Analytical study of reduced beam sections under monotonic load

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Abstract. This paper presents the result of three different type of reduced beam sections (RBS): radius cut, straight cut, and tapered cut under monotonic load using finite element analysis. Load is applied monotonically and divided into 9 steps, start from 500 N to 4500 N, which increasing 500 N for each step, continuously. The dimension for the beam is WF 500x200x10x16 is used for those three types of RBS. The results show that radius cut gives better performance than the other two types. Stress distribution, load-stress curve, and load-displacement curve of those three types of RBS are compared as the result, then lead to the conclusion that the most effective connection amongst those three types of RBS above is RBS with Radius Cut.

1. Introduction

Strong column and weak beam concept must be fulfilled when designing earthquake resistant structure. As the name implies, the plastic hinge should occur in the beams prior to the columns [1][2]. One of the ways to weakening the steel beam flanges is using Reduced Beam Sections (RBS), furthermore strong column and weak beam requirement is satisfied. The RBS connection is one of the most popular connections due to their effectivity in reducing the stress concentration at the connection [3][4] and [5]. The use of RBS has many advantages as a steel moment connections due to their seismic ductility by relocated plastic hinge away from the column face [6][7][8] and [9]. Some of RBS types were proposed: RBS with Radius Cut, RBS with Straight Cut, and RBS with Tapered Cut [9]. FEMA-350 [9] and AISC-358 [10] can be referred as guidelines for designing RBS connection. The purpose of this paper is to explain the behavior of those RBS types above.

2. Proposed connection details

The dimension of the beam are provided in Table 1.

Table 1. Details of model

Model	Beam size	fy (MPa)	fu (MPa)
Radius Cut			
Straight Cut	WF 500x200x10x16	250	410
Tapered Cut			

Figure 1 below shows three different types of RBS: RBS with Radius Cut, RBS with Straight Cut, and RBS with Tapered Cut that will be analyzed.

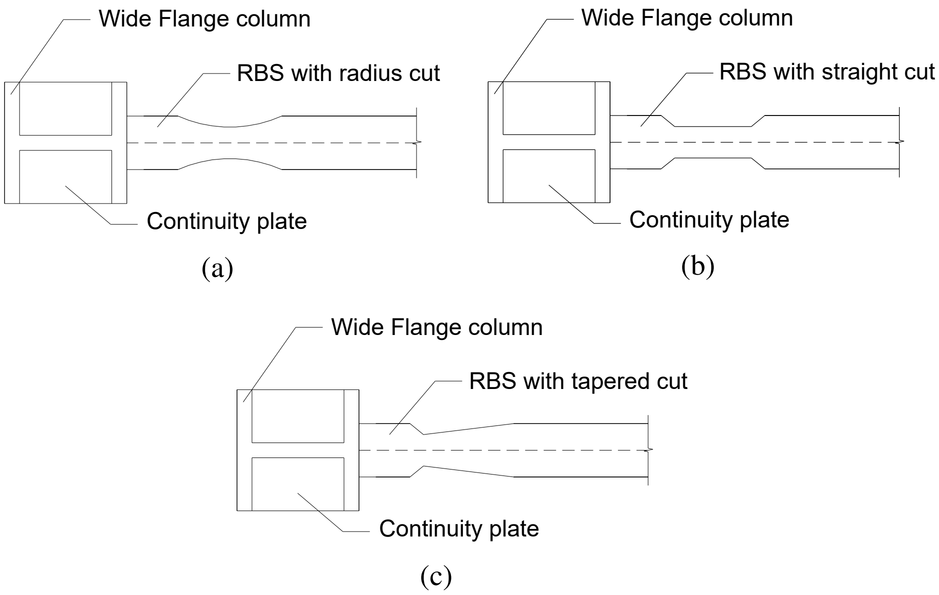

Figure 1. Top view of the RBS (a) with radius cut, (b) with straight cut, (c) with tapered cut

3. FEM analysis

3.1 Material properties

The elastic properties, Young Modulus *E* and Poisson's ratio *v* were set to be 200000 MPa and 0.3, respectively. For plastic properties is using stress-strain relationship formula [11].

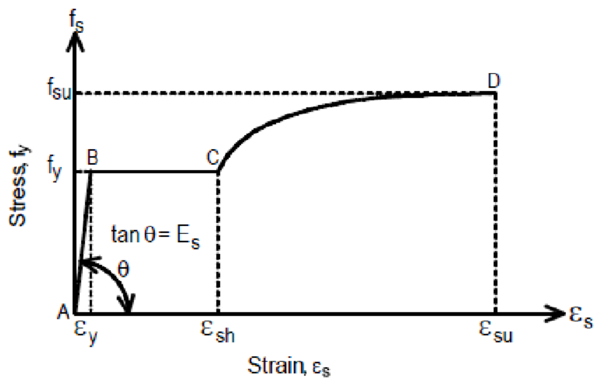

Figure 2. Stress-strain relationship of steel

A-B Region $(\varepsilon_s \leq \varepsilon_y)$

$$\varepsilon_y = \frac{fy}{Es}$$

$$fs = \varepsilon_s . Es$$

B-C Region $(\varepsilon_y \leq \varepsilon_s \leq \varepsilon_{sh})$

$$fs = fy$$

$$\varepsilon_{sh} = 16.\varepsilon_{sh}$$

C-D Region $\left(\varepsilon_{sh} \le \varepsilon_s \le \varepsilon_{su}\right)$

$$fs = fy\left[\frac{m(\varepsilon_s - \varepsilon_{sh}) + 2}{60(\varepsilon_s - \varepsilon_{sh}) + 2} + \frac{(\varepsilon_s - \varepsilon_{sh})(60 - m)}{2(30r - 1)^2}\right] m = \frac{(fsu - fy)(30r - 1)^2 + 60r - 1}{15r^2}$$

$$\varepsilon_{su} = \varepsilon_{sh} + 0.14$$

$$r = \varepsilon_{su} + \varepsilon_{sh}$$

Table 2. Stress-strain value of steel (fy 250 MPa)

Stress (MPa)	Strain	Plastic Strain
0	0	
250	0.00125	0
250	0.02	0.018
303.87	0.03	0.028
358.013	0.05	0.048
383.55	0.07	0.068
397.09	0.09	0.088
404.48	0.11	0.108
408.30	0.13	0.128
409.83	0.15	0.148
410	0.16	0.158

3.2 Boundary condotion and loading

In this model, the beam end is fixed to represent the rigid connection between the beam and the column. The load *F* is applied to the other beam end monotonically. The amount of monotonic loads are provided in Table 3.

Table 3. The amount of monotonic load

Step	Load (N)
1	$5x10^2$
2	10^3
3	$1.5x10^3$
4	$2x10^3$
5	$2.5x10^3$
6	$3x10^3$
7	$3.5x10^3$
8	$4x10^3$
9	$4.5x10^3$

3.3 Analysis FEM results

3.3.1. Stress distribution
The stress dsitribution of three types of RBS are shown in Figures 3.

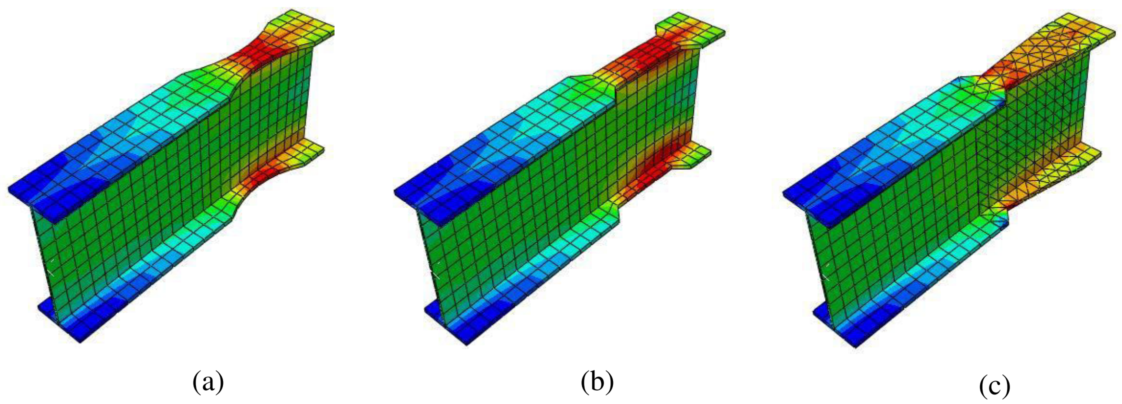

Figure 3. Stress distribution (S Mises) of RBS with (a) radius cut (b) straight cut (c) tempered cut on the first yield

According to the Figure 3 above, stress distribution of RBS with Tapered Cut shows that the first yield occures at the re-entrant corners.

3.3.2. Load - Stress Curve
Figure 4 shows comparison of the load – stress curve amongst three types in Figure 3. It showed that Stress (MPa) is directly proportional to Load (N). In RBS with Straight Cut, the first yield occures when 3000 N load is applied. Otherwise, the first yield in RBS with Radius Cut and Tapered Cut occures when 3500 N load is applied.

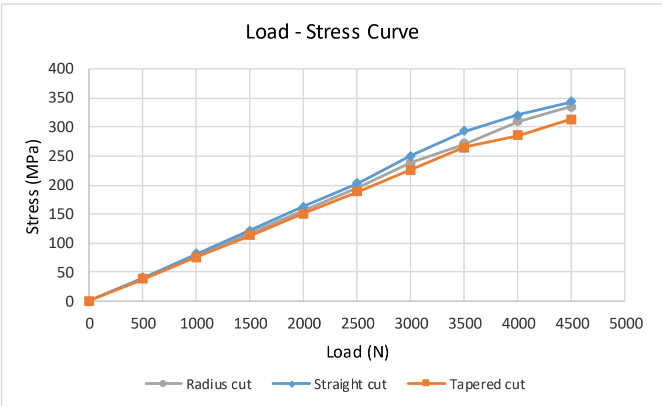

Figure 4. Load – stress curve

3.3.3. Load - Displacement Curve
Figure 5 shows comparison of the load – stress curve amongst three types in Figure 3. It showed that Displacement (mm) is directly proportional to Load (N). Compared to RBS with Radius Cut and RBS with Tapered Cut, the largest displacement occures in RBS with Straight Cut.

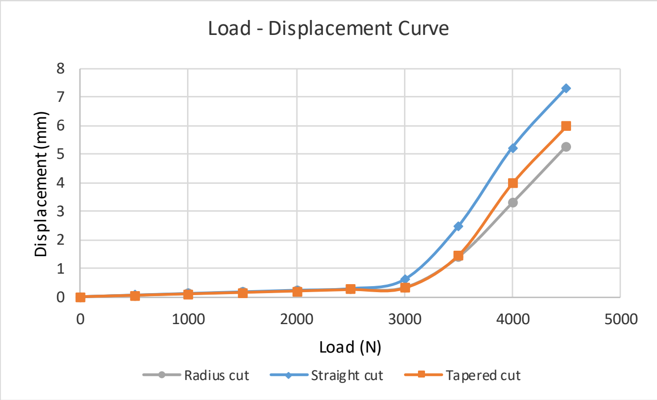

Figure 5. Load – displacement curve

4. Conclusion

According to the analysis above, following conclusions can be drawn:

1. Stress distribution of RBS with Tapered Cut shows that the first yield occures at the re-entrant corners which lead to fracture on the beam flange.
2. The first yield occures in RBS with Straight Cut earlier than RBS with Radius Cut and RBS with Tapered Cut when the load is applied monotonically.
3. The RBS with Radius Cut has the smallest amount of displacement. So, this type of RBS can reduces the amount of the inter-story drift of building structures.
4. The RBS with Radius Cut is the most effective connection amongst those three types of RBS above.

5. References

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