Seismic Energy Dissipation Enhancement Study of Steel Braced Frames with Steel Dual Ring Damper

Balkees EP, Anila S

Abstract— In this research, an innovative cost-effective steel dual-ring damper (SDRD) was utilized on the long member of the Y-bracing to increase ductility capacity and reduce the risk of buckling. For this purpose, a single-story single-span frame with Y-shaped bracing was considered and subjected to lateral seismic load and analytically in two cases of SMRF structure with and without damper on Y shaped braces and the parametric study is carried out by changing the parameters of the SDRD dimensions to find the optimum size that is bests suited for the seismic performance of structure. Stiffness, strength, and energy absorption capacities of these frames were compared.

Keywords— Buckling, Ductility, Energy absorption, Steel dual-ring damper, Stiffness, Strength, Y - shaped bracing

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1 INTRODUCTION

Bracing is a highly efficient and economical method to laterally stiffen the frame structures against wind and other lateral loads. A braced bent consists of usual columns and girders whose primary purpose is to support the gravity loading, and diagonal bracing members that are connected so that total set of members forms a vertical cantilever truss to resist the horizontal forces [1]. Bracing is efficient because the diagonals work in axial stress and therefore call for minimum member sizes in providing the stiffness and strength against horizontal Shear. The steel braces are usually placed in vertically aligned spans [2]. This system allows to obtaining a great increase of stiffness with a minimal added weight.

One of the concentric bracing types, which has recently become widely used, is Y-shaped concentric bracing, which is employed to solve architectural problems, however this bracing does not have adequate ductility. The system behaviour is very sensitive to the location of the bracing members connection; in a way that, by relocating the middle node to the frame corner and increase in the eccentricity of this point, stiffness of the frame decreases [5]. Subsequently, the natural vibration period of the brace rises, and as a result, displacement of the system under constant load increases. Moreover, due to the long length of some members and the presence of significant compression force in them, the occurrence of buckling affects the benefits of the system [4].

Extensive studies have been performed by researchers to increase the ductility and and energy-absorption of concentrically braced frames [8]. One of the most widely used strategies for increasing ductility and energy-absorbing is the utilization of energy-dissipation systems [6]. In this, energy dissipation system consisting of a steel dual-ring damper (SDRD) with different construction details is used, to improve hysteresis behaviour and performance of steel ring dampers (SRD). The SDRDs are composed of concentric steel rings connected by a gusset plate. The cyclic behaviour and energy absorption of this damper depend on the geometry and dimensions of the inner plus outer ring [7]. The most important cause of energy-dissipation in SRDs are the development of bending plastic hinges in the rings. Therefore, by adding an inner ring to the SDR system, it increases the number of moment plastic hinges and in turn increases energy dissipation [9]. The use of steel rings as dampers in controlling displacement and ductility as well as significant energy dissipation in concentrically braced frames systems (CBFs) has attracted the attention of many researchers [3]. The results of research on steel ring dampers as ductile and energy-absorbing elements in CBFs have shown good ductility, energy dissipation, and hysteresis-stable loops [10].

2 LITERATURE REVIEW

2.1 General

A literature review is the effective evaluation of selected documents on a research topic. A review may form an essential part of the research process or may constitute a research project in itself. In the next context of a research paper of thesis the literature review is a critical synthesis of previous research. The main purpose of this research is to provide information about various research works done in the field of study. It helps to know the various reviews about steel frames with damper integrated braces.

2.2 Research works

Mojtaba Gorji Azandariani et al. studied the energy absorption system of a steel dual-ring damper (SDRD) and cyclic behavior was done analytically and numerically. The purpose of this study was to provide an analytical relationship for estimating the yield strength, yield displacement, and elastic stiffness of the proposed SDRDs. For parametric studies, 50 finite element model steel dual-ring dampers have been selected and modeled. Extensive parametric studies have been carried out using a nonlinear finite element method to exam-

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ine the accuracy of the obtained analytical relationships. The parametric studies include investigating the influence of thickness parameters as well as the inner and outer ring diameters of SDRDs. Nonlinear static analysis was employed to analyse finite element (FE) models under cyclic loading. Based on parametric study data and dimensions of the steel ring, relations were presented to predict ductility coefficient, total dissipated energy, and equivalent viscous damping ratio. The proposed analytical relationship predicted the yield strength, yield displacement, and elastic stiffness of SDRD with good accuracy. Also, as the diameter to thickness (D/t) ratio increases, ductility and equivalent viscous damping ratio are reduced. The comparison between the proposed SDRDs and other metallic dampers revealed good seismic performance and high energy absorption [6].

Yong-Ming CAO et al. presented the seismic behaviors of the composite central brace with steel ring damper. A nonlinear finite element model was established to study seismic behaviours of the ring damper by use of ABAQUS software. For this, a 6-storey frame-brace structure was selected. The total lateral force is calculated by using the bottom shear method. The results indicate that ring damper has ample initial stiffness, bearing capacity, better deformation performance and energy dissipation ability in the control displacement range. The ring damper can be used as an energy dissipation component for central braces. It absorbs the earthquake energy and avoid the premature buckling of the brace. The ring damper reaches the ultimate bearing capacity through forms of multi-plastic hinges, and shows good seismic performance within the 30mm ranges [10].

Chandrashekhar B Adin conducted a study on the effect of bracings and dampers under earthquake and wind loads for industrial steel structures. This study has been mainly carried out to determine the change in various dynamic parameters due to consideration different bracings, dampers with different mass ratio and height by breadth ratios. On the basis of results obtained, some of the important conclusions are presented here. Modals with bracings are more effective in reducing structural parameters than dampers. Modals with damper are most effective in reducing systematic parameters than bracings. The usefulness of dampers is observed when the mass ratio of damper is 2%. In bracings x bracing is found out to be more economical. Also found that time period decreases with the increase in stiffness of building and base shear decreases with the increase in stiffness of building. From the study it has been found that dampers are more economical than bracing [2].

M.R. Solaimani Nezhad studied the seismic evaluation of the Y-shaped bracings equipped with a yielding diagonal damper. For this, single-story single-span frame with Y-shaped bracing in two modes of with and without damper was selected. The stiffness, strength, and energy absorption capacities of these two frames were compared. It is observed that different capacities of the have various effects on strength reduction and energy dissipation and have an optimal effect for the medium capacity damper. Dampers with high capacities do not have any effect due to them in activity. Results have shown that using yielding dampers decreases strength and stiffness by 20 and 27%, respectively. However, these dampers increase the capacity for energy absorption by about 30%. Since using dampers with lower capacities is more effective in decreasing the shear effect but the energy absorption and ductility are also among the important goals of the research, so the optimal mode to attain both goals is the use of medium - capacity dampers [5].

Farshad Alizadeh studied on mechanical properties of steel ring dampers. For this purpose, the data related to the mechanical characteristics of these elements has been extracted aiding ANSYS software. Thickness, width and diameter of steel ring have been considered as the element´s dimensional variables. The mechanical properties such as initial stiffness, secondary stiffness, yielding deformation, yield and ultimate forces were calculated for both tension and compression modes and the results have been presented. According to the obtained results, steel ring can be used as the fuse in concentric braced frame. All rings are rupture from the inside in their ultimate capacity. The ultimate capacity of the rings has direct relationship with ring width and diameter and inverse relationship with the ring thickness [3].

3 NUMERICAL MODELLING

In this research, the combination of a Y-shaped bracing system with steel dual ring dampers in both cases of with and without damper was evaluated non linearly.

3.1 Geometry

All specimens are single bay, one story frames, with 6.0 m span and 3.2 m height. Three models were created, a bare frame, Y-braced frame without SDRD damper and Y-braced frame with SDRD damper. The ring damper specimen and plate was made of A992 steel, with length of damper (L) = 200 mm, diameter of outer damper (D_o) = 500 mm, thickness of the outer ring (t_o) = 40 mm, diameter of inner ring (D_i) = 250 mm, and thickness of inner ring (t_i) = 20 mm, length of plate (Lp) = 280 mm

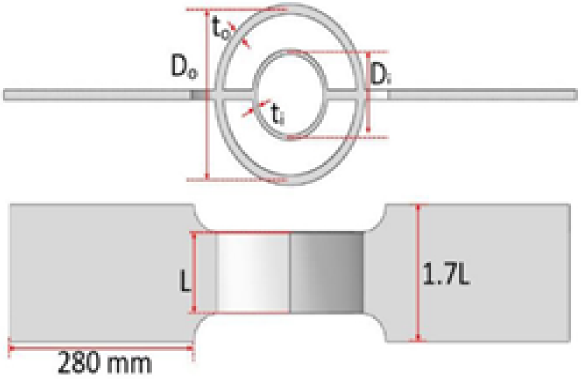

Fig. 1 Cross section of steel dual ring damper

The cross-sectional geometry of the ring damper is shown in Fig. 1. Fixed support was provided at one end of the damper and a displacement type loading was provided at the other end.

Sections of beam and columns were IPB 270 and IPB 160 respectively, which was same for all models.

TABLE 1 GEOMETRIC PROPERTIES OF BARE FRAME AND STEEL BRACE

Sections	IPE270 (Beam Section)	IPB160 (Column Section)	U100 (Brace)
Section height, h(mm)	270	160	100
Flange width, b (mm)	135	160	46
Flange thickness, t (mm)	10.2	13	8.5
Web thickness, s (mm)	6.6	8	4.5
Section area, A (mm^2)	4590	5430	1250

The geometric properties of steel bare frame and steel brace are given in Table 1. Cross sections of structural shapes used are based on German DIN-1025 (part 2&5) standard.

3.2 Material modelling

A992 steel was considered in this work. Steel was having a yield stress of 345 MPa and ultimate stress of 450 MPa. The density of the material was 7850 kg/m3. Modulus of elasticity of 200 GPa and Poisson's ratio of 0.30 was considered for the elastic property of the material. Bilinear kinematic hardening was provided for the stress strain relationship.

3.3 FE modelling of SDRD

Using ANSYS Design Modeler, Steel dual ring damper in braced steel structure is to be modelled. Solid 186 element was used to model the damper. Solid 186 element is defined by 20 nodes having three degrees of freedom per node with translations in the nodal x, y and z directions. 23428 elements were used to model the damper in ANSYS.

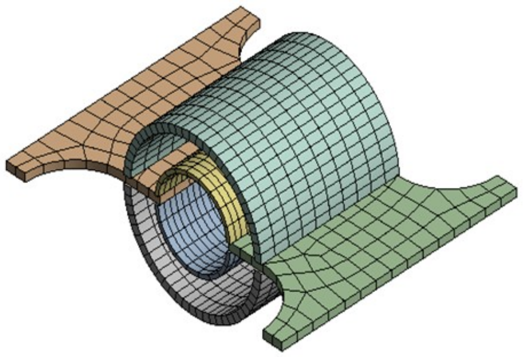

Fig. 2 Meshed model of SDRD

The mesh size of 10 mm was considered. The finite element mesh model of SDRD is shown in Fig 2. Single bay, one story frames, with 6.0 m span and 3.2 m height are designed. The design of these frames is in such a way that the main failure mode is becaue of the in-plane buckling. For this purpose, the selection of sections, which have sufficient strength to out-of-plane buckling, was considered.

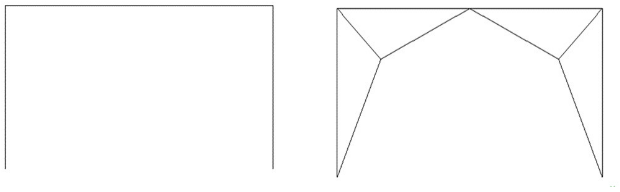

Fig. 3 Bare frame and frame with Y bracing

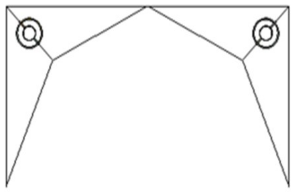

Fig.4. SDRD in steel braced frame

Fig 3 shows the bare frame and Y- braced frame withoutdamper. Fig 4 shows the Y-braced frame with SDRD.

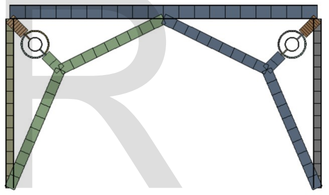

Fig. 5 Meshed model of frame with SDRD

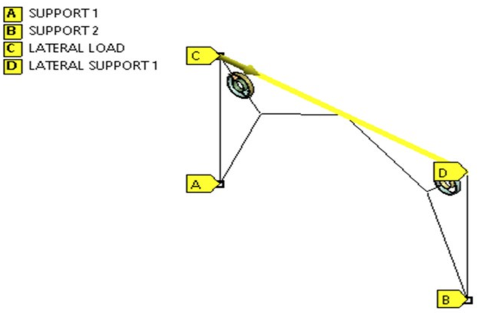

Fig. 6 Support conditions for FE model

The finite element mesh model of Y braced frame with SDRD is shown in Fig.5. The boundary conditions were taken in the FE model as illustrated in Fig. 6.

4 RESULT AND DISCUSSIONS

In this research, the combination of a Y-shaped bracing system with steel dual ring dampers and with the optimal connection node of e1=0.3 condition in both cases of with and without damper was evaluated non linearly. They are analyzed using finite element analysis in ANSYS WORKBENCH. The results of finite element analysis are given below. Comparing the parameters like load carrying capacity, maximum deflection and ductility index of each model.

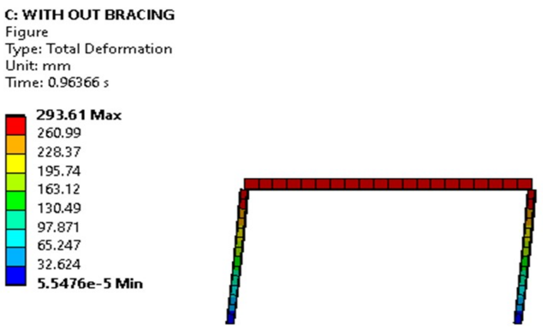

Fig. 7 Deformation of bare frame

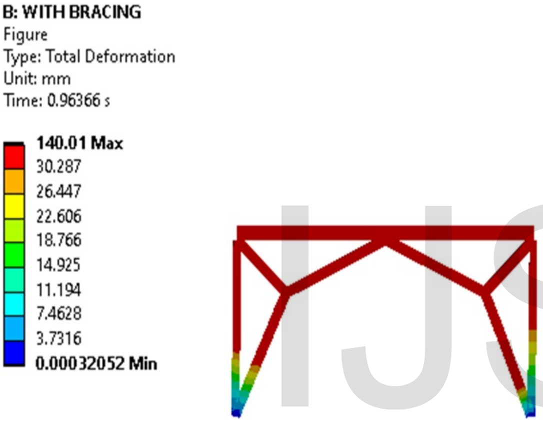

Fig. 8 Deformation of frame with bracing

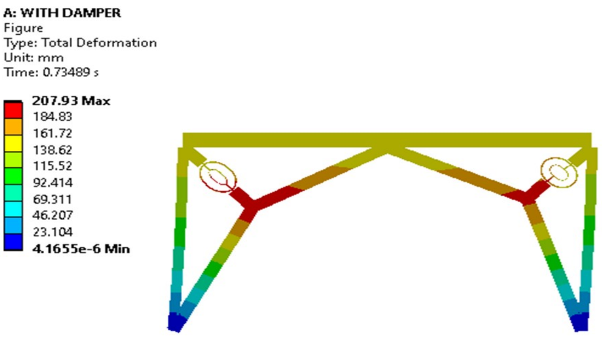

Fig. 9 Deformation of braced frame with damper

The total deformation of a bare frame, braced frame and braced frame with SDRD are shown in fig 7, fig 8 and fig 9 respectively. Maximum deformation in braced frame with SDRD was occurred at the joint of braces. Minimum deformation was occurred at the support area.

According to analyses, all the steel frames subjected to a similar loading protocol. Examination of analysis shows that adding a damper to the frame induces an almost symmetrical hysteretic behavior on the frame in which there is no sudden drop in strength like in the case without damper. In the compressive part of the hysteresis with damper, due to the reduction of internal force in the frame, the brace does not buckle, while in the case without a damper, the brace buckles and does not have proper performance in compressive mode.

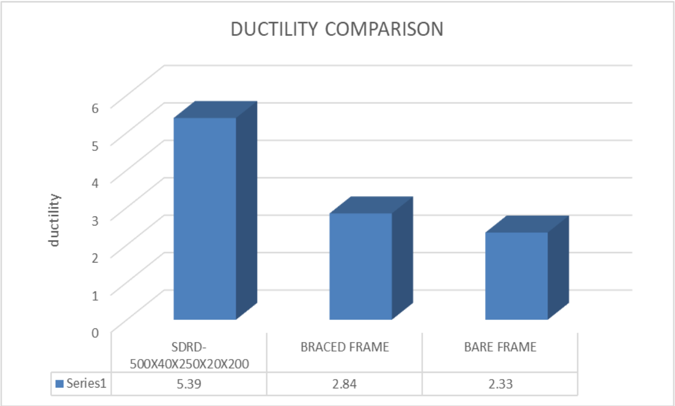

Fig. 10 Ductility comparison of SDRD, braced frame and bare frame

Here fig 10 shows the ductility comparison of braced frame with SDRD having outer ring diameter of 500mm, outer ring thickness of 40mm, inner ring diameter of 250mm, inner ring thickness of 20mm and ring length of 200mm with braced frame without damper and a bare frame. The ductility of Y braced frame with SDRD increased about 48% than Y-braced frame without SDRD. There is 17% increase in ductility of braced frame when compared with a bare frame.

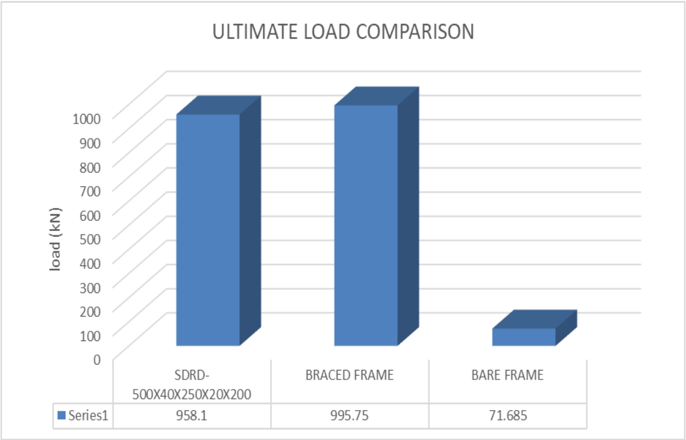

Fig. 11 Ultimate load comparison of SDRD, braced frame and bare frame

Fig 11 shows ultimate load carrying capacity comparison of braced frame with SDRD, braced frame and a bare frame. The load carrying capacity of braced frame without damper was about 3% greater than that of braced frame with damper. About 93% increase in the load carrying capacity of braced frame than a bare frame. So, the importance of braces in frame can be understand.

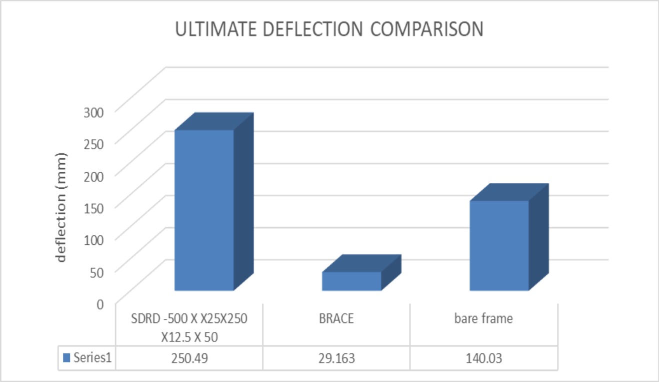

Fig. 12 Ultimate deflection comparison of SDRD, braced frame and bare frame

Fig 12 shows the deflection comparison of braced frame with SDRD, braced frame without SDRD and a bare frame. In bare frame, 80% of increase in ultimate deflection than braced frame.

5 CONCLUSIONS

The SMRF structure with and without damper on Y shaped braces are analyzed. The ultimate load carrying capacity in the case where a damper is added to the frame is 3% less than the frame without damper. The braced frame has load carrying capacity of about 93% greater than the bare frame. The ultimate deflection of braced frame without SDRD damper decreases about 85% than braced frame with SDRD damper. In bare frame, 80% of increase in ultimate deflection than braced frame. The Y-braced frame with SDRD damper has almost 48% increase in ductility than Y-braced frame without SDRD damper. And about 57% increase in ductility than bare frame. The overall results show that using a damper in the frame lessens the forces applied to the structural elements (column - beam - bracing) in a way that most members of the structure remain in the elastic zone and the damper bear the damages by experiencing a high plastic deformation.

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