A study on the capacity of ductility and energy dissipation of Special Moment Resisting Frames (SMRFs)

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Abstract

Special Moment Resisting Frame (SMRF) is one of the most ductile and energy dissipating Seismic Force Resisting Systems which uses the bending strength of moment resisting of frames to oppose the lateral force of earthquakes. It is expected that the bending stiffness of beams and columns assembled to construct these bending frames, and the strength of beam-to-column connections are some of the most important parameters which affect the amount of the maximum drift, ductility, and energy dissipation of structures. In this paper, the capacity of ductility and energy dissipation of SMRF systems are studied. For this purpose, four single story-single bay Special Moment Resisting Frames constructed of different Reduced Beam Sections (RBSs), are analyzed using non-linear finite element method under cyclic loading according to AISC Seismic Provisions 2010 and the results are compared.

Key words: Cyclic loading, Ductility, Energy dissipation, Earthquake, SMRF.

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1. Introduction

One of the most regular phenomena which causes the structures to be destroyed under seismic forces, is the rupture in the points of beam-to-column connections. This type of rupture can result in a significant decline in the strength of structures and a complete collapse of their stories. Before the Northridge earthquake in 1994, Special Moment Resisting Frames (SMRFs) were very common in the seismic areas of America. The beam-to-column connections with full penetration groove welds were utilized regularly and it was believed that the connections had high levels of ductility and energy dissipation, but in this earthquake, the observation of wide cracks in the connections, proved that this thought was wrong. More than 150 steel buildings were found damaged through the earthquake, despite all of them were designed according to the provisions of that time [1]. In order to solving the problem of rigid connections, researchers suggested two solutions: strengthening of the connection or weakening of the beam section [2]. In the second method, a reduction is made in the beam section at a distance away from the column face to refuse the organization of concentrated stress in the connections and shift it to the point of reduced section. However, it is required to know that how much the amount of reduction in the beam flanges are effective to the amount of ductility and energy dissipation of SMRF systems in order to find the optimum amount for this reduction.

2. Data and Material

For the purpose of investigating the effects of the reduction amount in the reduced beam section on the capacity of ductility and energy dissipation of the SMRF systems, four models containing different amounts of this parameter, are modeled in ABAQUS [3] software. The details of the models are presented in Table 1.

Specimen I.D.	Column	beam	The amount of Reduction in each side of the Beam flange (cm)	Connection
s1	IPB 260	IPB 200	2	Rigid End
s2			3	
s3			5	
s4			7	

Table 1. Properties of the frames

The material properties used for all of the frame members are presented in Table 2.

Young's modules (Kg/cm²)	Yield stress (Kg/cm²)	Ultimate stress (Kg/cm²)	Poisson's ratio	Density (Kg/cm²)
2100000	2400	3700	0.3	7850

Table 2. Material properties

The size of the frame designed in this study is shown in Fig. 1.

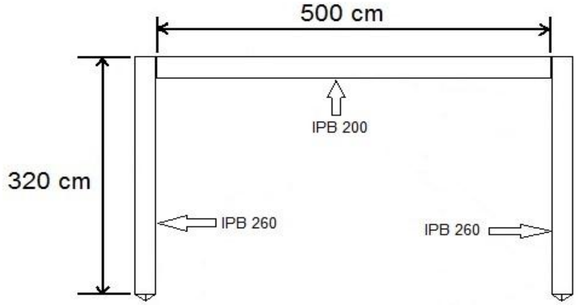


Fig 1: The detail of the frame models used in this study

The quasi-static loading suggested by SAC-ATC 24 [4] used in the analyses, is shown in Fig 2.

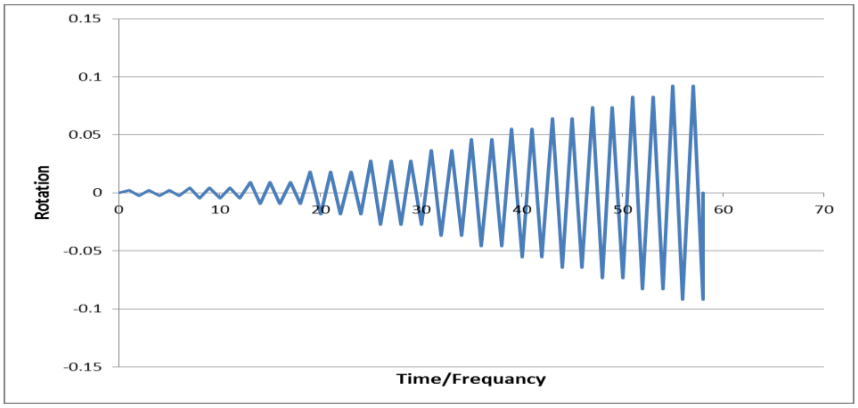


Fig 2: Loading pattern used in this study

3. Research Methodology

According to AISC Seismic Provisions 2010 [5], beam-to-column connections used in the Seismic Force Resisting Systems (SFRS) shall satisfy the following requirements:

1. The connections shall be capable of accommodating a story drift angle of at least 0.04 rad.
2. The measured flexural resistance of the connection, determined at the column face, shall equal at least $0.80M_p$ of the connected beam at a story drift angle of 0.04 rad.

The detail of the Weld Access Hole is presented in Fig. 3. For IPB 200 profile, which is used for the beam, the amounts of A, B and C are chosen 25, 11 and 15 millimeters, respectively.

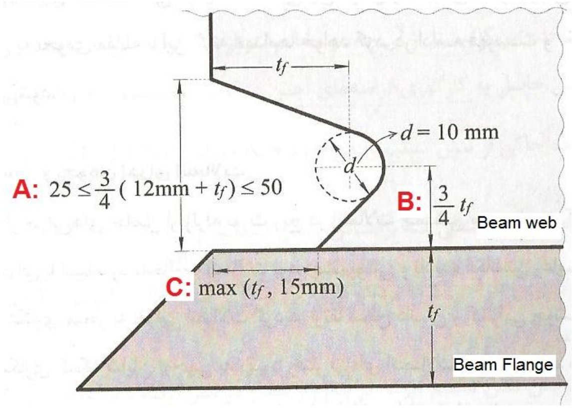


Fig 3: Detail of the Weld Access Hole **[**6**]**

The detail of the RBS used in this study is depicted in Fig. 4.

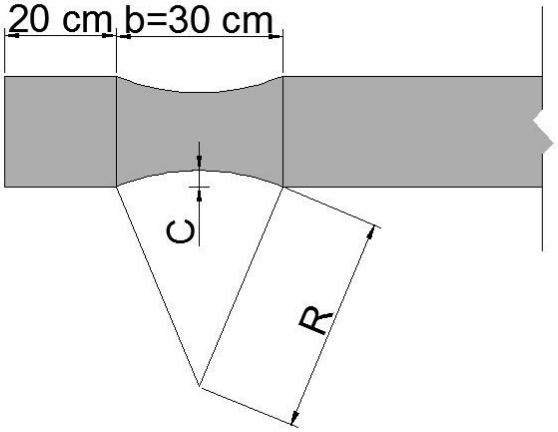


Fig 4: detail of the RBS

The amount of R can be found by Equation 1 [6].

$$R= (4c^2+b^2) / (8c) \tag{1}$$

In this paper, for C=2, 3, 5, 7 (cm) and b=30 cm, the amounts of "R" are calculated as 57.3, 39, 25 and 19.6 centimeters, respectively.

4. RESULTS OBTAINED FROM ANALYSIS OF THE MODELS

Von Misses stress contour of the models are presented in Figs. 5~8. It can be seen from the figures that as the amount of reduction of the beam flange (c parameter) increases, the concentration of stress in the reduced section point goes up accordingly, and in the S4 model, a complete plastic hinge is occurred.

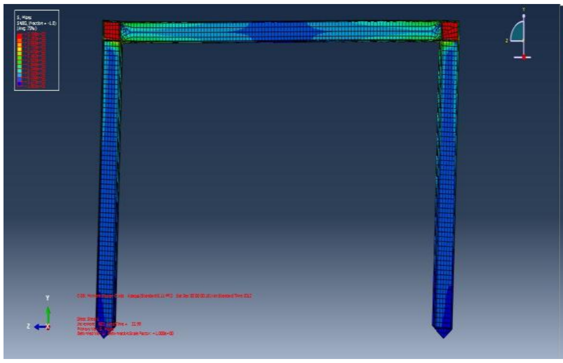


Fig 5: Stress Distribution in S1 Model

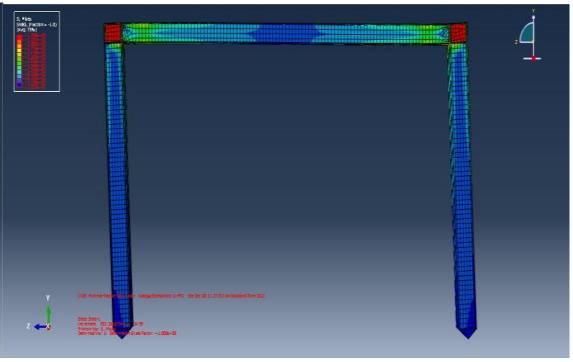


Fig 6: Stress Distribution in S2 Model

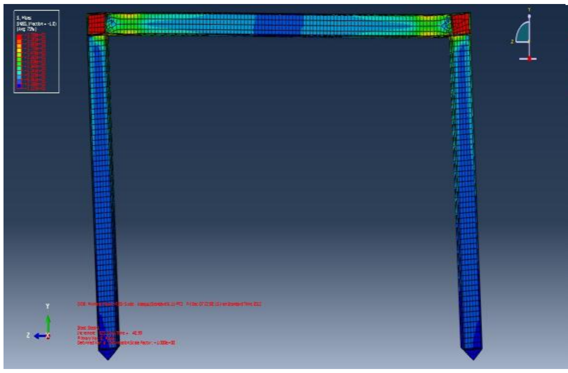


Fig 7: Stress Distribution in S3 Model

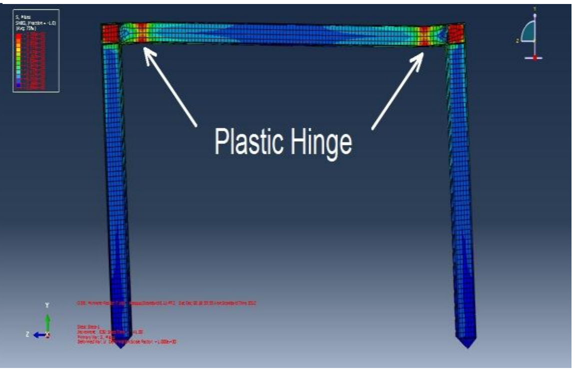


Fig 8: Stress Distribution in S4 Model

Hysteresis curves of the models S1 and S4 are presented in Figs. 9~10, respectively. It is observed that the hysteresis curve of the model S4 (Fig. 10), has more upward slope.

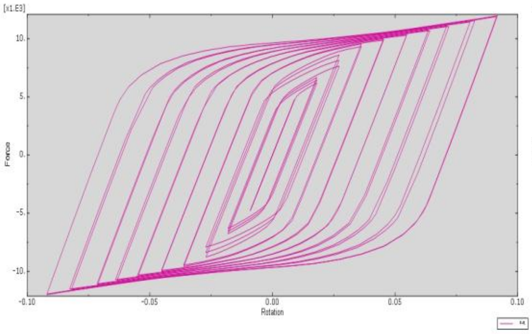


Fig 9: Hysteresis curve for S1 model

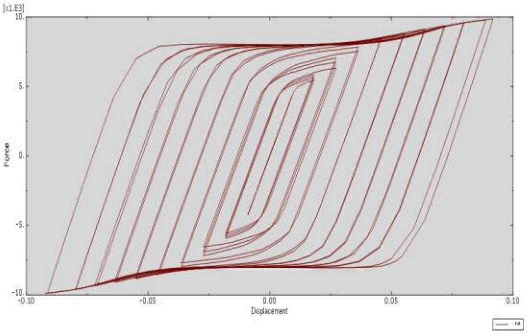


Fig 10: Hysteresis curve for S4 model

The capacity of ductility (the ultimate lateral displacement of the frame over the yield lateral displacement) and the maximum amount of rotations in the models are compared in Figs. 11~12, respectively. It can be clearly seen that the increase of the beam reduction, causes the enhancement of ductility and maximum rotation. In addition, it is observed that in the model S1, the value of the maximum rotation is less than 0.04 which is suggested as the least required amount of maximum rotation by AISC Provisions 2010.

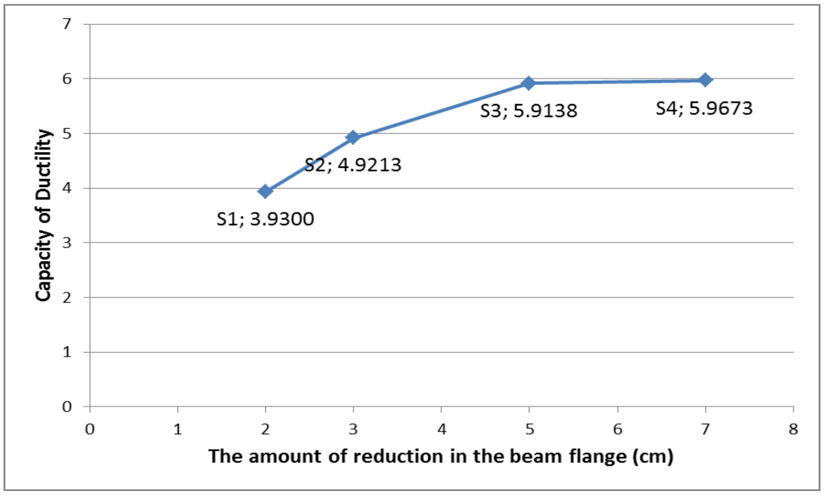


Fig 11: Capacity of Ductility of the models

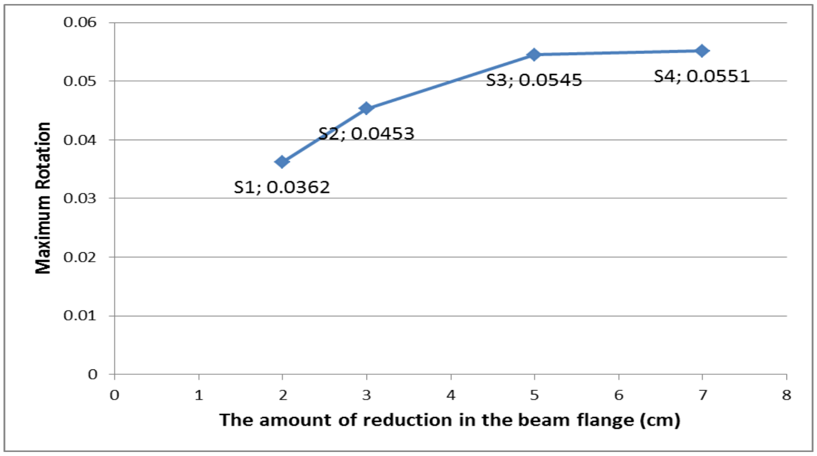
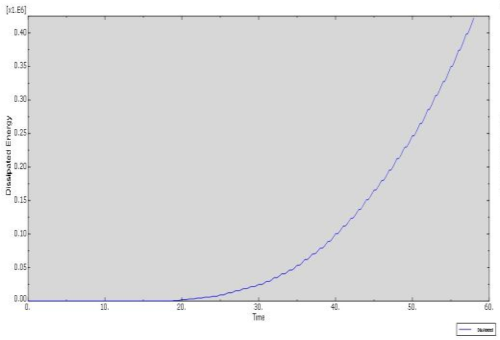


Fig 12: Maximum amount of Rotation of the models

The dissipated energy by plastic deformation in the models is shown in Figs. 13~16. It can be seen that the amount of dissipated energy in all the frames is almost equal.



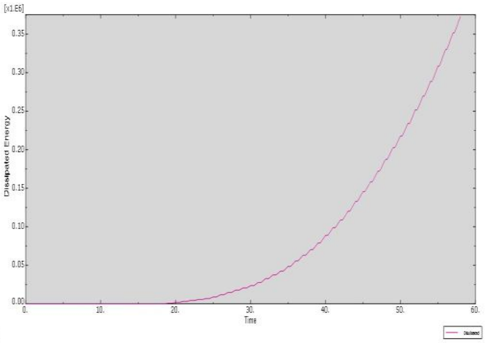
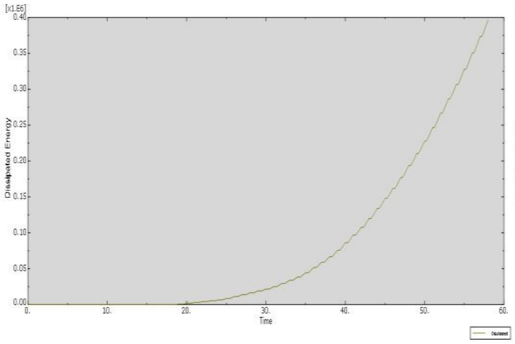


Fig 13: Dissipated Energy in model S1 **Fig 14:** Dissipated Energy in model S1



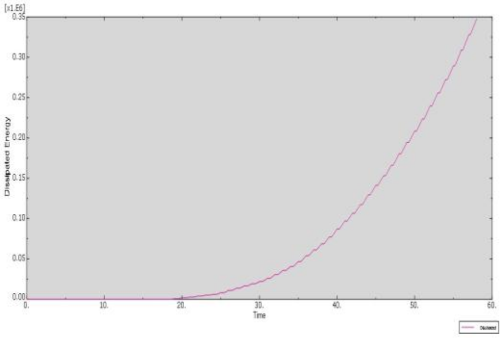


Fig 15: Dissipated Energy in model S1 **Fig 16:** Dissipated Energy in model S1

5. Conclusions

Special Moment Resisting Frame (SMRF) is one of the most ductile and energy dissipating Seismic Force Resisting Systems, however, there are some parameter which are important in improving the seismic performance of this system. In this paper, the effect of the decrease in the width of the beam flanges has been studied and the results show that by increasing the amount of this parameter, the following results are observed in SMRF systems:

1. An enhancement in the capacity of ductility
2. An enhancement in the maximum value of rotation
3. A diminution in the stress concentration in the panel zone
4. A Little fluctuation in the energy dissipation.

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