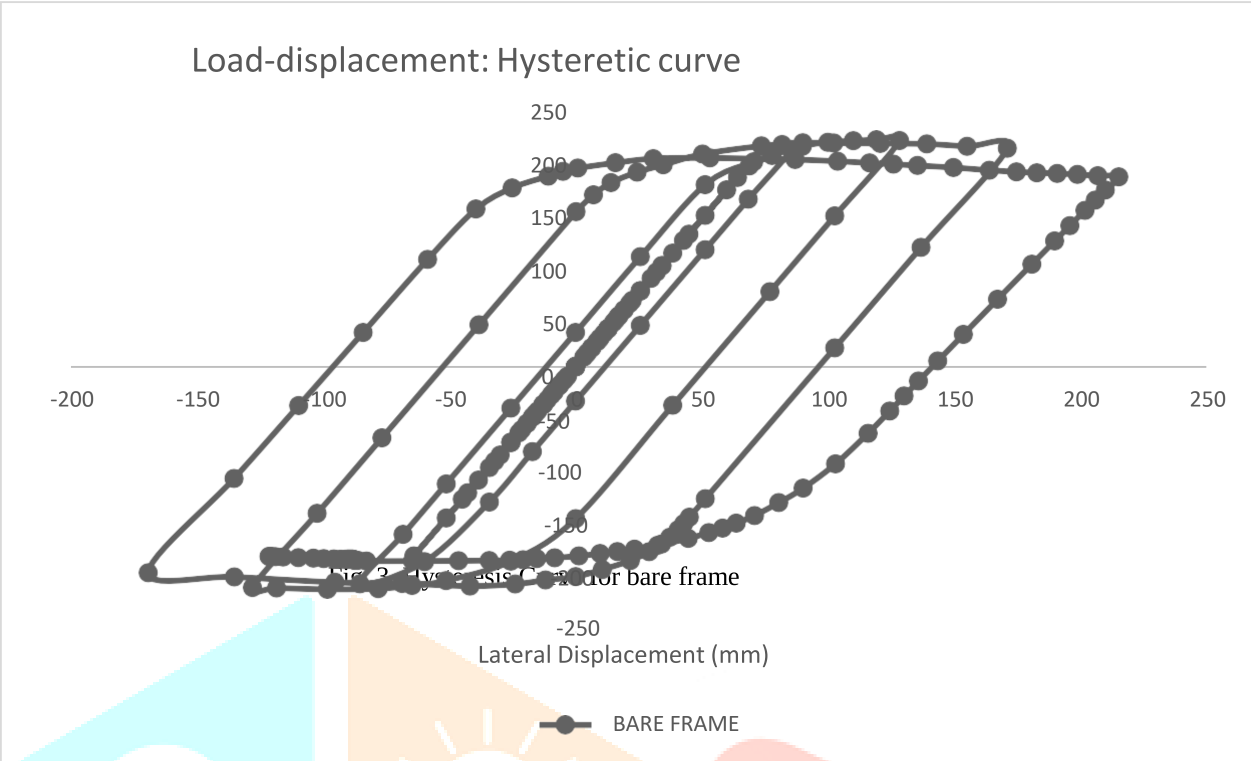

Fig. 3 Hysteresis Curve for bare frame

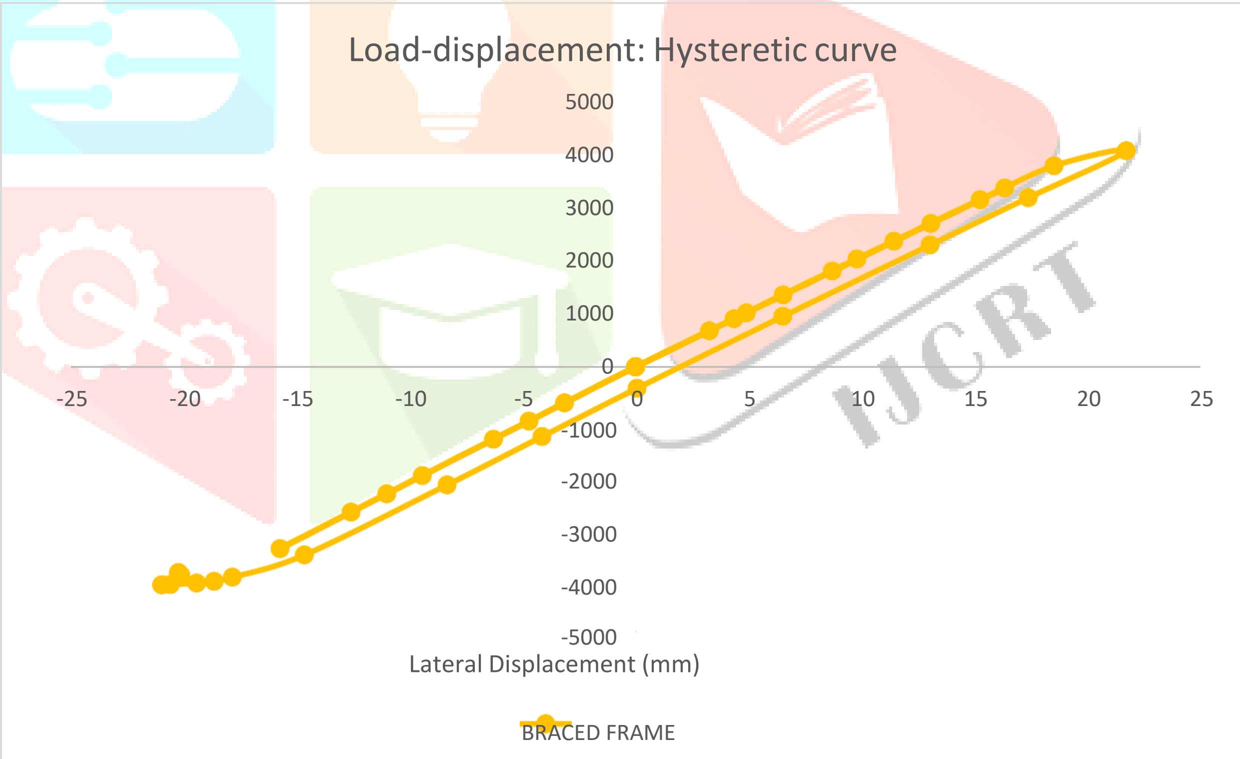

Fig. 4 Hysteresis Curve for braced frame

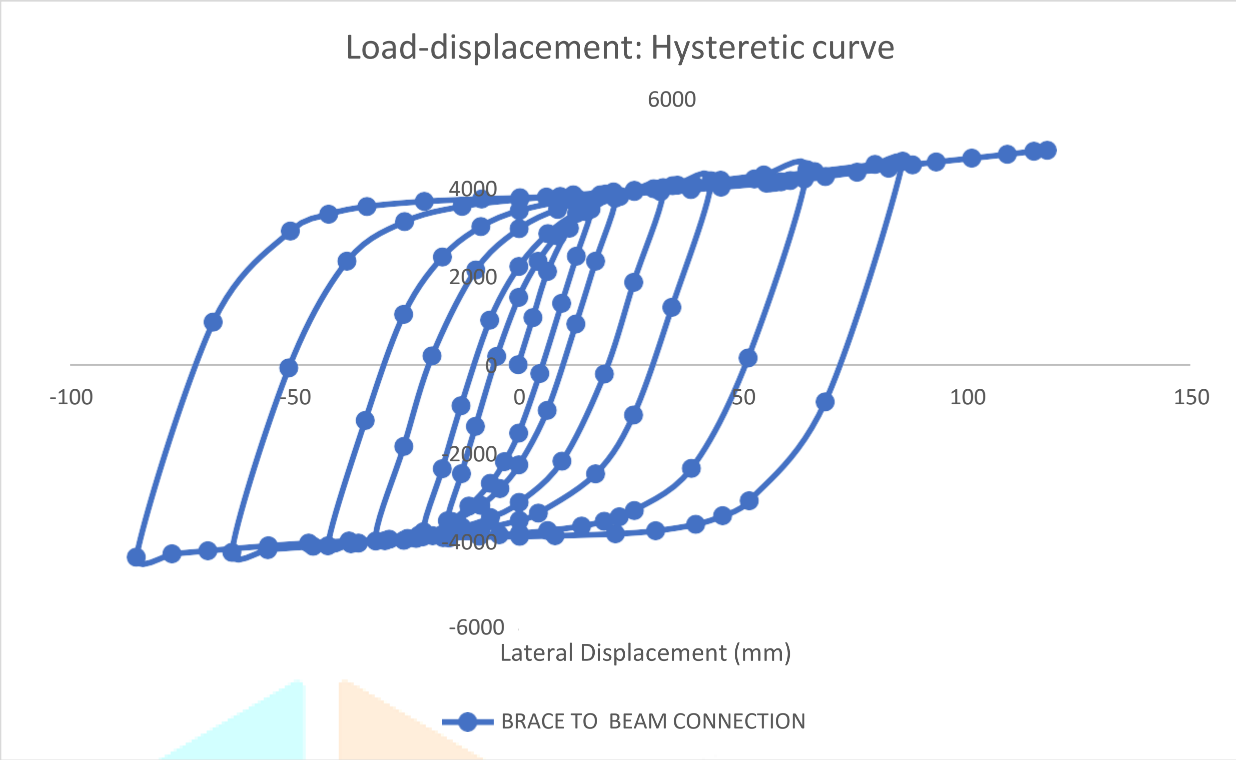

Fig. 5 Hysteresis Curve for Brace to Beam connection

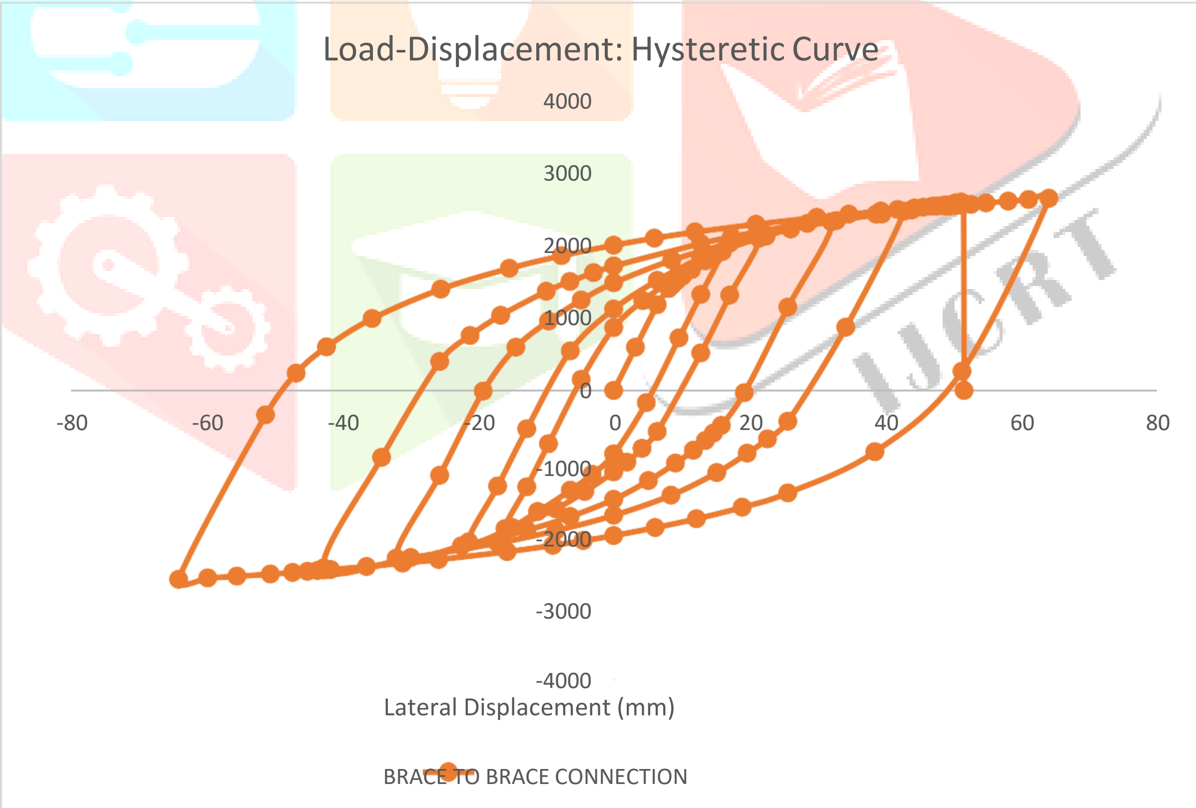

Fig. 6 Hysteresis Curve for Brace to Brace connection

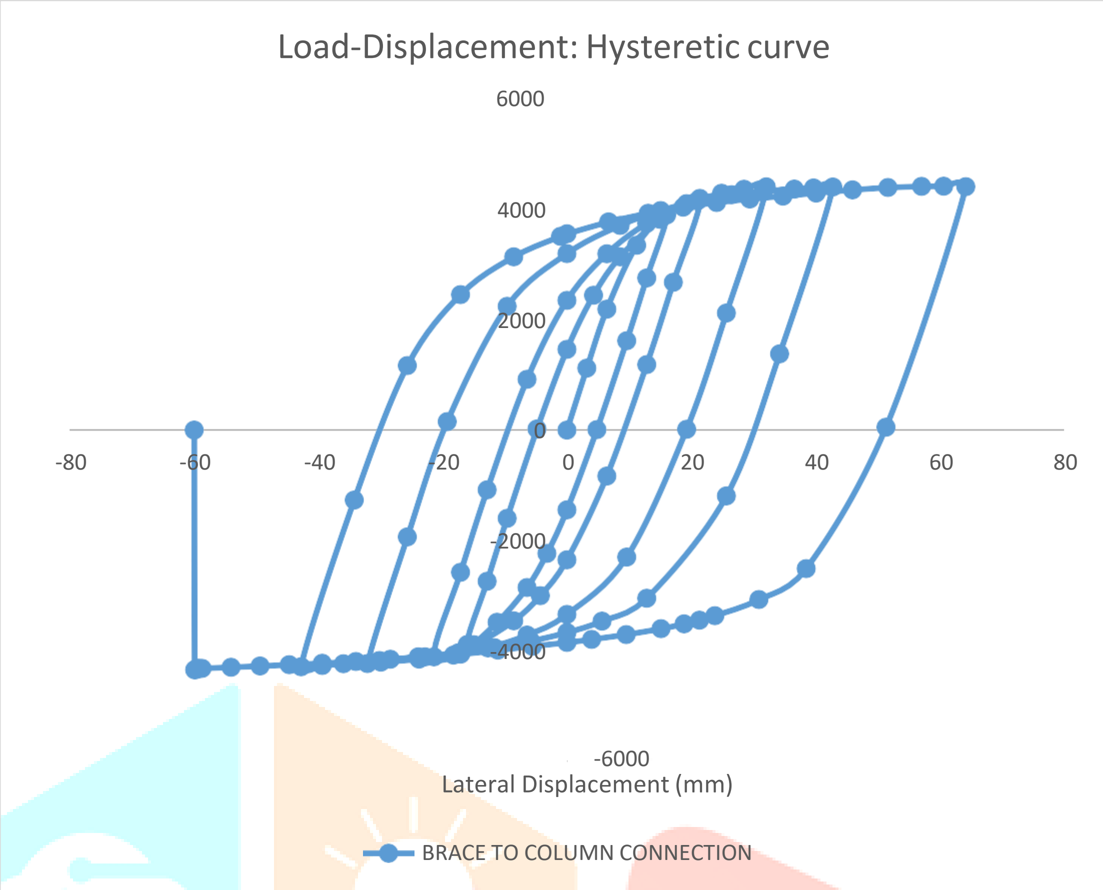

Fig. 4.13 Hysteresis Curve for Brace to Column connection.

Conclusion

This project helps to conclude the damper-frame configuration of two numbers of damper with dimensions 399mm x 120mm x 15mm was found to be the optimum model for the analysed braced frame. This model not only produced satisfactory load capacity and ductility values, but also had favourable yield and ultimate deflection values. Even though the dampers exhibited stable hysteresis loops and favourable dissipation capacities at all the analysed connections, the damper placed at the beam to brace joint is recommended for future analysis owing to its greater energy capacity. This configuration is recommended for further research and eventual practical usage. The ultimate capacity was enhanced about 25 times in the optimum damper-frame combination when compared with the initial bare frame. A subsequent improvement of about 7 times was observed in the ductility measurement of the frames. The increase in ultimate load values of the frame with increasing size could be due to the increase in stiffness with the larger moment of inertia. A considerable rise in the ductility values with dimensions was not observed due to the simultaneous increase in load bearing capacities.

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