International Journal of Engineering Sciences &Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EVALUATION OF PERFORMANCE OF BEAM COLUMN JOINT WITH REDUCED BEAM SECTION

Vinayak S Patil*[1], Dr. Mukund R Shiyekar[2]& Dr. Milinda M Mahajan[3]
*[1]P. G. Student (M-Tech Structures), G.C.E. K., Karad-415124
[2]Adjunct Professor (Applied Mechanics Department), G.C.E. K., Karad-415124
[3]Head (Design & Development), Ashoka Structural Consultant, Pune-411013

DOI: https://doi.org/10.29121/ijesrt.v9.i7.2020.1

ABSTRACT
This study reviews mainly holistic design of PEB structure and comparison of behavior of reduced beam section at beam column sub assemblage. Commercial software based on finite element analysis is used for carrying out mathematical modeling and analysis. In recent construction work it is observed that during conditions like earthquake or cyclone connections fails resulting in to progressive collapse. Also it damages column resulting in failure of strong column weak beam theory.
In present work after identifying problem structure is fused at connection by reducing beam cross section at location of connection. This is done by reducing cross section of beam in plan expected to result in shifting of plastic hinge from face of column. Reduced beam sections capacity is calculated by simple calculations and verifying them with moment curvature relationships at desired locations. This will concentrate on failure of fuse and not of connection during load application.
Motivation of this study is to improve connection by fulfilling strong column and weak beam theory. This will motivate construction industry to utilize steel structures more often assuring repairing of structure as element failure will be dominant over failure of entire structure

KEYWORDS: PEB, Fuse, RBS, Strong Column Weak Beam, Moment Curvature.

1. INTRODUCTION
A pre-engineered building (PEB) is designed by a structural engineer, to be fabricated using available plates of varying thicknesses as per design such that it satisfy a wide range of structural and aesthetic design requirements.
For PEB connections developed is generally dependant on column fixing condition at base. However one cannot ensure safety of connection for lateral loads. This may cause formation of plastic hinge near connection or even at face of column. This will leads to failure of connection that could lead to progressive collapse of entire structure. To shift plastic hinge formation away from connection or from face of column reducing beam section is easiest possible method. In this particular procedure beam size is reduced at suitable location either in plan.

The RBS forces yielding and hinge formation to occur within the reduced section of the beam and limits the moment the can be developed at the face of the column by reducing demands on the beam flange groove welds and the surrounding base metal regions, the RBS reduces the possibility of fractures occurring in this vulnerable region. Although the RBS essentially weakens the beam, its impact on the overall lateral strength and stiffness of a steel moment frame is generally small. Its primary intended effect is to significantly enhance ductility. The RBS plays a role similar to that of connection reinforcement schemes such as cover plates, ribs and haunches.

2. MATERIALS AND METHODS
Materials
Steel (Specified as per IS 800:2007)
Methodology
The following study design is performed for two aspects one is global frame design and second is fuse perspective of this dissertation work. Design of PEB steel space frame by manual calculation is a tedious work as well as time consuming. The accuracy provided by the manual procedure is limited as multiple iterations

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

needs to be done to arrive at design parameters. The analysis and design steps which are tedious for manual calculation are mentioned below:

- Linear as well as nonlinear analysis
- Formation and calculation of 3D solid FE stiffness matrices
- Formation and calculation of 2D surface FE stiffness matrices
- Formation and calculation of 1D member FE stiffness matrices
- Formation of global stiffness matrices

The analysis and design of the structure is done in FEM software SAP 2000. The software provides the detailed analysis and design of steel frame as per IS 800:2007, also all the structural elements are redesigned by manual calculations and verified.

For RBS modeling ETABS software is used as it provide special feature for design of RBS in it. M-Ø curves are plotted from software also simple excel spreadsheets are developed for verification.
Methodology executed

1. Analysis and design of PEB structure for the various phases of structural behavior & identification of weakest link.
2. Development of programme for M-Ø Curve for Beams
3. Design of reduced beam section & validation in ETABS.
4. To evaluate the effect of fuses by reduced beam section in sub assemblage for desired mode of global failure

Modeling
A simple beam column arrangement is considered in this global study of PEB structure. For G+1 structure hot rolled steel sections are used and for remaining part tapered sections are used. For Purlin cold formed Z sections are used and bar of size 32 mm is used as a cross bracing as shown in figure below. Analysis and design is performed in software and validated manually. Indian codes are referred for loading, its combinations and design. Beams are identified as weak link in design and RBS is used for these beams for further study.

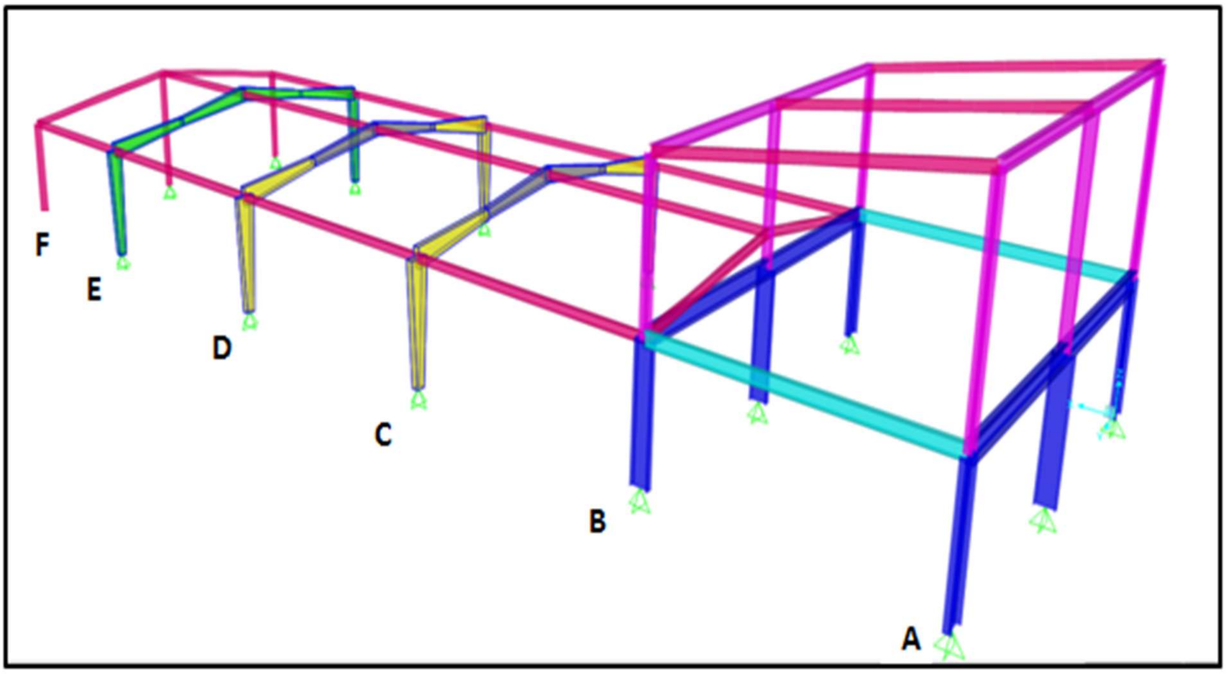

Figure 1: Global Model of PEB under consideration

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Design of RBS

Following figure represents design dimensions of reduced beam section. The major consideration for design of RBS i.e. sizing of dimensions is concerns with reduction of percentage of moments occur at face of column from beam. This value is expected to range 85% to 100%. Referring figure below dimension 'a' and 'b' are chosen from test results and previous research done. It is make sure that dimensions are large enough to uniformly transfer stresses in flange of beam near column and small enough to reduce moments at face of column. Large value of b could form the inelastic strain in flange. Based on literature studied following relations are used to decide the 'a' and 'b' value for RBS:

$$a = (0.5 \text{ to } 0.75) * bf$$
$$b = (0.65 \text{ to } 0.85) * d$$

Where, 'bf' is width of beam and'd' is depth of beam

Depth of cut i.e. 'c' value should be chosen keeping moment reduction in mind as stated above. This value should not be too large (maximum 50% of beam flange).

$$C = 0.25 * bf$$

These results are compared with ETABS tool which enables user to assign RBS to beam section with manually designed spreadsheet.

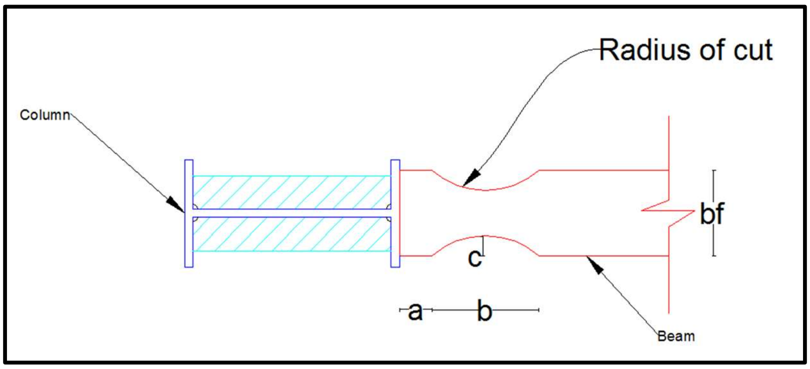

Figure 2: RBS dimensioning

Modeling of RBS frame

One bare frame from global model is taken for study of RBS. Four comparative models are prepared with same geometric properties but variation of RBS by means of size and location. It is ensured that RBS lies at specific distance from column face such that central hinge formation due to gravity load is avoided.

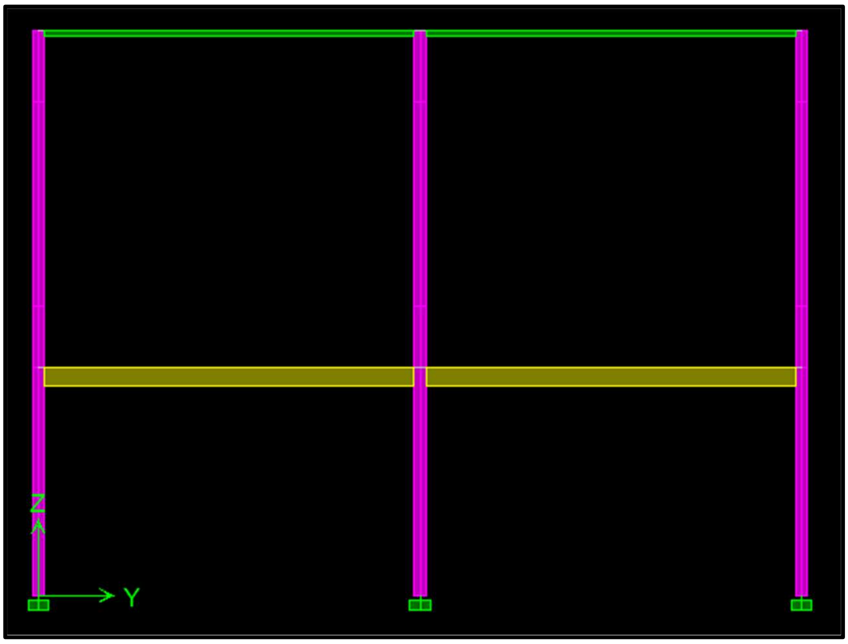

Figure 3: Frame under consideration for study of RBS

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Models for RBS study

a) Conventional beam column arrangement

Referring figure below it is clear that in first bare frame simple beam column connection is assumed in modeling.

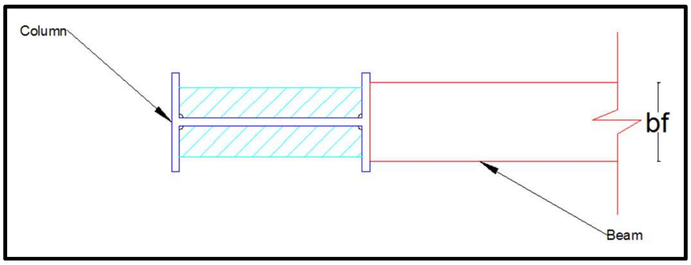

Figure 4: Conventional beam column joint

b) RBS with software defined dimensions

Refer figure 2 for typical beam column arrangement for RBS. In this model values suggested by software are considered without any alterations.

c) RBS with manual maximum designed dimensions

In this model maximum values of a, b, c are considered Where a = 0.75 bf, b = 0.85 db, c = 0.25 bf, where bf is width of beam.

d) RBS with manual minimum designed dimensions

In this model maximum values of a, b, c are considered Where a = 0.50 bf, b = 0.65 db, c = 0.10 bf, where bf is width of beam.

e) RBS with manual minimum stiffness ratio

In this model maximum values of a, b, c are considered Where a = 0.75 bf, b = 0.85db, c = 0.3 bf, where bf is width of beam.

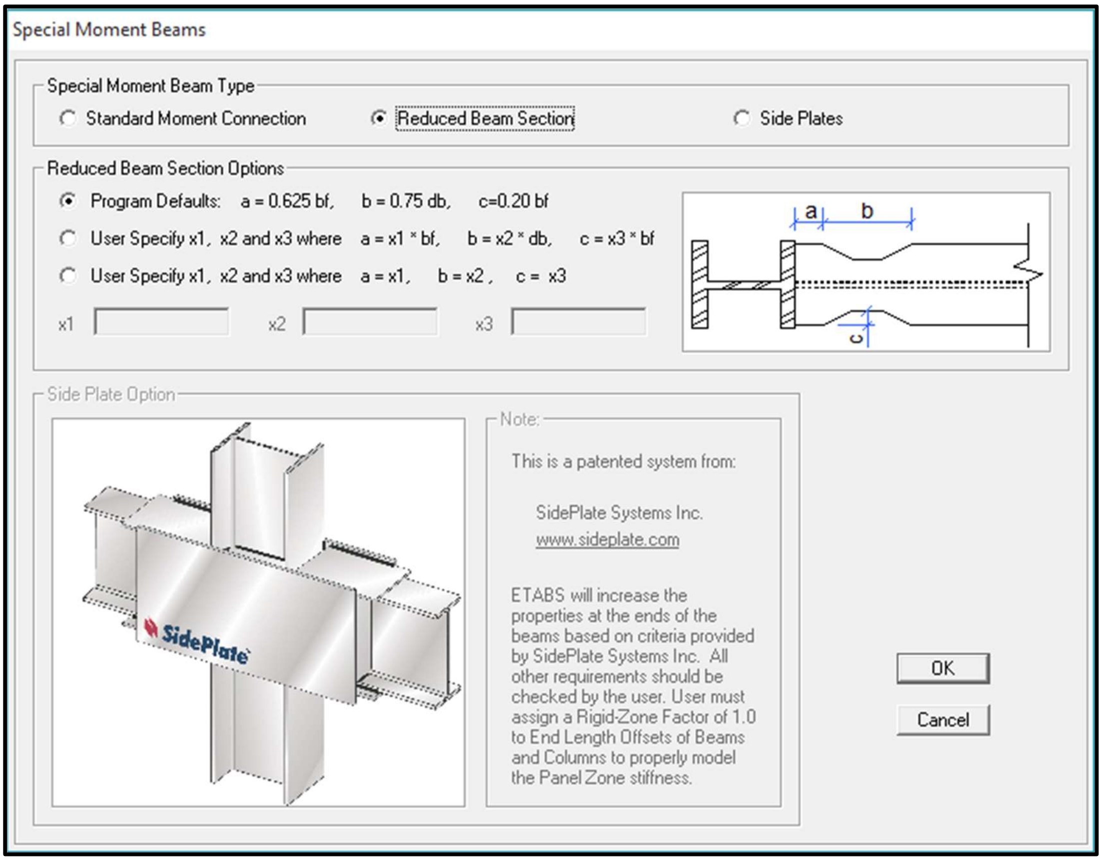

Figure 5: Special Moment Beams in ETABS

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

3. RESULTS AND DISCUSSION

For results study a moment curvature curve is used as a reference for studying effect of RBS on beam column joint. Stiffness is determined from M-Phi curve and compared with conventional frame to get stiffness ratio.

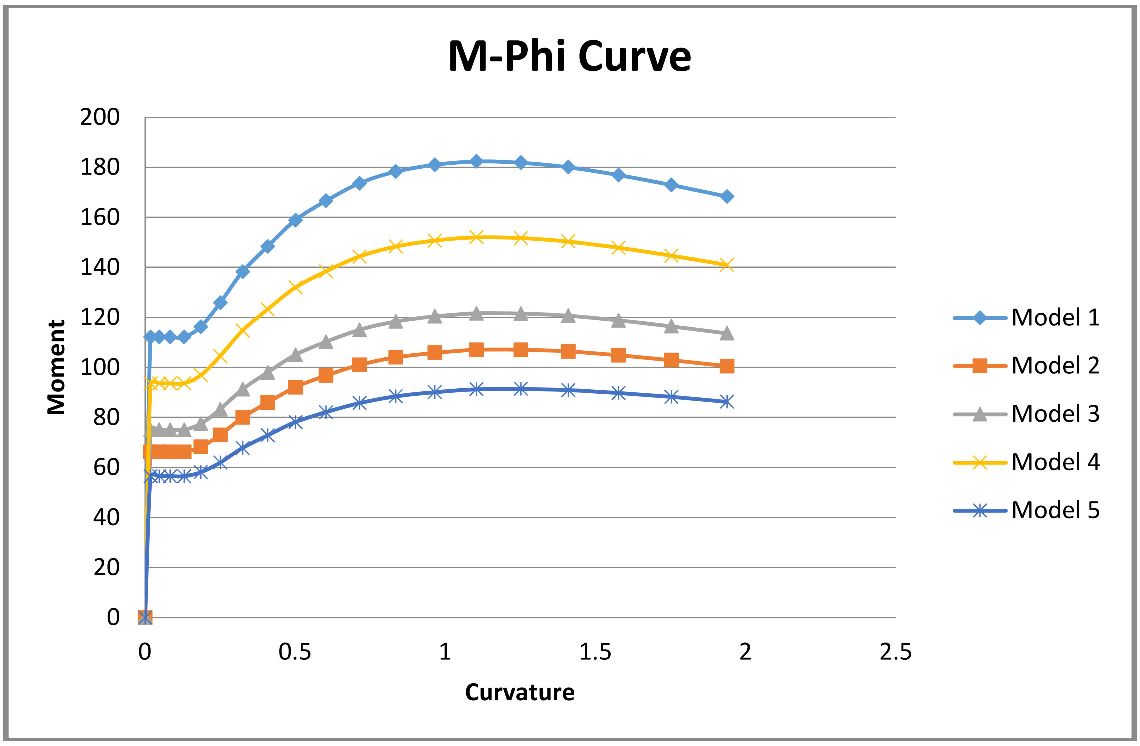

Figure 5: Moment Curvature curve for various models

From graphs of moment curvature Table 1 is obtained. It is observed that with reduction in beam size the ratio and hence stiffness decreases. It is clear that stiffness of section in reduced for RBS also it varies along the reducing shape of RBS. Hence dimensions of RBS effects into variation of stiffness. 16% to 41% variation in stiffness is observed in RBS according to its dimensions.

Table 1: M/Ø ratio for different location for given section

M/Ø ratio for different location for given section			
Section/Location	Elastic Range	Plastic Range	Remark
ISMB 250	864.92	86.91	Model 1
Centre of RBS	510.13	51.93	Model 2
Quarter span of RBS	684.66	69.13	
Centre of RBS	578.79	58.68	Model 3
Quarter span of RBS	721.86	72.79	
Centre of RBS	721.86	72.79	Model 4
Quarter span of RBS	793.37	79.86	
Centre of RBS	435.74	44.56	Model 5
Quarter span of RBS	672.2	65.74	

In

Table the stiffness ratio is calculated which gives the reference for comparison of the results obtained from each

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

model. It is calculated simply by comparing stiffness of each frame section with conventional frame section.

$$\text{Stiffness ratio} = \frac{\text{Stiffness of Conventional Frame Section}}{\text{Stiffness of RBS}}$$

Table2: Stiffness ratio of section at different location

Section/Location	Elastic Range	Plastic Range	Remark
ISMB 250	1	1	Model 1
Centre of RBS	0.589800213	0.59751467	Model 2
Quarter span of RBS	0.791587661	0.79542055	
Centre of RBS	0.669183277	0.675181222	Model 3
Quarter span of RBS	0.834597419	0.83753308	
Centre of RBS	0.834597419	0.83753308	Model 4
Quarter span of RBS	0.917275586	0.918881602	
Centre of RBS	0.503792258	0.512714302	Model 5
Quarter span of RBS	0.777181705	0.756414682	

For frame under consideration two possible beam column arrangement is done. In first one conventional arrangement is done as shown in Figure 6 in second arrangement RBS with stiffness ratio of 0.58 is used as shown in Figure

a) Conventional Frame

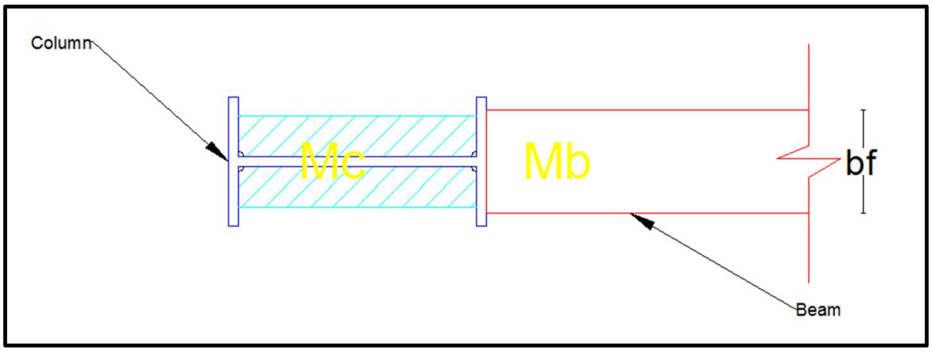

Figure 6: Conventional beam column arrangements

Mc = 202.18 kNm, Mb = 154.58 kNm & Mc/Mb=1.3

b) RBS frame

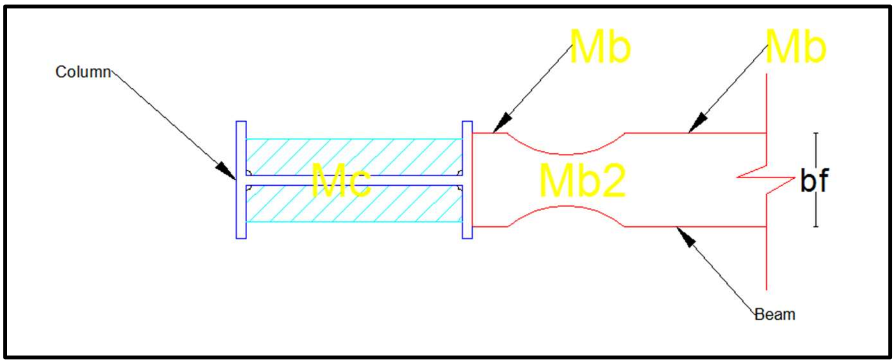

Figure 7: RBS beam column arrangement

Mc = 148.12 kNm, Mb = 110.46 kNm, Mb2 = 61.34 kNm
Mc/Mb=1.34, Mc/Mb2 = 2.41

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Frame beam column sizes (Refer Figure 1)

Table3: Section Sizes for frame

Grid	Column	Beam
A & B (GF)	ISMB 500	ISMB 500
C, D & E (Built-up Section)	bf=200mm, d=600mm, tf=tw=8mm	bf=200mm, d=600mm, tf=tw=8mm
F (Built-up Section)	bf=150mm, d=200mm, tf=tw=8mm	bf=150mm, d=200mm, tf=tw=8mm

a) Grid A & B:

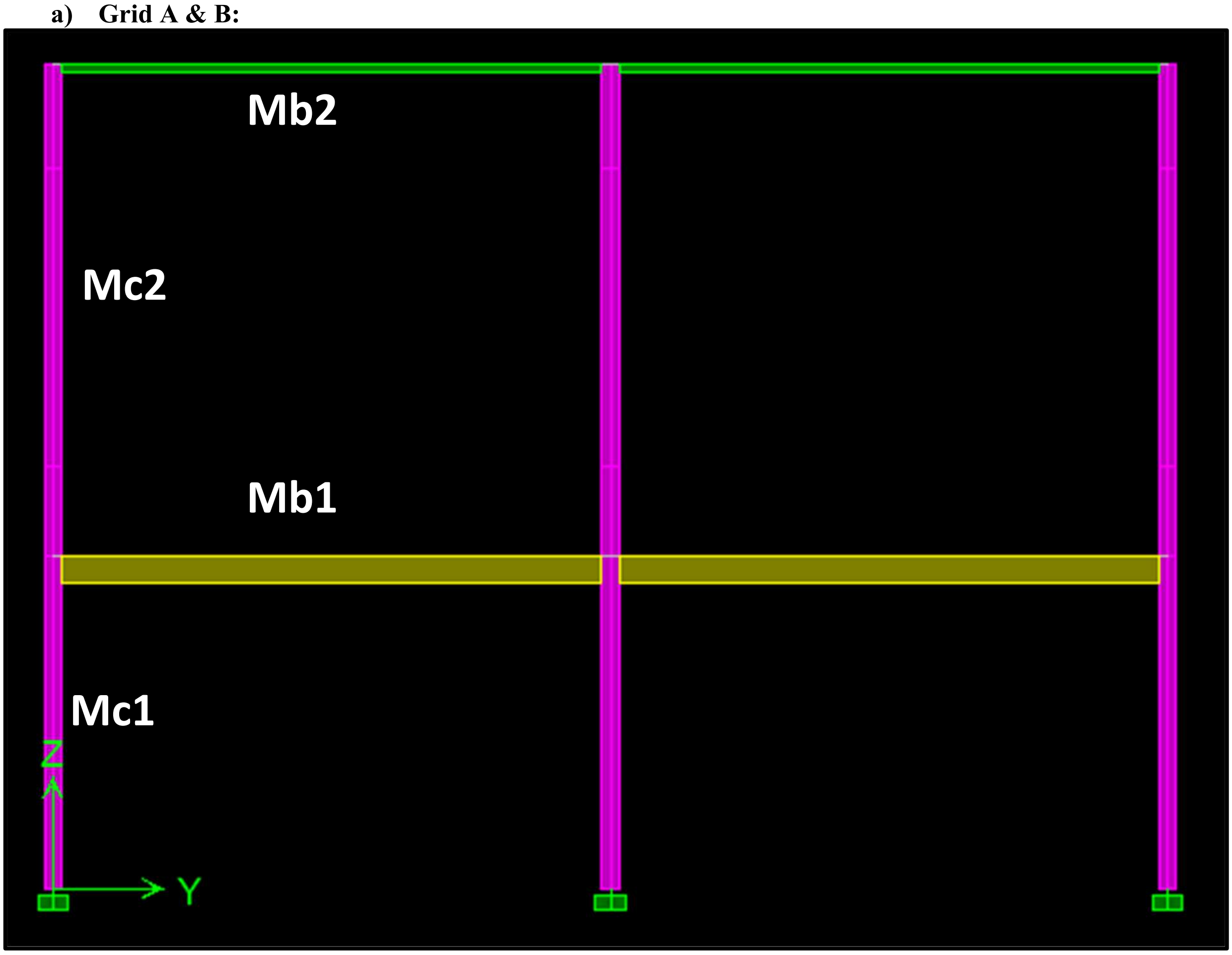

Figure 8: Grid A & B of PEB Frame

Table4: Beam Column Capacities

Section	Notation	Capacity (kNm)
Column	Mc1	471.52
	Mc2	116.49
Beam	Mb1	492.11
	Mb2	98.71
Reduced Beam Section	Mb1(RBS)	282.96
	Mb2 (RBS)	77.96

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Table 5: Beam Column Capacity Ratio

Strong Column Weak Beam Ratio		
Column/Beam	Mc1/Mb1	0.958
	Mc2/Mb2	1.18
Column/RBS	Mc1/Mb1(RBS)	1.66
	Mc2/Mb2(RBS)	1.49

b) Grid C, D, E:

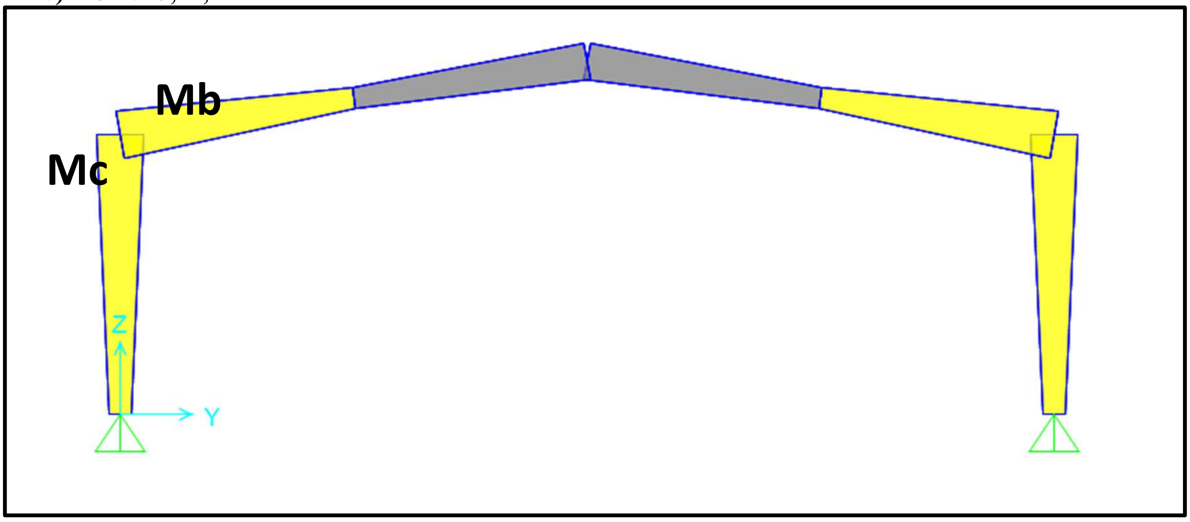

Figure 9: Grid C,D,E of PEB

Table 6: Designed sections capacity

Section	Notation	Capacity (kNm)
Column	Mc	350.57
Beam	Mb	326.69
Reduced Beam Section	Mb(RBS)	241.73

Table 7: Beam Column Capacity Ratio

Strong Column Weak Beam Ratio		
Column/Beam	Mc/Mb	1.07
Column/RBS	Mc/Mb(RBS)	1.45

c) Grid F:

Table 8: Designed sections capacity

Section	Notation	Capacity (kNm)
Column	Mc	88.98
Beam	Mb	100.6
Reduced Beam Section	Mb(RBS)	60.70

Table 9: Beam Column Capacity Ratio

Strong Column Weak Beam Ratio		
Column/Beam	Mc/Mb	0.88
Column/RBS	Mc/Mb(RBS)	1.47

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

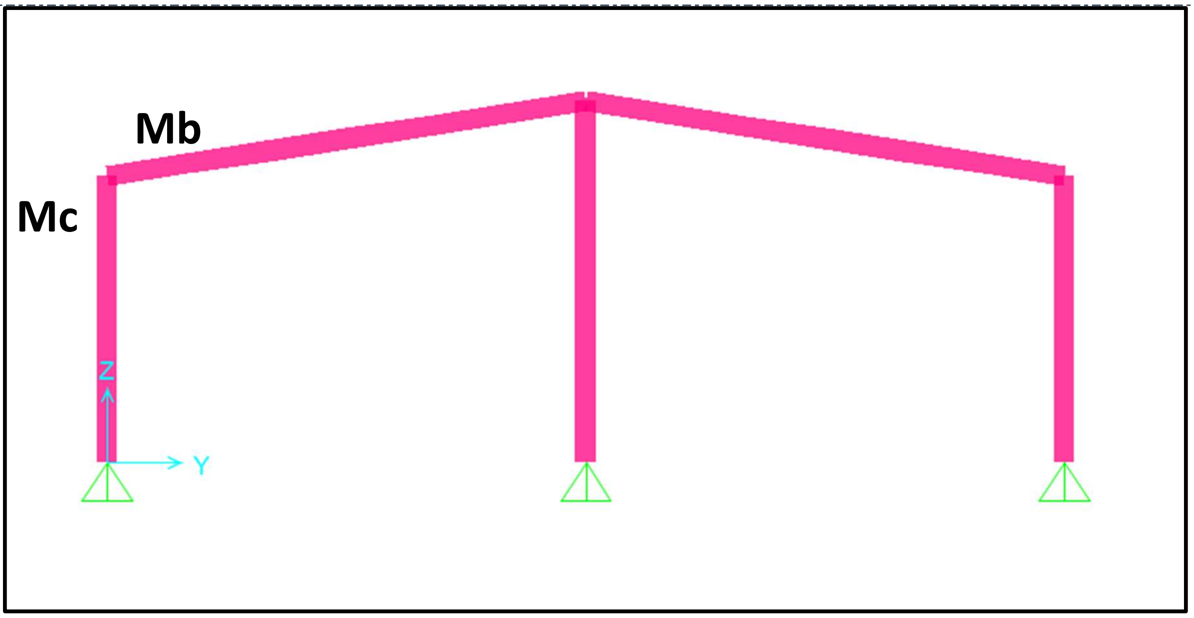

Figure 10: Grid C,D,E of PEB

4. CONCLUSION

In this chapter strong column weak beam concept is concluded for various sections considering stiffness ratio as a reference. Previous research and studies have proved that for strong column weak beam concept validation this ratio must be between 1.2 to 1.4

A single frame model was studied in details also global frame is studied for similar analysis. A nonlinear analysis was performed in these models. Following conclusions are drawn from current study:

i. To fulfill strong column weak beam concept in steel frame design results into uneconomical design of column.
ii. RBS is a fuse introduced in beam which ensures the failure of beam first when lateral loads are applied to the structure.
iii. As cross section of beam is reduced it ensures shifting of formation of plastic hinge away from column face resulting into beam failure mechanism and again ensuring strong column weak beam concept.
iv. All the capacity ratios of column to beam are way higher than 1.4 at centre of RBS, assures the strong column weak beam concept.
v. Moment curvature study has concluded that it is a section property representing stiffness of section and depends on cross section hence can be controlled by adjusting section dimensions.

5. ACKNOWLEDGEMENTS

It gives me great pleasure to thank my guide, Prof. M. R. Shiyekar and my co-guide Dr. M. A. Mahajan, for their scientific support, accurate and consistent recommendations and their tireless patience during the work of the project. I sincerely thank all the Applied Mechanics Department professors. I also would like to thank those kind-hearted and helpful professors whom I met across my entire course. I would like to thank my classmates and friends for their continued help and encouragement throughout my entire M-Tech studies.

REFERENCES

[1] Ali Irfani, Mohd Moazzam, and A Vimala. "Collapse Mechanism of Strong Column Weak Beam Buildings of Varying Heights." (International Journal of Engineering and Advanced Technology) 9, no. ISSN: 2249 – 8958 (2019): 5.

[2] Calado, Luis, Jorge M Proença, Miguel Espinh, and Carlo A Castiglioni. "Hysteretic behaviour of dissipative bolted fuses for earthquake resistant steel frames." *Journal of Constructional Steel Research* (Elsevier Ltd), 2013: 12.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[3] Calado, Luis, Jorge M Proença, Miguel Espinha, and Carlo A Castiglioni. "Hysteretic behavior of dissipative welded fuses for earthquake resistant composite steel and concrete frames." *Steel and Composite Structures* (ResearchGate), 2013: 23.
[4] Castiglioni, C A, A Kanyilmaz, L Calado, and i Vayas. "Dissipative Devices for Seismic Resistant Steel Frames." ResearchGate, 12. 2010.
[5] Chen, Sheng-Jin, and Y C Chao. "Effect of composite action on seismic performance of steel moment connections with reduced beam sections." *Elsevier Science Ltd.*, 2001: 18.
[6] Dhakal, Suresh, and Mohamed A Moustafa. "MC-BAM: Moment–curvature analysis for beams with advanced materials." *SoftwareX* (Elsevier B.V.), 2019: 8.
[7] Eatherton, M R, J F Hajjar, G G Deierlein, H Krawinkler, S Billington, and X Ma. "CONTROLLED ROCKING OF STEEL-FRAMED BUILDINGS WITH REPLACEABLE ENERGY-DISSIPATING FUSES." *World Conference on Earthquake Engineering.* 2008. 8.
[8] Egloff, O, R Tremblay, R Vincent, and S Dussault. "Finite element analysis of ductile fuses for W-shape steel bracing members." (WCEE) 2012.
[9] Engelhardt, Michael D. "Design of Reduced Beam Section Moment Connection." *The 1999 T.R.Higgins Lecture.* 1999. 28.
[10] Jina, Jun, and Sherif El-Tawilb. "Seismic performance of steel frames with reduced beam section connections." *Journal of Constructional Steel Research 61 (2005) 453–471* (www.elsevier.com/locate/jcsr), 2004: 19.
[11] Liewa, Andrew, Leroy Gardnerb, and Philippe Blocka. "Moment-Curvature-Thrust Relationships for Beam-Columns." *Strutures* (www.elsevier.com/locate/structures), 2017: 9.
[12] Milner, David, James Wesevich, Lisa Nikodym, Vincent Nasri, Darell Lawver, and John Mould. "Improved Blast Capacity of Pre-engineered Metal Buildings using Coupled CFD and FEA." *Journal of Loss Prevention in the Process Industries*, 2018: 22.
[13] Moghaddam, H, and I Hajirasouliha. "An investigation on the accuracy of pushover analysis for estimating the seismic deformation of braced steel frames." *Journal of Constructional Steel Research* (Elsevier Ltd.), 2005: 9.
[14] Nikoukalama, M T, and Kiarash M Dolatshahi. "Development of structural shear fuse in moment resisting frames." *Journal of Constructional Steel Research* (Elsevier Ltd.), 2015: 13.
[15] Perry, Dale C, James R McDonald, and Herbert S Saffir. "PERFORMANCE OF METAL BUILDINGS IN HIGH WINDS." *Journal of Wind Engineering and Industrial Aerodynamics* (Elsevier Science Publishers), 1990: 15.
[16] Tena-Colunga, A, and H J Nangullasmú-Hernández. "Assessment of seismic design parameters of moment resisting RC braced frames with metallic fuses." *Engineering Structures* (Elsevier Ltd.), 2015: 16.
[17] Vargas, Ramiro, and Michel Bruneau. "Analytical Response and Design of Buildings with Metallic Structural Fuses." *AISC* (AISC), 2009: 8.
[18] Yun, Xiang, and Leroy Gardner. "Stress-strain curves for hot-rolled steels." *Journal of Constructional Steel Research* (Elsevier Ltd), 2017: 11.