EARTHQUAKE STABILITY EVALUATION OF BRACED STEEL FRAMES INTEGRATED WITH SEISMIC ENERGY DISSIPATION SYSTEM

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Abstract – *Seismic energy dissipation consists of many methods like dampers, viscous dampers etc... But no cost-effective method is available for seismic energy dissipation. When seismic energy transfers to the building, the joints like beam and column joint, brace-beam joint etc. tends to fail due to shear. To minimize this shear failures, we can provide shear fuses as energy dissipating system. The beams in which these fuses are installed is referred as "Shear Energy Dissipation Beams" (SEDB). This fuse is placed on the beam where deformations are likely to happen. When seismic energy transfers through this fuse, the fuse fails and protects the primary structure. Then, failed fuse can be replaced with another one. This shear fuses are very cost effective and cheapest method. The modelling and analysis are done using ETABs software.*

Key Words: **Shear energy dissipation beam, Seismic, Base shear**

1. INTRODUCTION

A braced steel frame is a structural system designed to resist earthquake. Members in braces frame are not allowed to sway laterally. They exhibit ductile behaviour when subjected to transient lateral loading, caused by earthquake action. The two types of bracingsystems are; concentrically braced system and eccentrically braced system. During the earthquakes, theEBF system mainly dissipates seismic energy acting structure through the inelastic deformation of the energy dissipating beam (EDB).EDB has replaceable fuses on it.So that the EDB is prone to yield before other members in the structure. Replaceable fuses are introduced in the beams at the locations where plastic hinges are expected to develop. According to the yieldmechanism theory, the EDBs can be divided into three categories, namely, shearing type, bending-shearing hybrid type and bending type. Compared with bendingand bending-shear hybrid types, the shearing type is better in deformability and energy consumption capacity. Accordantly, shear-type energy dissipating beams (SEDBs) has been used as an important part of the energy dissipation capacity system in various EBF structures as it plays a major role in preventing earthquake loads. Therefore, understanding the influencing of the SEDBs geometrical parameters is needed.

Traditional seismic-resistant steel frames prevent damage and ensure safety of life. But, two major drawbacks of conventional systems are that they experience significant damage in main structural members and residual storey drifts after a strong seismic force act on it. Socio-economic losses associated with repairing damage in structural members include high repair costs and excessive disturbance to building use or occupation. Braced frames indicates a system with high seismic performance due to their high initial stiffness, which can effectively reduce story drifts.

The buckling-restrained braces (BRBs) shows a stable hysteretic response and it has the ability to withstand significant ductility demands. However, they may be prone to large residual drifts. An effective strategy to overcome the issue of repairability of structural members is to concentrate damage in replaceable elements, named as energy dissipation beam.

2. LITERATURE REVIEW

Jixiang Xu et al. (2021)[1] developed computation model of shear energy dissipation beam in D-shaped eccentrically braced steel frame in 2021 by using finiteelement software ANSYS, the computation model wasverified via the existing experimental results[1]. In order to investigate the aseismic performance of shear energy dissipation beam in D-shaped eccentrically braced steel frame, 19 computation models of the SEDB in D-shaped eccentrically braced steel frame were established by considering the parameters including the cross-section height, flange width, web thickness, flange thickness[1] and the number of stiffeners (spacing) from practical engineering, then a parameterstudy was performed to explore the hysteresis performance, stiffness degradation, stress distribution, ductility[1] and energy consumption[1]. The section height of the shear-type energy dissipating beam section had a significant influence on the hysteretic performance of the SEDB[1]. The increase in height could effectively improve the bearing capacity of the member, but it will also reduce the ductility of the structure accordingly. From the study it is concluded that the cross-section height of SEDB should be controlled within the range of 180 mm to 220 mm.

Yan-Wen Li et al. (2021)[2] conducted an experimental and numerical study of beam through energy-dissipative rocking columns for mitigating seismic responses. The energy dissipative rocking column is a novel seismic mitigation device that could effectively mitigate maximum inter story drift and driftconcentration of low-rise buildings under earthquakes. The beam-through configuration could effectively reduce the necessary work load in the practical application of EDRC's. Feasibility of the configuration is verified by cyclic-loading tests. Effectiveness of the EDRC in mitigating maximum drift and drift concentration is verified by non-linear time history analysis.

Feifei Shao, Miki Taguchi (2020)[3] proposed a paper with new-brace type shear fuses (BSF's)in seriesconnection. Damage of the proposed axial-type shear fuses is detectable and can be correlated with inter- story drift. Experimental study on effects of critical design parameters is conducted. Excellent cumulative ductility, stable and symmetric hysteretic properties isachieved. Damage control in a frame is verified throughtime history analysis.

Alper Kanyilmaz et al. (2019)[4] investigated the influence of repairable beam splices (structural fuses) on reducing the seismic vulnerability of steel-concrete composite frames. A benchmark building frame has been studied with and without bolted dissipative beamsplices[6]. The performance of both structures has been quantified in terms of energy dissipation, floor displacement and inter-story drift[6].

Yiyi chen and Ki Ki (2019)[5] investigated the seismic performance of high-strength steel frame equipped with sacrificial beams of non-compact sections in energy dissipation beams[5]. This work focuses on the seismic performance of the high- strength-steel frame equipped with mild-carbon-steel sacrificial beams of non-compact sections in energy dissipation beams namely the HSSF-NCEDB structure. This work was commenced with a test programme of a HSSF-NCEDB system as a feasibility study[5]. The test results indicate that the novel structure exhibits the desirable damage control behavior with inelastic actions locked in the sacrificial beams with non- compact sections for the expected deformation[5] range[5]. The findings from this work indicate that the HSSF-NCEDB structure is a promising option for structures in low-to-moderate seismic regions[5].

3. ANALYSIS OF DIFFERENT SECTIONS OF LINK BEAMS ON THE PERFORMANCE OF STEEL BUILDING

This chapter deals with the analysis of link beams of different sections like I-Section, box section, circle section. The seismic performance of different sectionsvaries and it can be assessed by different parameters like drift, displacement etc…

According to AISC 341-16 Provisions, ISMB 175 I-Section is used as the link beam. Section dimensions of 175 mm I-Section is given in the below figure.

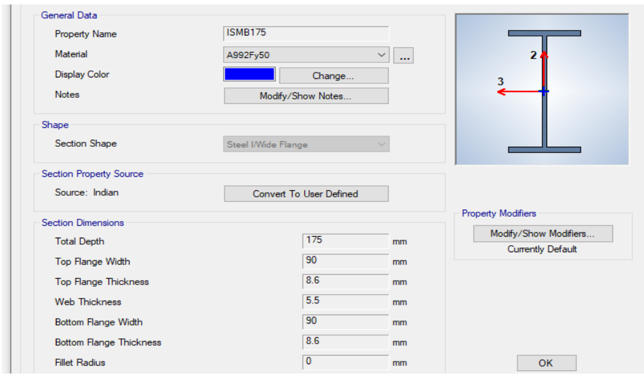

Fig-1: Section dimensions of 175 mm I-Section

Analysis results obtained by using I-Section 175 mm is given in the table below.

TABLE-1: Displacement and drifts of various storiesof Link beam I section of 175 mm size.

SB- I section -175 mm					
	THX			THY	
STORY NO	DISPLACEMENT	DRIFT	STORY NO	DISPLACEMENT	DRIFT
4	73.93	0.0036	4	77.142	0.0037
		93			76
3	62.852	0.0057 33	3	65.815	0.0060 45
2	45.654	0.0072 15	2	47.68	0.0075 15
1	24.008	0.0080 03	1	25.134	0.0083 78
0	0	0	0	0	0

ISMB 175 Box section is used as the link beam.

FIG-2: Section dimensions of 175 mm Box-SectionThe following table gives the analysis results.

TABLE-2: Displacement and drifts in various stories by placing Link beam box section of 175 mm size.

SB- B-WITH EDB					
	THX			THY	
STORY NO	DISPLACEMENT	DRIFT	STORY NO	DISPLACEMENT	DRIFT
4	73.795	0.003683	4	77.188	0.003778
	62.745	0.00572	3	65.855	0.006048
2	45.585	0.007202	2	47.71	0.00752
1	23.978	0.007993	1	25.151	0.008384
0	0	0	0	0	0

Section dimensions of circle link beam is given below.The outside diameter taken is 90 mm and wall thickness is 9.8 mm so as to attain the same area as that of I-Section link beam and box section link beam.

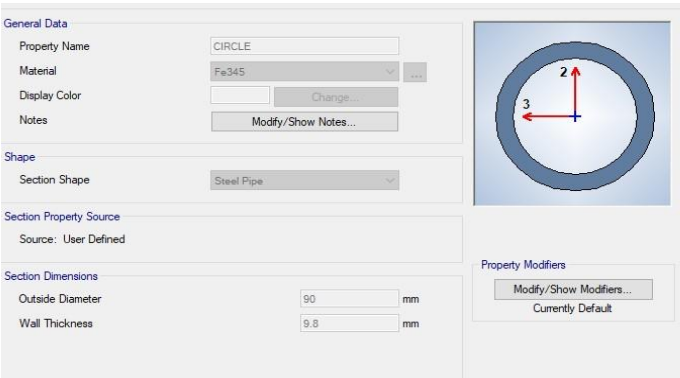

FIG-3: Section properties of circular section

The drift and displacement in x and y directions of various stories obtained by placing circular section linkbeam in steel building is given in below table.

TABLE-3: Displacement and drifts in various stories by installing Link beam circle section of 175 mm size

SB- C-WITH EDB					
	THX			THY	
STORY NO	DISPLACEMENT	DRIFT	STORY NO	DISPLACEMENT	DRIFT
4	75.509	0.003786	4	79.526	0.003808
3	64.151	0.00588	3	68.102	0.006114
2	46.512	0.007378	2	49.76	0.007934
1	24.377	0.008126	1	25.957	0.008652
0	0	0	0	0	0

From above results, it is clear that Link Beam of I- SECTION is more effective as it has comparatively less displacement(73.93 mm)than Box section and Circle section link beam.(displ=75.509 mm).The base shear for all of those section found to be almost equal, but there is a small decrease in case of I-Section link beam.

4. ANALYSIS OF I-SECTION LINK BEAM OF SIZE 200 mm

This chapter deals with the analysis of I-Section link beam of size 200 mm in 2 different patterns; in forward pattern and back to back pattern.

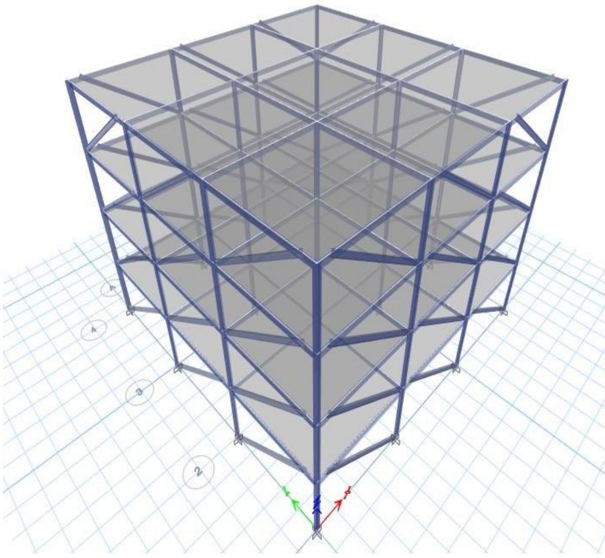

FIG-4: 3D View

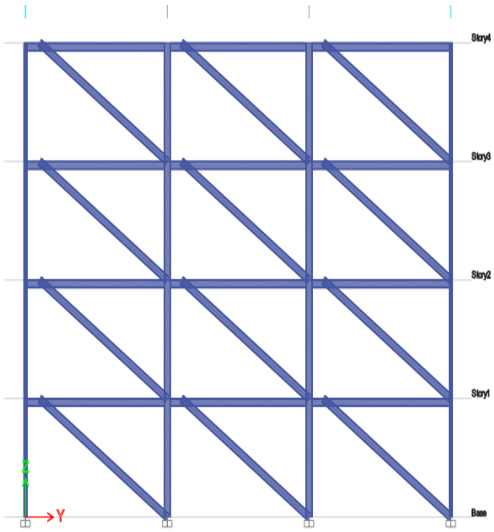

FIG-5: Elevation

TABLE-4: Displacement and story drift of SB I-Section 200 mm in forward pattern.

SB- I section -200 mm (in forward pattern)					
	THX			THY	
STORY NO	DISPLACEMENT	DRIFT	STORY NO	DISPLACEMENT	DRIFT
4	72.822	0.003629	4	77.183	0.003781
3	61.936	0.005632	3	65.841	0.006044
2	45.039	0.007101	2	47.708	0.007513
1	23.736	0.007912	1	25.17	0.00839
0	0	0	0	0	0

The following figures shows 3D view and elevation of asteel building with I-Section link beam of size 200 mmin back to back pattern.

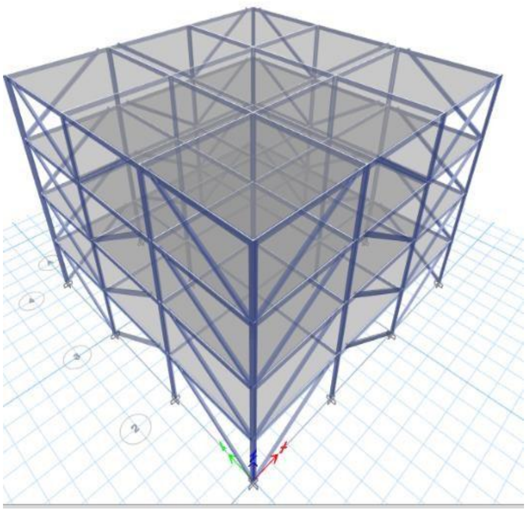

FIG-6: 3D View

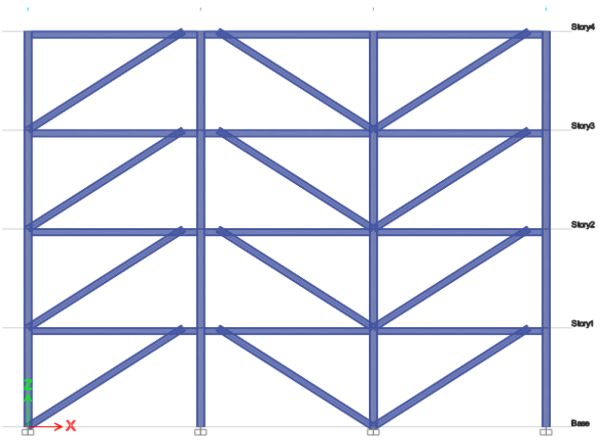

FIG-7: Elevation

TABLE-5: Displacement and story drift of SB I-Section 200 mm in back to back pattern.

SB- I section -200 mm (back to back)					
	THX			THY	
STORY NO	DISPLACEMENT	DRIFT	STORY NO	DISPLACEMENT	DRIFT
4	74.804	0.004085	4	84.321	0.004289
3	63.24	0.00597	3	72.254	0.006704
2	45.882	0.007267	2	52.702	0.00841
1	24.24	0.00808	1	27.572	0.009191
0	0	0	0	0	0

Link Beam I-Section of size 200mm (in forward pattern) is more effective than 175 mm size. Displacement, Drift and Base shear of 200 mm is less compared to 175 mm I-Section.So,We take I-section of 200 mm size as link beam for further comparative studies.

The story displacement variations and story drift variations in x and y directions of different pattern compared with bare frame is given below:

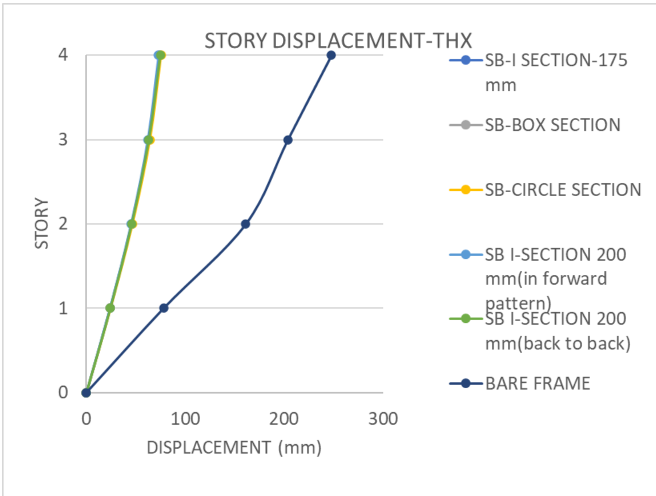

FIG-8: Story displacement in x direction

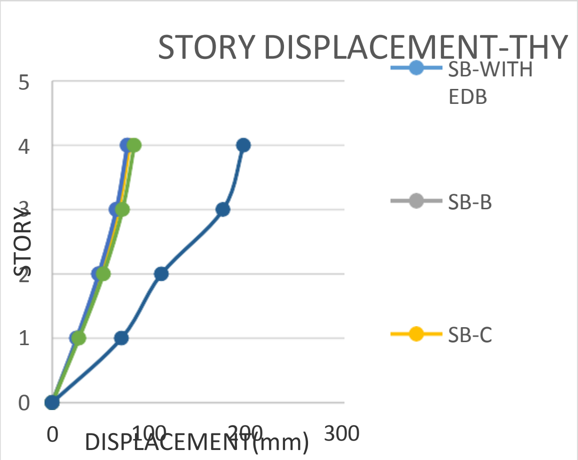

FIG-9: Story displacement in y direction

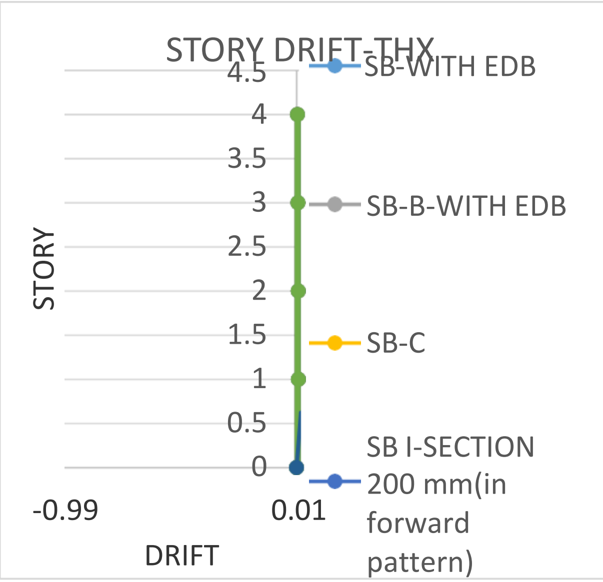

FIG-10: Story drift in x direction

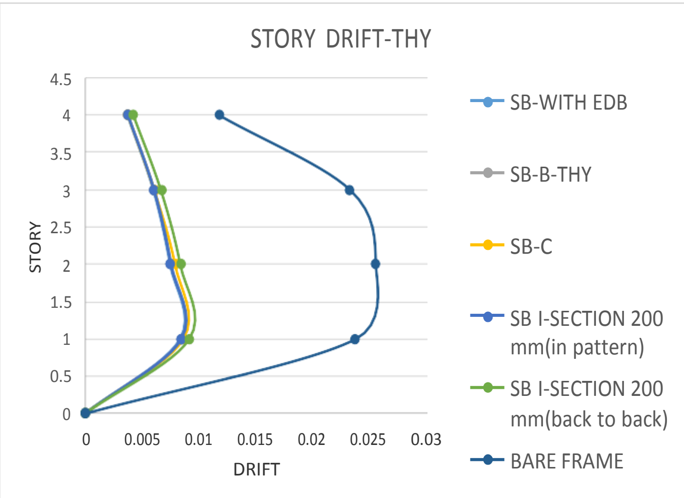

FIG-11: Story drift in y direction

5. ANALYSIS OF SB WITH ENERGY DISSIPATING BEAMS ON DIFFERENTLOCATIONS

This chapter deals with the analysis of steel building with energy dissipating system on different locations. For this study we selected bracings placed on alternatebases since it found to be comparatively effective. Thedifferent locations include interior, exterior, interior middle, exterior middle, X shape, diagonal.

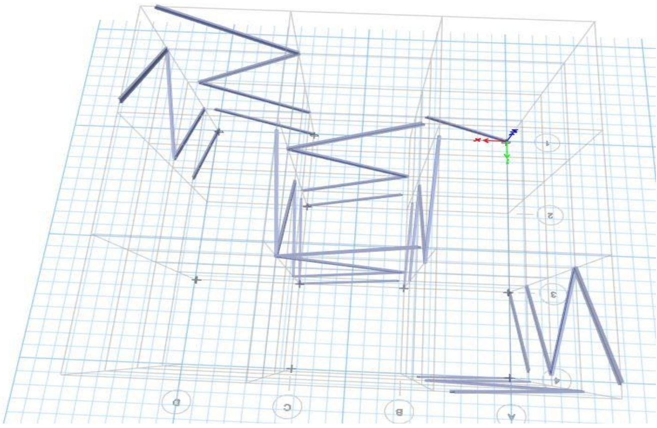

FIG-12: 4S-alternate base-exterior

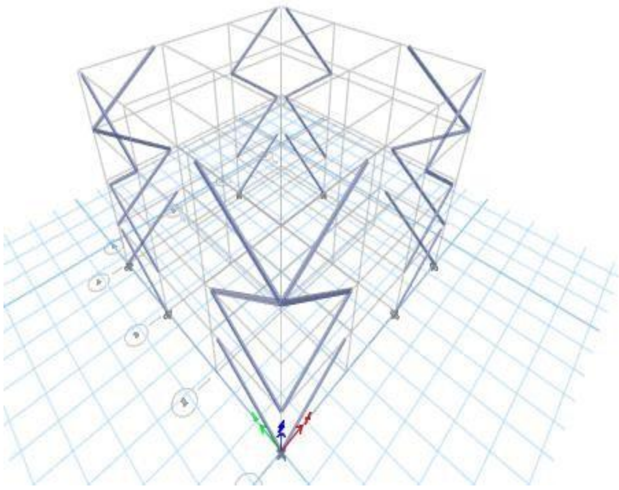

FIG-13: 4S-alternate base-exterior

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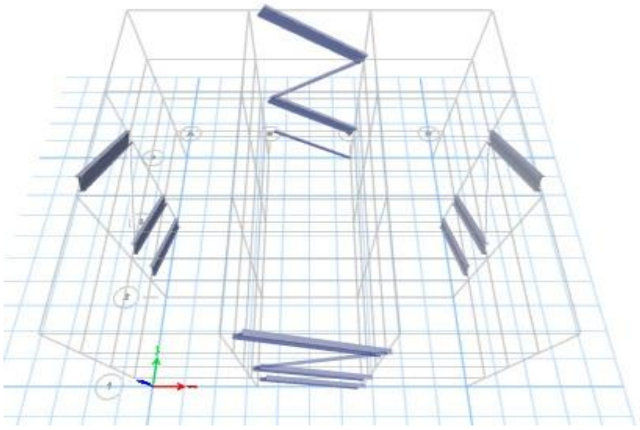

FIG-14: 4S-alternate base-interior middle

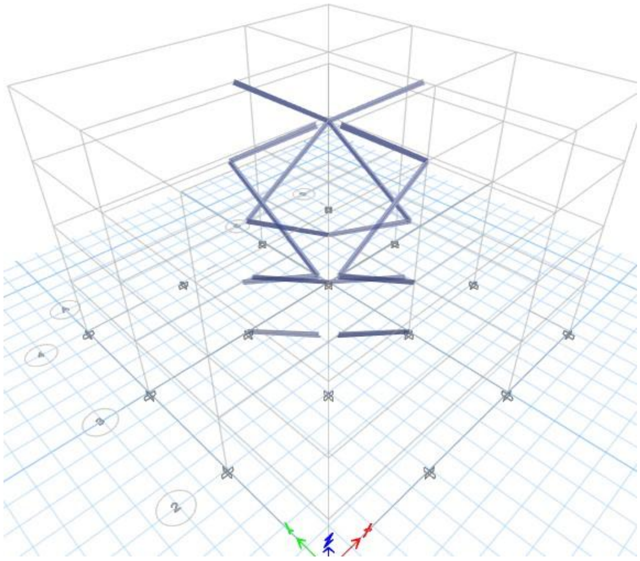

FIG-15: 4S-alternate base-diagonal

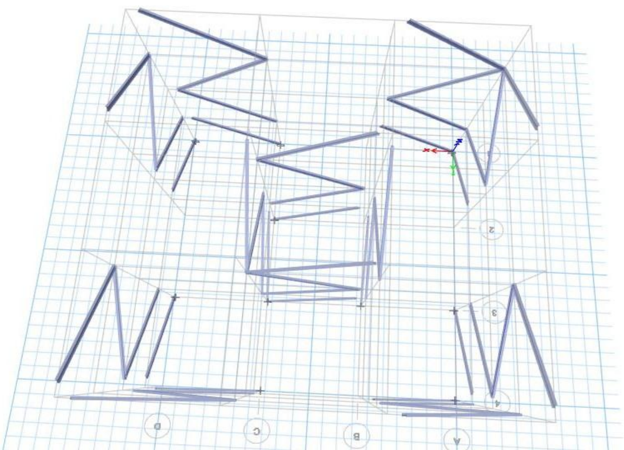

FIG-16: 4S-alternate base-X Shape

Table-6: comparison of Displacement, drift, base shear and time period of link beams on different locations.

	DISPLACEMENT		BASE SHEAR		DRIFT		TIME PERIOD	
	X	Y	X	Y	X	Y	X	Y
4S-ALTERNATE BASE-EXTERIOR	168.665	124.306	8659.824	5683.523	0.0162	0.0126	0.7431	0.7929
4S-ALTERNATE BASE-INTERIOR	130.652	140.188	5039.225	5326.238	0.0171	0.0152	1.0303	1.107
4S-ALTERNATE BASE-DIAGONAL	188.688	130.083	8644.314	6341.074	0.0195	0.013	0.7087	0.7707
4S-ALTERNATE BASE-EXTERIOR MIDDLE	127.094	122.322	4737.644	3916.518	0.01595	0.0167	0.8637	0.8808
4S-ALTERNATE BASE-INTERIOR MIDDLE	128.748	127.348	5804.933	5489.891	0.0147	0.0151	0.9874	1.125
4S-ALTERNATE BASE-X	104.154	125.575	8339.845	6509.688	0.0106	0.0126	0.603	0.6408

Among the EDB's placed on interior, exterior, interior middle, exterior middle, diagonally Shaped, EDB placed on exterior middle is found to be more seismically effective. Since its displacement in X direction is

127.094 mm and displacement in Y direction is 122.322 mm, base shear in X and Y directions are 4737.644 and 3916.518 KN respectively. Similarly drift and time period is also less compared to other locations.

6. SHEAR FORCE DISTRIBUTION ON STEEL BUILDING WITHOUT EDB AND WITH EDB.

Shear force distribution of steel building with and without EDB figures is given below.

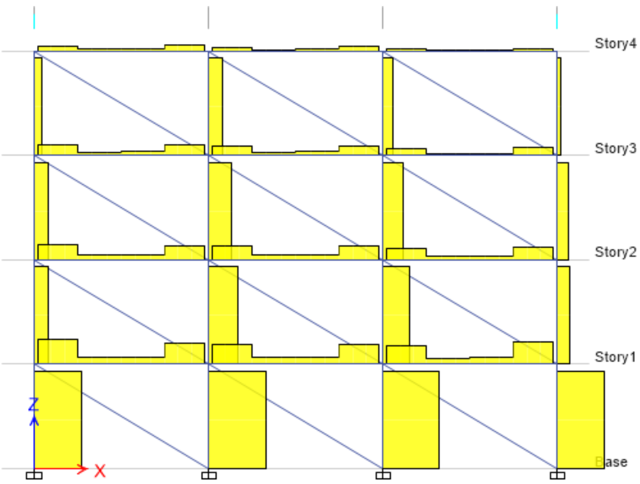

FIG-17: SB without EDB

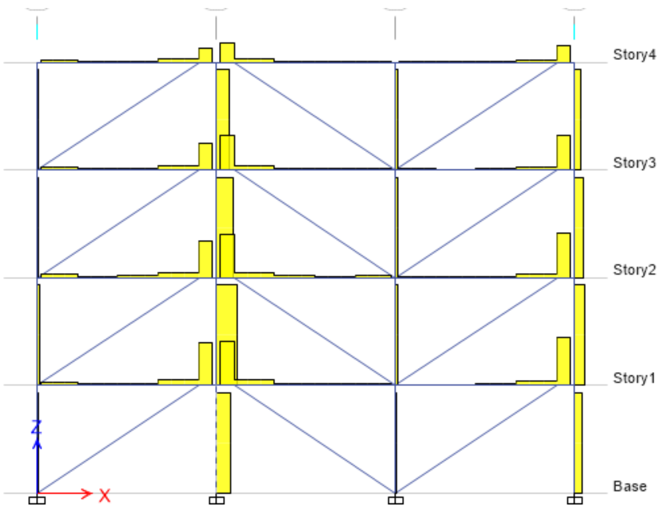

FIG-18: SB with EDB

This comparative study is conducted by introducing energy dissipation beam (EDB) on steel building to effectively concentrate the shear forces on the link beam only. Thus, protecting the main structural components in a steel building from seismic hazards. Among different sections used for link beam, I-Section is the most effective section.

7. CONCLUSIONS

From the analysis of different SEDB models following conclusions can be drawn:

1. I-Section link beam have comparatively less displacement (73.93 mm in X-axis,77.141 mm along y axis), less base shear (around 10000KN along x and y directions) and less drift.
2. By selecting I-Section link beam, various sizes for I-Section say 175 mm and 200 mm is analysed.
3. Among 175 mm and 200 mm I-Section ,200 mm I-Section performed well.
4. I-Section of 200 mm is arranged in 2 configurations; in forward pattern and back to backpattern. Out of these 2 patterns, Link Beam I- Section of size 200 mm (in forward pattern) is more effective than 175 mm size since its displacement, drift etc. are less.
5. It has 72.822 mm displacement in x direction,77.183 mm displacement in y direction, around 10160 KN base shear on x and y direction,0.008 drift on x and y directions.
6. Among the EDB's placed on interior, exterior, interior middle, exterior middle, diagonally, X Shaped, EDB placed on exterior middle is found to be more seismically effective.
7. Since its displacement in X direction is 127.094 mm displacement in Y direction is 122.322 mm
8. Base shear in X and Y directions are 4737.644 and 3916.518 KN respectively.
9. Least base shear results in least stiffness, hence greater flexibility of the building.
10. steel buildings installed with energy dissipation beam (shear fuse) concentrate the shear force distribution on EDB itself.
11. Thus, the damage is mostly concentrated on EDB instead of beams and columns and the fuse can be replaced when failed.

12. Repairing of structural members can be reduced to a greater extent.

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