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Seismic and progressive collapse mitigation of shear energy dissipation beam in dual braced moment frames

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Abstract - *In general, a structure collapses gradually when one of its critical members fails, causing adjacent elements to fail and be damaged. In building structures, progressive collapse often starts when the vertical members like columns fail. Progressive collapse is defined as a condition that begins with a local failure, leads to the collapse of neighbouring members, and then triggers additional collapses. The influence of seismic force resistance capacity and progressive collapse resistance capacity of moment-resisting frames on dual system response is examined in this study. When the seismic force resistance share of moment frames in dual systems was increased, the structure became more robust against progressive collapse when the moment frame experienced column loss.*

Experimental work was conducted to analyse the effect of energy dissipation beams on the behaviour of dual-braced moment resisting frames in seismic and progressive collapse. Energy dissipation beams will act as a ductile fuse to absorb energy. This system is one of the simplest and cheapest passive energy dampers. This study analysed a dual frame with inverted V braces with and without energy dissipation beams

Key Words: **Seismic analysis, Progressive collapse, Energy dissipation beam, Dual braced moment resisting frame, SAP2000, Time history analysis, Pushover analysis**

1 INTRODUCTION

Advances in the methods of analysis and design of structures and the development of performance-based concepts, together with the observation of collapses in many structures as a result of natural and non-natural events, have directed researchers toward investigation of structures in conditions far beyond the service conditions which are generally considered in conventional designs. There have been or are being built a huge number of moment-resisting frame buildings. Additionally, more are being planned for construction around the world. These structures serve a variety of social and practical purposes. Although several researchers have worked on the seismic design of a dual system of moment-resisting frames, very few studies have been conducted with regard to their progressive collapse. In building structures, progressive collapse often starts with omitting vertical members like columns. The failure of main vertical members might happen due to abnormal and extreme loadings such as earthquakes, gas explosions, fires, and accidental impact of a vehicle. If the building's continuity, ductility, and redundancy are insufficient, it will collapse, potentially causing significant casualties.

In this paper, the effect of the horizontal energy dissipation beam on the seismic and progressive collapse resistance of dual braced moment resisting frames was analysed. Progressive collapse resistance decreases from lower to upper stories under column removals from different stories at the same location [3]. Beams mainly resist collapse by the flexural capacity to span damaged parts, and beams on lower stories have higher flexural capacity because of higher seismic demand during design [3]. The energy dissipation beam is designed to act as a fuse by yielding and dissipating energy [2].

2 SCOPE

The study is limited to seismic and progressive collapse analysis. The structure analysed is a dual inverted V-braced moment resisting frame. Only a few parameters like displacement, base shear, and progressive collapse resistance are studied. SAP2000 software is used.

3 METHODOLOGY

The main objective of this research is to study the performance of energy dissipation beams on the seismic and progressive collapse resistance of dual braced moment resisting frames. To examine the behaviour of a dual-braced moment resisting frame with and without energy dissipation beams, a six-storey building is considered. Then the selected structure with and without energy dissipation beams was modelled and analysed in SAP2000 software and the results are compared. Nonlinear static pushover analysis was carried out to study the progressive collapse of the frame. Nonlinear dynamic analysis (time history analysis) was carried out to study the seismic performance of the frame.

4 MODELLING

The analysed structural models were dual systems with an inverted V-bracing configuration. The buildings were six-storey residential buildings with four bays and plan dimensions of 24 m x 24 m. Each storey had a height of 3.2 metres and a span of 6 metres. The beams and columns were wide-flanged. The cross members were made of ASTM A992 steel, while the braces were seismically compact, square hollow steel sections (HSS). The designed dead and live loads were 6.5 and 2.0 kN/m^2, respectively. A uniform linear dead load equal to 4.0 kN/m was applied to perimeter beams to consider wall loads. As per the journal, the design seismic load was obtained from ASCE 7 (2016). The buildings were designed for seismic design category D (high seismic risk). Table 1 shows the member sizes of the model. The structures with and without energy dissipation beams were modelled as shown in Fig. 1 (a) and (b).

Table -1: Member size of model

Storey	Column		Beam		Brace
	Internal	External	Internal	External	
1^{st}	W 12×136	W 12×136	W 12×35	W 12×22	HSS 6×6×3/8
2^{nd}	W 12×136	W 12×136	W 12×35	W 12×22	HSS 6×6×3/8
3^{rd}	W 12×120	W 12×136	W 12×35	W 12×22	HSS 6×6×3/8
4^{th}	W 12×120	W 12×136	W 12×35	W 12×22	HSS 5×5×5/16
5^{th}	W 12×96	W 12×136	W 12×35	W 12×22	HSS 5×5×5/16
6^{th}	W 12×96	W 12×136	W 12×35	W 12×19	HSS 5×5×5/16

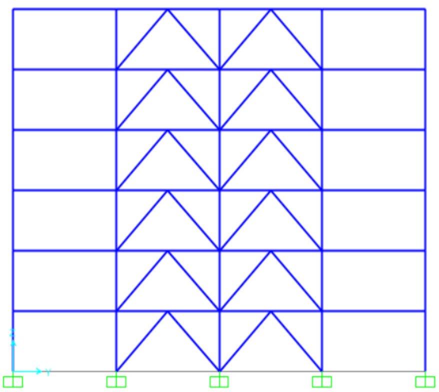

Fig. 1 (a) Dual braced moment resisting frame without EDB

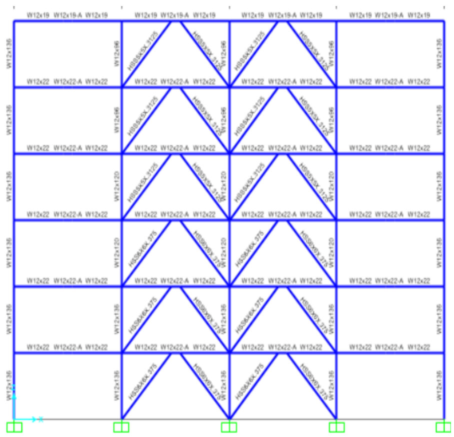

Fig. 1 (b) Dual braced moment resisting frame with EDB

4.1 Design of Energy Dissipation Beam

In this study horizontal energy dissipation beams were provided between braces to act as a fuse by yielding and dissipating energy while preventing the buckling of the brace members. The performance of the energy dissipation beam is highly influenced by the link length and the plastic shear strength (V_p) to plastic moment strength (M_P) ratio. Using plastic analysis V_p and M_P can be written as:

$$V_p = \frac{f_{yw}}{\sqrt{3}} t_w(d - 2\, t_f)$$

$$M_P = f_{yf} \cdot t_f\, (b - t_w) \cdot (d - t_f) + \frac{f_{yw}\, t_w\, d^2}{4}$$

Where f_{yw}, f_{yf} are the web and flange yield strength, respectively,

t_w is the web thickness, d is the overall beam depth, and t_f is the flange thickness and b is the flange width. In order to impose shear yielding before bending yielding of the horizontal link, the link length e must be limited to:

$$e \leq \frac{2 \times 1.2\, M_P}{1.5\, V_P} = 1.6 \frac{M_P}{V_P}$$

According to AISC seismic provisions, links with e ≤ 1.6 are energy dissipation beams that yield principally in shear and have a maximum link rotation of 0.08 rad under design seismic stress. As a result, the frame's drift angle θ, may be represented in terms of the link rotation angle γ, as follows:

$$\theta_P = \gamma_P \frac{e}{L}$$

Design

The steel used for energy dissipation beam was of grade Fe 250. Grade of steel used for the energy dissipation beams should be less than grade of steel used for other members.

f_y = 250 N/mm, t_w= 6.604 mm, d = 312.67 mm, t_f= 10.795 mm, b = 102.362 mm

V_P = 277458.9971 N

M_P= 118364105 N.mm

5 ANALYSIS

5.1 Seismic Analysis

The best technique for evaluating structural reactions under earthquake excitations defined by ground acceleration records is time-history analysis, which is a nonlinear dynamic analysis. A number of short time increments are used to evaluate the performance. A representative earthquake time history for the structure being analysed is required to perform such a study. Ground motions have been selected to perform the dynamic analysis of the current study. The ground motion records are obtained from the PEER Strong Motion Database (http://peer.berkeley.edu/smcat/). Fig 2 provides the acceleration time history for the earthquake ground motion used in the current analysis. Since earthquake resistant design considers the shear at base as a governing parameter, the parameters studied in this analysis were mainly base shear and displacement.

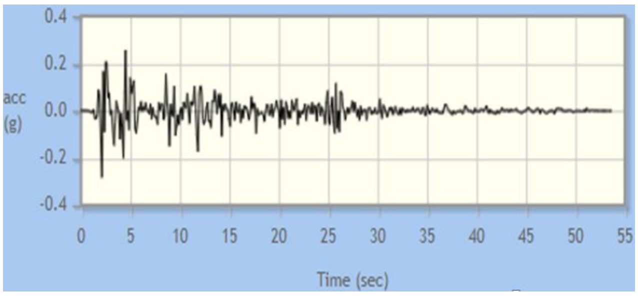

Fig. 2 Acceleration time history record for the earthquake ground motion

5.2 Progressive Collapse Analysis

In progressive collapse analysis, it is assumed that the primary members that lose their load-bearing capability due to an earthquake are removed from the structure, and then the structure is analysed. Some columns are chosen for removal, and the progressive collapse analysis is stated. These are usually on the lowest floor and are attached to a braced and moment frame. This is a new trend in the field of progressive collapse, in which the column is removed as a result of an earthquake and then a structure is that has been damaged by an earthquake, which is known as 'seismic progressive collapse'. Pushover analysis was carried out to study the performance of moment resisting frames with bracing and energy dissipation beams and without energy dissipation beams .

In this paper, two different sets of models were analysed. Each set of models includes three models. In the first set, all of the models considered were without EDB. In addition to this, different columns were eliminated from each model. In the first model, the left-side corner column was eliminated, and the second model was without the second column from the left side of the ground floor. In the third model, the eliminated column was the middle column on the ground floor. The next set of models considered was with EDB between braces, and the column eliminated from each model was the same as the first set. In accordance with the UFC guidelines, the gravity load combination "Ω_N(1.2D+0.5L)" was applied to bays adjacent to the removed column at all floors above that. The gravity load combination "(1.2D +0.5L)" was applied to the other bays. Dead and live loads are represented by D and L, respectively. Eq. (1) (UFC 2016) was used to derive the dynamic increase factor for nonlinear static analysis in steel buildings.

$$\Omega_N = 1.08+0.76 / (\frac{\theta_{pra}}{\theta_y}+0.830) \qquad \text{…….. Eq. (1)}$$

where θ_{pra} is the plastic rotation angle, and θ_y is the yield rotation.

Then the analysis of the model was carried out to determine the progressive collapse resistance or load factor of the structure. The load factor is defined as the ratio of the applied load at step of the pushdown analysis to the total progressive collapse loads.

Fig 3 (a) & (b) shows the one set of models for progressive collapse analysis.

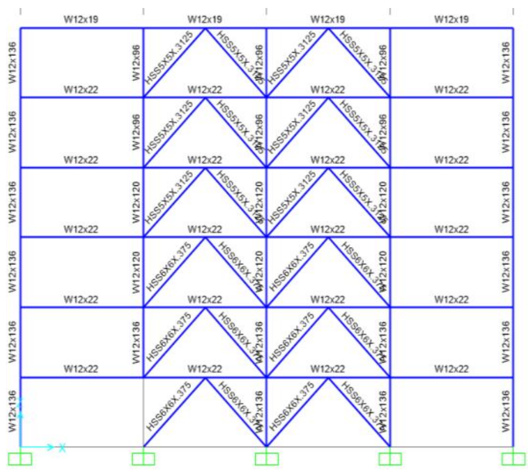

Fig 3 (a) Frame without EDB and without second column in the ground floor

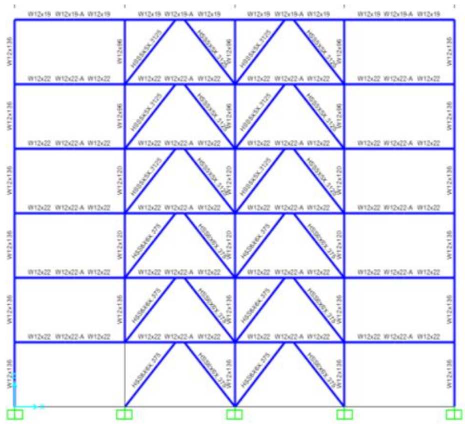

Fig 3 (b) Frame with EDB and without second column in the ground floor

6 RESULTS

6.1 Seismic Analysis

The structural performance of the investigated building models across time, during and after the application of the seismic load is determined using time-history analysis. The result of time history analysis is shown in Table 2.

Table 2. Results of Time History analysis

MODEL	DISPLACEMENT (mm)	BASE SHEAR (kN)
Without EDB	121.919	64425
With EDB	118.339	50922

The results are compared and analysed. The comparison graphs are shown in Charts 1 and 2.

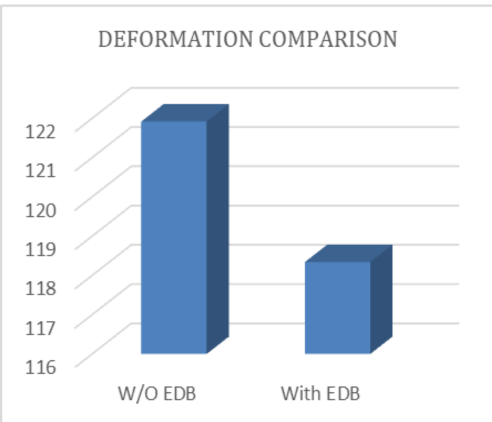

Chart 1 Comparison of deformation for frames with and without EDB

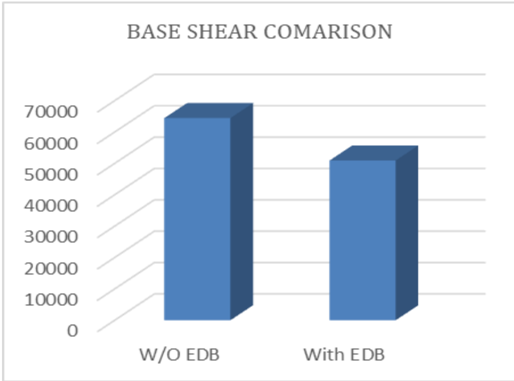

Chart 2 Comparison of base shear for frames with and without EDB

6.2 Progressive Collapse Analysis

The progressive collapse resistances of frames obtained after static pushover analysis were compared to identify the effect of energy dissipation beams on moment resisting frames during earthquakes. The load factors of frames with and without energy dissipation beams were compared. The results of the investigation are shown in Table 3.

MODEL	PROGRESSIVE COLLAPSE RESISTANCE (kN)		
	W/O corner column	W/O second column	W/O third column
Without EDB	1.01	2.205	3.10
With EDB	0.91	2.575	3.37

Chart 3 (a), (b) & (c) shows the comparison of progressive collapse resistance values of frames with and without EDB.

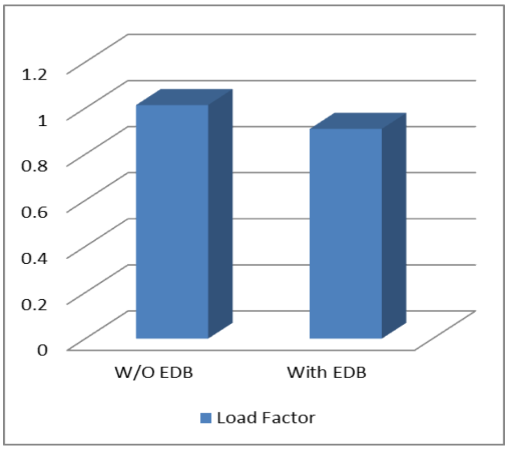

Chart 3 (a) Without the left corner column in the ground floor

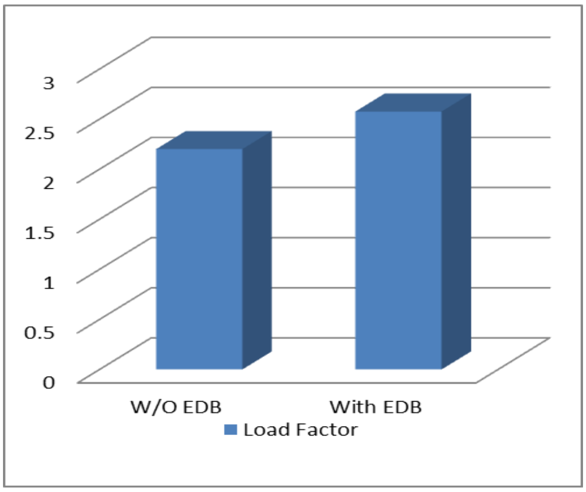

Chart 3 (b) Without the second column from the left side in the ground floor

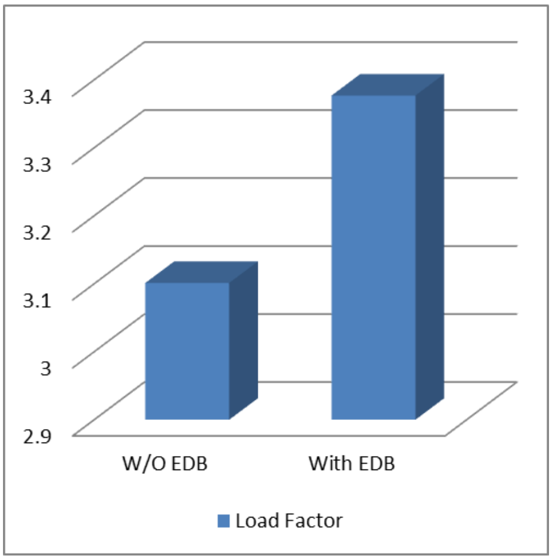

Chart 3 (b) Without the second column from the left side in the ground floor

7. CONCLUSIONS

This research studied the effect of energy dissipation beams on dual braced moment frames in resistance to seismic and progressive collapse. Pushover analysis has been performed to study the effect of energy dissipation beams on progressive collapse resistance of the moment frame. A time-history analysis has been carried out to study the seismic performance. In both cases, the structure with an energy dissipation beam has an improved resistance to progressive collapse and seismic forces. As a result of the investigation, the following observations were made:

- The result of time history analysis shows that the energy dissipation beams reduce the displacement of the frames by 3% and base shear by 23%.
- The structure with EDB has lower maximum displacement and base shear compared to the structure without EDB.
- The progressive collapse resistance obtained in the case of corner column removal of a frame with EDB was less than the frame without EDB.
- But in the other two cases, the EDB shows much improvement in the progressive collapse resistance of frame with EDB over frame without EDB.
- EDB improved the progressive collapse resistance by 15.48% and 8.35% for frame without second and third column respectively.

From the overall research it can be concluded that EDB improves the seismic and progressive collapse resistance of dual braced moment frames.

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