

Seismic Behaviour of Bracing Damper Systems by Utilizing Steel Dual Ring

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ABSTRACT: The major concern in designing multistoried steel structure is to have good lateral load resistance framing system so that the lateral load could be transferred straightforwardly, and the building can sustain during the seismic response. Bracing system along with dampers can be used to control the lateral stability of the structure. Passive energy dissipation devices such as dampers absorb a part of such energies reducing energy dissipation demand and in turn reducing possible structural damages. Steel dual ring dampers (SDRD) are one such recent effective innovation, owing to its better energy dissipation capacity. Initially a bare frame, a braced frame and an SDRD installed braced frame of similar dimensions are analysed both experimentally and analytically to study the effects of building and energy dissipation capability during an earthquake and to find out the optimum damper configuration. The complete analytical model and extensive parametric studies have been carried out using nonlinear static analysis in ANSYS Software

KEYWORDS- Cyclic analysis, Metallic dampers, Passive energy dissipation, Pushover analysis, Steel dual ring damper

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I. INTRODUCTION

Control systems are used to control earthquake effects on structures and on rehabilitation of existing structures that has low lateral strength. There are a wide variety of such devices, each of them designed for the reduction of seismic attacks. Passive energy dissipation devices are one of the most common type of such systems.

In this paper, a new passive energy dissipation device named Steel dual ring damper is analysed. It is a cost-effective variant that could help in seismic mitigation of braced steel structures. This device was found to exert the load bearing and energy dissipation more efficiently and also have the added merit of its simple fabrication ways. An SDRD is constituted by welding two concentric rings which are connected to each other by steel plate. In this damper, the earthquake input energy is dissipated by the flexural plastic hinges in each inner and outer ring. One of the important factors in the proper seismic performance of this damper is determining the proper thickness for the simultaneous occurrence of plastic hinges in both rings. The SDRD is proposed as a fuse and ductile element with the nonlinear behavior and is responsible for the absorption and energy dissipation. Thus, the steel ring must be designed such that it has good ductility and strength. Also, the other members should be designed as the capacity-based design method so that they necessarily remain in the elastic zone. Hence, instead of being designed based on the earthquake's internal forces the structural members are designed according to the force generated by the expected real capacity of the ductile member. This study focuses analytic study on the newly introduced SDRD model. As this type of damper hasn't been tested w.r.t an actual frame, further study focuses on the selection of an optimum damper in terms of dimensional study.

The outline of this study can be stated as the following: an experimentally tested SDRD is analysed for its seismic performance with finite element (FE) software ANSYS. The results were then compared for evaluation of the seismic behaviour of the damper on a braced frame. To determine the damper behaviour in a frame, model of a frame installed with SDRD will be modelled and then analysed in ANSYS. Based on the results of the dimensional studies, optimum damper configuration will be determined and recommended for further analysis.

II. DAMPERS AND STEEL DUAL RING DAMPERS

2.1 .History of Dampers

Passive, active and hybrid systems are the major control systems. Passive control systems are those without a feedback system between the device and the ground whereas active control devices are installed with

feedback recorders with recorders, processors and actuators within the structures. The combined features of active and passive control systems constitute a hybrid device [1]. Passive control systems are widely used due to its ability to add damping and/or stiffness to the structure without external energy sources.

Dampers are one of the most effective passive energy dissipation device. Dampers dissipate the input energy caused due to seismic action and controls the resultant vibrations of the structure. The structural response when subjected to an earthquake is reduced by installing a passive energy dissipation devices into the building, reducing the energy-dissipating demand on primary structural members and minimising possible structural damage. The seismic energy can be directed towards these devices installed in the lateral resisting sections of building, to intercept the waves by using proper placement and connection of the elements. The earthquake produces additional mechanical energy in the system which gets converted into thermal energy inside such devices. These dampers improves the damping capacity of the structure and as a result reduces the amplitude of the motion, resulting in reducing the forces on structural members.

Passive energy dissipation devices are again classified into hysteresis devices, viscous devices, tuned mass dampers, magnetic negative stiffness devices, resetting passive stiffness devices and viscoelastic dampers [2]. In hysteresis damping, a part of the input energy contributing to the repetitive deformation and restoration of initial shape is dissipated in the form of random vibrations of the solid crystal lattices. Furthermore, hysteresis devices are divided into metallic and friction dampers, and their energy dissipation is independent of the loading rate.

Metallic dampers dissipate input energy by the inelastic deformation of the constitutive material. Their seismic performance can be studied based on the force–displacement hysteresis loops obtained from cyclic tests as per FEMA 461 are generally followed. Dampers are generally classified based on their constituent material into steel, aluminium, copper and shape memory alloy dampers. A general classification of dampers leading to metallic dampers are shown “Fig. 1”. Steel is mostly preferred as they are designed to deform so much when the building vibrates during an earthquake that they cannot return to their original shape. Some of the recent variations of steel damper are shown in “Fig. 2” was proposed by Ghaedi K et al. [3], [4].

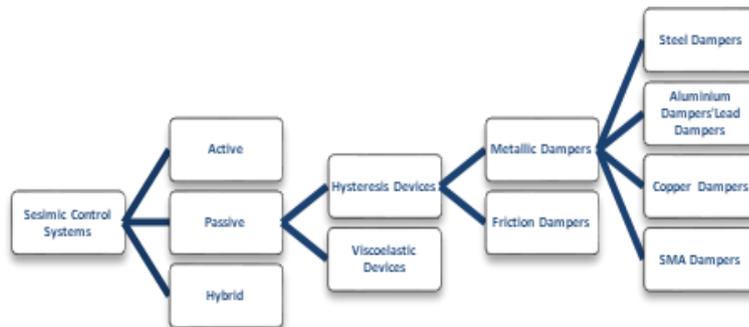


Fig.1. A general hierarchy of Dampers

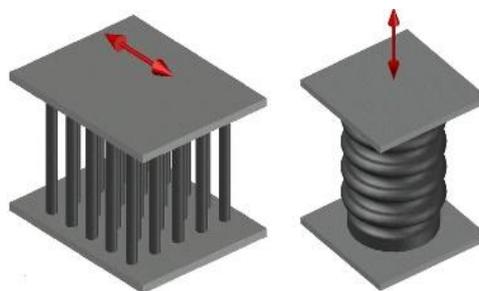


Fig. 2. Recent variants of steel damper – Bar Damper [3] and Accordion Metallic Damper [4]

Steel dual ring dampers are one of the simple metallic damping devices that could be fabricated through welding of steel dual rings. On comparing with other passive metallic dampers, steel dual ring dampers generally possess superior ductility. Tests conducted by P Castadio on a series of steel dual ring dampers showed that they are capable of excellent hysteretic deformation and has excellent energy dissipation capacity. They suggested that appropriate design and implementation of steel ring dampers could prevent the structure from collapse and gives a higher reliability to structures during severe earthquakes. SDRD dampers has the advantage of ease of replacement without any complex and expensive constituents .

2.2. Steel dual ring damper

P Castadio et al proposed a new variant of the damper termed as steel dual ring damper (SDRD). An SDRD is constituted by welding two concentric rings which are connected to each other by steel plate through welding. The main advantage of an SDRD is the simple fabrication process.

A major advantage of the SDRDs were that they were able to acquire similar damping capacity of the previous variants, but with lesser material usage, thus vastly improving the energy dissipation efficiency per steel material usage. Also SDRDs suggest either a fillet or circumferential weld which possesses a better weld quality than the sharp edge mode weld employed in the previous models such as dual-pipe dampers.

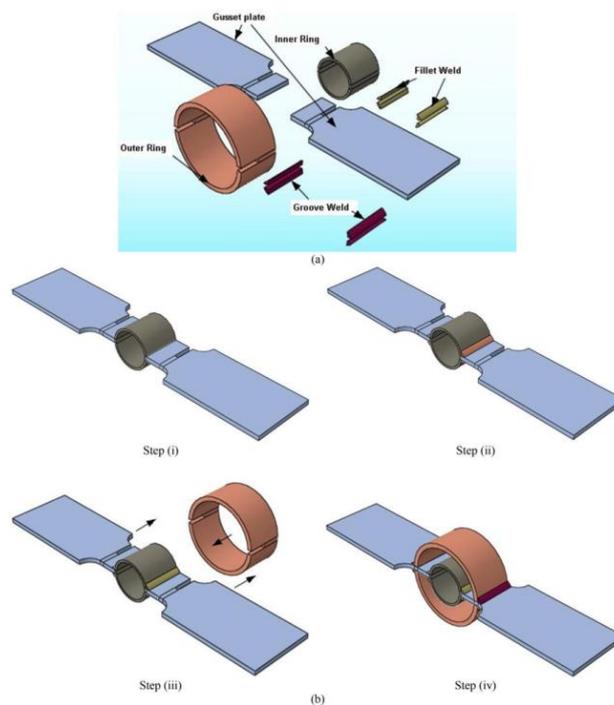


Fig. 3. (a) Steel dual ring damper and (b) construction process of steel dual ring dampers

III. SEISMIC EVALUATION OF STEEL DUAL DAMPERS

To analyse the seismic performance of a frame, non-linear or push over analysis need to be performed. The main advantage of steel frame is that its elastic behaviour . Results of FE analysis has showed that they could be used in design and could accurately predict the overall structural seismic performance in terms of lateral load-bearing capacity.

The push over analysis could be carried to determine the response of the frame. This could be done with a horizontal force at the top corner of frame using ANSYS software. The response gives us the ultimate load and deflection characteristics and the ductility demand of the damper – frame configuration, which would lead us to determine the energy dissipation capacity of the configuration by cyclic analysis.

A cyclic analysis on the seismic behaviour of a frame would follow the FEMA 461 guidelines, in order to derive a displacement load reversal. The target displacement required for calculating the required loading history would be selected based on results of the earlier monotonic pushover tests. The force is then applied with an increment until the ultimate failure of the frame-damper configuration.

Many studies have been conducted to determine the effect of geometrical and dimensional parameters on the damping efficiency of a frame. P Castadio was one of the firsts to evaluate the behaviour of steel dampers as a hysteretic damper and they analysed the effects of length, thickness and diameter on the hysteretic

behaviour of steel pipes. They also suggested that increase in number of devices at connections would result in subsequent improvement of the ultimate load carrying capacity. Among the various dimensions analysed, it was concluded that length of dampers has no effect on the cyclic behaviour. But whereas plate thickness, geometry and placement had significant effect on damping performance. Later, R. Aghlara et al. proposed that mechanical properties of the dampers could be controlled with parameters such as number, length, diameter and thickness of the pipes. He also reported the ease of replacement of the pipe components after each failure.

Advanced finite element programs such as ABAQUS, ANSYS, LS-DYNA, etc. are the most used computational methods in studying metallic dampers. These programs are capable of modelling the metallic dampers meticulously with the primary frames. Usually initial design and analysis of metallic dampers or the extension of experimental investigation are conducted on these platforms. Primary structures that are incorporated with metallic dampers can also be modelled in these mentioned programs, though it requires a deeper understanding of the programs and also high-performance computers. ShervinMaleki and SaeedMahjoubi reports that most of these studies on metallic dampers are now mostly conducted on ABAQUS and ANSYS platforms.

IV.FE ANALYSIS OF SDRD

To perform the analysis non-linear finite models of the dampers were developed in ANSYS as shown in “Fig. 4”. An SDRD with dimensions of 100mm, 100mm and 20mm 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.

From here on this sample would be represented as 100x100x20 Material properties were provided as per the source paper.

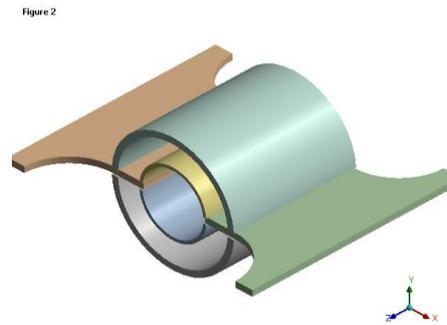


Fig. 4. Steel dual ring damper

The material and dimensional properties chosen as per P.Castadio et al. is shown in TABLE. 1. The model was analysed after providing boundary conditions as welded connections with a displacement controlled cyclic load as per FEMA 461.

Table 1. Properties of the selected sample 100x100x20

Material Property		Dimensions	
Property	Value	Property	Value
Elastic Modulus	202.03 GPa	Outer ring Diameter	100 mm
Yield Stress	341 MPa	Length of damper	100mm
Ultimate Stress	491 MPa	Outer ring dia to thickness	20mm

Displacement history of the cyclic loading is given in “Fig. 5” which consist of repeated cycles with step-wise increasing displacement amplitudes at 0.624, 0.884, 1.235, 1.729, 2.418, 3.38, 4.732, 6.633, 9.282 and 13.00 mm.

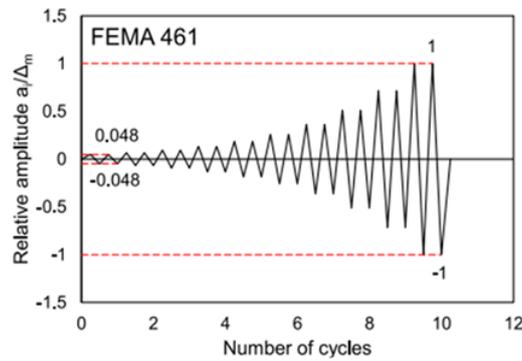


Fig. 5. Cyclic loading Protocol adopted

“Fig. 6”and “Fig.7” shows the Force- Displacement curve and hysteresis curve of the FE analytical values under cyclic loading. The values obtained are summarised in TABLE 2. Ductility demand ratio, μ is used in this study as an indicator for the ductility measurement of the damper samples. As per ASCE/SEI 41–17 approach, ductility demand ratio is the ratio of ultimate deflection (Δ_u) to that of yield displacement (Δ_y). The ductility demand is the maximum ductility level that a structure can attain in an earthquake. It could be said that μ depends on both the seismic activity and the structure’s ability.

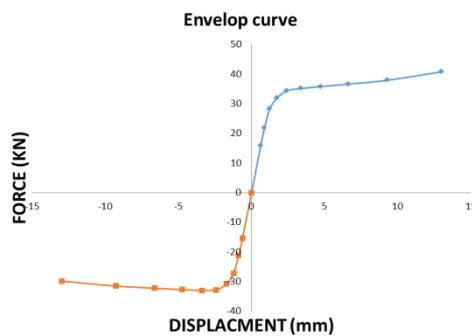


Fig. 6. Force –Displacement curve

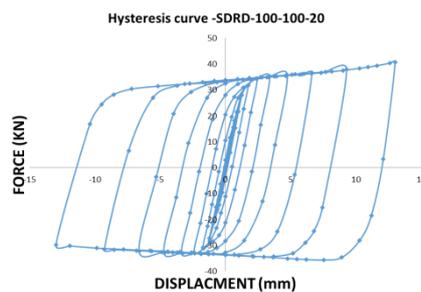


Fig. 7 Force –Displacement Hysteresis curve

Table 2. Comparison of results

	<i>ABAQUS</i>	<i>ANSYS</i>
Yield Deflection (mm)	0.96	0.88
Ultimate Deflection (mm)	13.00	13.00
Ultimate Load (kN)	22.50	21.78
Ductility demand	13.54	14.71

V. DIMENSIONAL STUDY OF DAMPERS ON FRAME

For the installation of SDRDs in seismic mitigation, an optimum damper that has significant impact on the seismic performance of a frame need to be determined. Studies have identified that dimensions and

placement of dampers has an important role in the seismic behaviour of a frame. In this study, It concentrates on finding appropriate damper that improves the damping efficiency of the frame. This study intends to analyse frame-damper configurations under monotonic pushover loading, which would give ultimate bearing capacity of the configuration that could lead into cyclic loading analysis on the frames in future.

The stages can be divided as Preliminary study and Dimensional study. In the preliminary study of damper dimension, a bare frame, a braced frame and a frame installed with an SDRD are analysed with ANSYS. The frame model and its material properties are shown below.

5.1 Specimens:

The frame adopted was a single bay frame of height 9m and width of 5.5m, modelled image is shown in “Fig. 8”. The type and material property of the steel elements are given in TABLE 3.

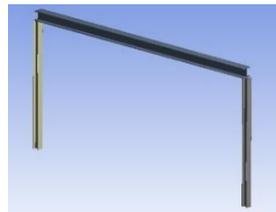


Fig. 8. ANSYS Modelled image of bare frame

Table 3. Specifications of columns beams & braces adopted for the analysis

	Columns	Beams	Braces
Material Grade	ASTM W-sections, A992 grade		Hollow circular sections, A500 Gr-B42 grade
Steel Section	w8x40	w12x10 6	0.5” thick
Yield Stress	F _y = 344 MPa		F _y = 289 MPa

5.2 Test Setup and Loading Protocol:

The supports and loading protocols are As demonstrated in Fig. 9, the columns are fixed at the bottom and additional supports are provided at the column-beam junction. Loading protocol followed here is displacement controlled with a 450mm lateral displacement at position “C” shown in “Fig. 9”. ANSYS developed models of bare frames are given in “Fig 8”.

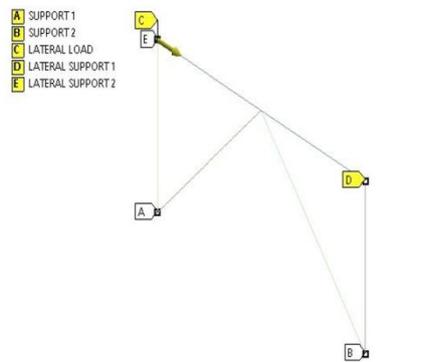


Fig. 9 Loading protocol

5.3 Results and Discussions:

Results obtained from this study is summarised in TABLE 4. As shown, a damper installed frame doesn’t show any considerable increase over a bare frame in terms of both ultimate Load (P_u) and ductility ratio (μ).

Therefore, our aim for further analysis is to achieve characteristic values for a damper installed frame that are similar to that of a braced one.

5.4 Dimensional study:

Since installation of damper had not generated desirable results when compared with bare and braced frames, dimensional analysis was carried out with proportional increase in dimensions of the SDRD. Analysis was further carried out with samples 300x25x150x12.5x250, 400x25x150x12.5x250, 500x25x150x12.5x250, 400x25x150x12.5x350, 400x25x200x12.5x350, 500x25x250x12.5x400 where dimensions shown are outer ring diameter, thickness of outer ring, inner ring diameter, thickness of inner ring, length of damper and plate thickness taken is 50 to determine a frame-damper connection with optimum results. Deflection map obtained on each frame is shown in "Fig. 10". On analysing the results obtained, as depicted in TABLE 4 and 5, and Fig. 11, it could be observed that SDRD with configuration 500X30X250X12.5X400PLATE-50 has the most satisfactory result in terms of both ductility and ultimate load(3316,24.812). This could be attributed to the increase in stiffness, as a result of variation in thickness. As clear from TABLE 4 and 5, the configuration of 500X30X250X12.5X400PLATE-50 shows a satisfactory set of characteristics in both ultimate load capacity and ductility ratio. Hence this configuration could be considered as the optimum damper-frame configuration and is recommended for further FE cyclic analysis on frames.

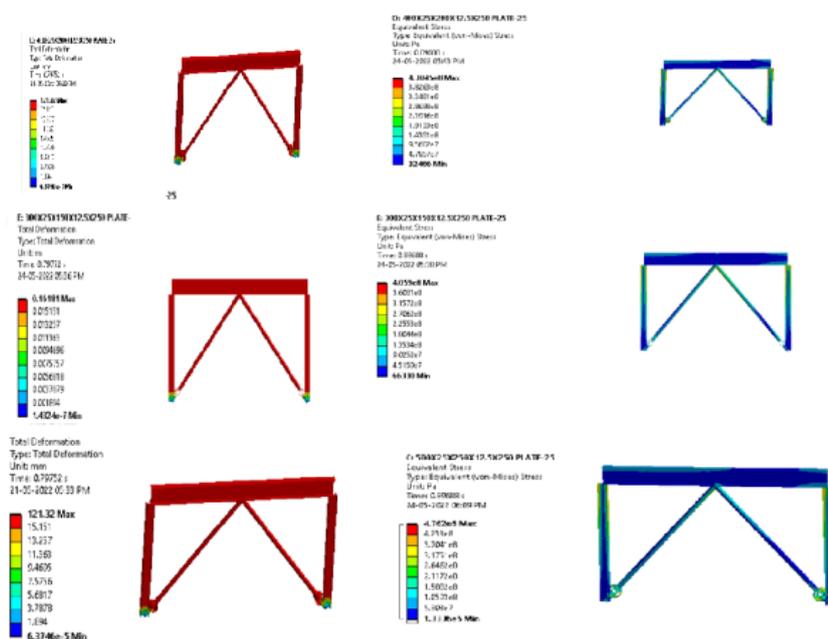


Fig. 10 Deflection and stress diagrams (samples 300x25x150x12.5x250, 400x25x150x12.5x250, 500x25x150x12.5x250)

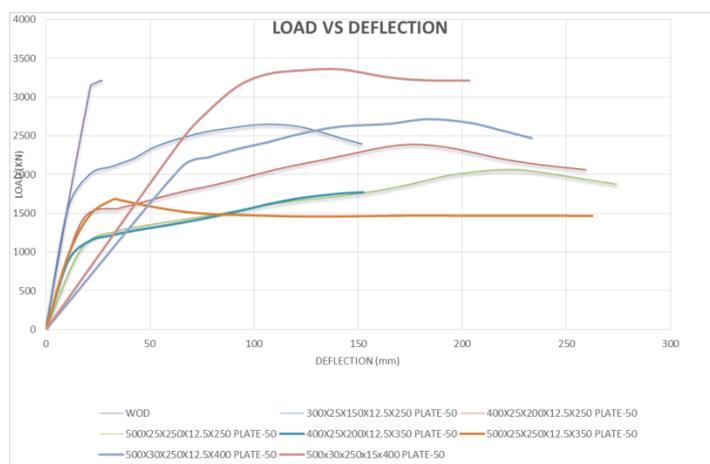


Fig. 11 Load- Deflection curve

Table 4: Comparison of results

MODELS	DEFLECTION (mm)	LOAD (KN)	% DECREASE IN LOAD
WOD	26.86	3214.00	1
300X25X150X12.5X250 PLATE-50	42.07	1934.00	39.82576229
400X25X200X12.5X250 PLATE-50	125.10	1880.20	41.49968886
500X25X250X12.5X250 PLATE-50	138.17	1589.50	50.54449284
400X25X200X12.5X350 PLATE-50	152.55	1770.00	44.928438
500X25X250X12.5X350PLATE-50	33.47	1686.00	47.542003
400X30X250X12.5X400PLATE-50	60.20	2713.90	15.560049
500X30X250X12.5X400PLATE-50	24.12	3316.00	3.07599

Table 5: Comparison of results

MODELS	YIELD DISPLACEMENT	DUCTILITY
WOD	12.2	0.180448804
300X25X150X12.5X250 PLATE-50	20.1	0.104140987
400X25X200X12.5X250 PLATE-50	10.59	1.11548925
500X25X250X12.5X250 PLATE-50	10.52	1.248481979
400X25X200X12.5X350 PLATE-50	10.56	1.367994576
500X25X250X12.5X350PLATE-50	10.57	15.667098
400X30X250X12.5X400PLATE-50	10.59	19.9734
500X30X250X12.5X400PLATE-50	13.56	24.812

VI. CONCLUSIONS

Steel dual ring damper were proposed as a new variant to existing dampers to be installed on steel frames, owing to its higher energy dissipation capacity per steel material usage. This project aimed to analyse these devices on a real scale frame, using FE software. As depicted in TABLE 4, 7 such configurations were analysed. This was followed by analysing variations of the validated damper with a steel frame to determine the optimum damper frame configuration. SDRD damper was validated by FE analysis and was recommended for analysing on frames. Since a single unit of the validated damper didn't yield satisfactory results, the study was further widened in terms of dimensional parameters.

- With increase in size of the damping devices, there is a subsequent increase in load capacity of the damper. This could be due to the increase in stiffness with the larger moment of inertia.
- The damper configuration of 500X30X250X12.5X400PLATE-50 was found to be the optimum model. This model not only produced satisfactory load capacity and ductility values, but also had favourable yield and ultimate deflection values. This configuration is recommended for further studies on this topic.

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