IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 6, Issue 4 (May. - Jun. 2013), PP 01-06
www.iosrjournals.org

A Study of Reduced Beam Section Profiles using Finite Element Analysis

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Abstract: *Reduced beam section (RBS) is one of the several connection types, which is economical and popular for use in new steel moment frame structures in seismic zone. To form RBS connection, some portion of the beam flanges at a short distance from column face is purposefully trimmed so that the yielding and plastic hinge occurs within this area of flanges. Use of RBS connection is found advantageous due to: a) the shear force in the panel zone is reduced; b) the force demand in column continuity plates i.e. stiffeners are reduced; and c) strong-column – weak-beam requirement is satisfied. Although, radius cut RBS is qualified by ANSI/AISC, FEMA codes, various flange cut shapes like constant, tapered, radius cut, drilled holes are possible to reduce the cross sectional area of beam flanges. The purpose of this study is to understand behavior of RBS beam-to-column moment connections for various flange cut geometries. This document represents nonlinear finite element analysis of the connection models performed using the computer program, ANSYS/Multiphysics*
Keywords - *Steel structures, steel connections, reduced beam section, RBS profiles*

I. INTRODUCTION

Before Northridge and Kobe earthquakes, welded flange and bolted / welded web connection i.e. pre-Northridge connection (Fig. 1) was the commonly used connection for steel moment resisting frames. Steel moment resisting frames are rectilinear assemblies of columns and beams that are typically joined by welding or high strength bolting or both. Resistance to lateral loads is provided by flexural and shearing actions in the beams and the columns. Lateral stiffness is provided by the flexural stiffness of the beams and columns [1]. The poor performance of pre-Northridge moment connections led the research to investigate the causes of failure and to develop alternative connections for repair, rehabilitation and new construction [2, 3]. In response to this, many solutions to the moment resisting connections for steel buildings have been proposed. These connections fall in one of the two categories: strengthening connection by addition of cover plates, ribs or haunches or weakening the beam cross-section away from the column face. Reduced beam section (Fig. 2) is a weakening strategy in which the strategic trimming of beam flanges at a short distance from column flange is planned to promote stable yielding at trimmed portion as well as to protect welded joint.

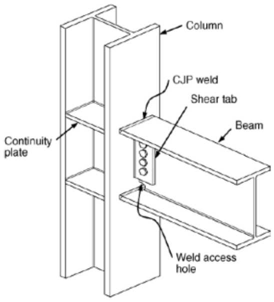

Fig.1 Typical pre-Northridge beam-to-column moment connection.

To learn the behavior of various flange cut profiles, in this paper nonlinear finite element study of connections subjected to straight cut, tapered cut, radius cut is conducted using ANSYS software.

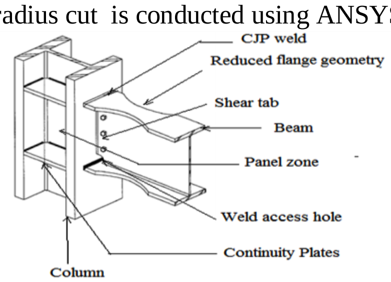

Fig. 2 Typical reduced beam section moment connection.

II. Flange-Cut Profiles Literature Study

The concept weakening was proposed by Plumier A [4, 5] has been adopted as an appealing alternative after Northridge and Kobe earthquake research developments. Many flange-cut geometry schemes were analyzed and tested by researchers as shown in Fig 2.

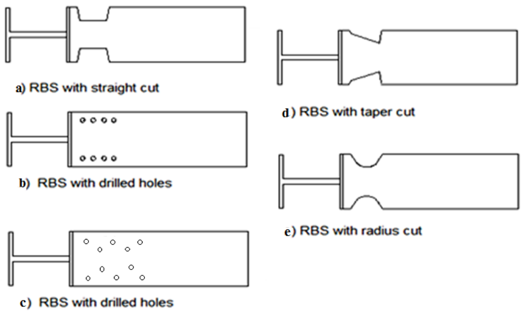

Fig.3 Reduced beam section patterns

- Performance of the 'straight cut' RBS (Fig. 3a) was not found well because of fractures after initial yielding due to stress concentration at the corner of the cut [4-8].
- Further, the constant / staggered 'drilled holes' weakening pattern (Fig.3b, 3c) was studied as one of the flange weakening strategy. Although, RBS beam with staggered holes shows plastic deformation capacity more than RBS beam with arranged holes in a line.It was observed that, the clear strain concentration regions occurred at the beam flanges with drilled holes. [9-10].
- For tapered cut [6, 87, 11-17] geometry used to be defined on the moment demand (Fig. 3d). Plastic straining in the taper cut reduced beam flange was found uniform. However, for tapered cut RBS the stress concentration at the re-entrant corner eventually led to fracture of the beam flange at the narrowest section. This problem has been found avoidable with radiused section cut at re-entrant corners of a tapered RBS. After significant plastic rotation, both the constant cut and tapered cut RBS connections have experienced fractures within the RBS.
- In order to provide a cut-out shape with minimum stress concentration and uniform strain distribution as well as economical fabrication, the concept of 'radius cut' or 'dog bone' (Fig. 2, 3e, 4) then found wide adaptability, achieves significant plastic rotational capacity and it is less sensitive to fabrication details than the tapered RBS section. Table 1, shows the standard cut parameters which are followed by various codes to have RBS geometry.

Since 1994, extensive research on the cyclic behavior of the RBS connection has been carried out in US and Japan. A substantial research has been carried out to study its various properties. Prequalified RBS connection details are described in Federal Emergency Management Academy (FEMA) 350-353, 355D [18-21, 6] and American Institute of Steel Construction (ANSI/AISC) 341-10,358-10,360-10 and AISC Steel design guide series –13 [22-25] and National Institute of standards and Technology-NEHRP Seismic Design Technical Brief No. 2 [26].

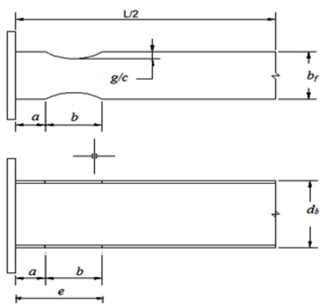

Fig.4 Radius cut RBS geometry detail

Table 1: Geometrical characteristics of reduced beam section

FEMA350-2000 OMF (Ordinary Moment Frame) ,SMF	EC8, Part 3	AISC 358-05 (IMF, SMF)
$a \cong (0.5 \text{ to } 0.75)b_f$	$a = 0.6\ b_f$	$a \cong (0.5 \text{ to } 0.75)b_f$
$b \cong (0.65 \text{ to } 0.85)\ d_b$	$b = 0.75\ d_b$	$b \cong (0.65 \text{ to } 0.85)\ d_b$
$c \le 0.25b_f$	$g{=}c \le 0.25b_f$	$0.1b_f \le c \le 0.25b_f$
$s = a + b/2$	$s = a + b/2$	--
$r = (4\,c^2 + b^2)/8\,c$	$r = (4g^2 + b^2)/8g$	--

III. Finite Element Analysis

Sections, W14 × 283 as a column and W 30 × 132 as beam, as considered by Pantelides et al. [27] are used for current study. For further study, section profile details (Fig. 5) as suggested by Iwankiw N [15] are followed. For all connections 50% flange reduction is done. For this study specimens are assumed without continuity plates. Geometric details of all models are tabulated in Table 2 and 3.

Table 2: Selected member's section properties

Member	Depth d in.	Web Thk t_w(in)	Flange Width b_f (in)	Flange Thk t_f (in)	Moment of Inertia $I_{x\,(in^3)}$
W 14× 283	16.74	1.29	16.11	2.07	3080
W 30 × 283	30.31	0.62	10.55	1.00	5770

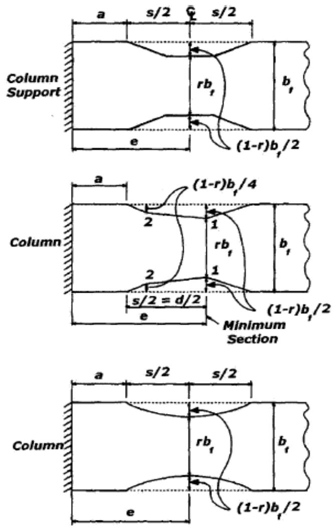

Fig. 5 Reduced beam section profile options (Ref: Iwankiw N[15])

Equation given by Iwankiw N [15] is as followes:

$$(1-r) = \left[\frac{\left(1-\frac{z}{Z}\right)}{\frac{Z_f}{Z}}\right] \quad \ldots\ldots \quad (1)$$

Where, z = plastic section modulus of beam strong axis at minimum RBS

Z = plastic section modulus of original beam about its strong axis

Z_f = plastic section modulus of the beam flanges only

$1-r$ = maximum flange-width reduction factor

Table 3: Reduced beam section –straight/taper/circular cut details

RBS 2 (W 14 ×283)	Straight Cut	Taper Cut	Radius Cut
z (in.^{3})	278.82	278.82	278.82
Z(in.^{3})	433.64	433.64	433.64
Z_f(in.^{3})	309.22	309.22	309.22
$(1-r)$	0.5	0.5	0.5
'a' (in.)	6.5	6.5	6.5
$\frac{(1-r)b_f}{2}$ (in.)	2.64	2.64	2.64
e (in.)	17	23.505	17
Length of the beam from column centre (in)	156	156	156
Height of the column (in)	194	194	194

The fundamental assumptions made to idealize steel mechanical properties are: Young's modulus of 2×10^5 MPa, Poisson's ratio of 0.3 and yield stress = 50ksi. Multi-linear stress strain curve are input directly as element material property for cyclic analyses (Figure 6A). An element SOLID45 from ANSYS element library is used for the 3-D finite element modeling of the RBS moment connection (Figure 6B). The column base was assumed as pin connected at both the ends. The beam top and bottom flange is laterally restrained at, $L_b = 0.86 r_y E/F_y$. In ANSYS model, the beam to column element connection is configured as fully restrained. Weld access hole configuration is considered as per FEMA350-2000. Beam tip is subjected to incremental monotonic displacement (Figure 7A, B) for 0.05 radians as per standard loading history considered AISC 341 2002 [30], is shown in Figure 5D. von Mises stresses for the specimens with RBS, as well as with RBS and CP are observed (Figure 6, 7, 8).

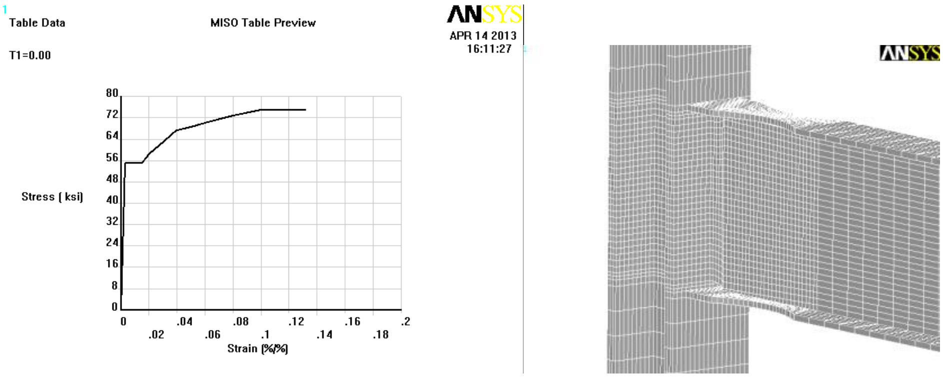

Fig. 6 A) Material property, B) . Meshing (Element - SOLID 45)

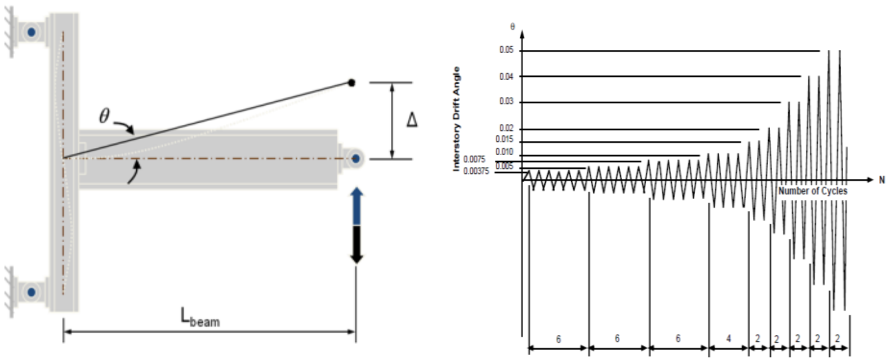

Fig. 7 A) Boundary condition B) Loading history

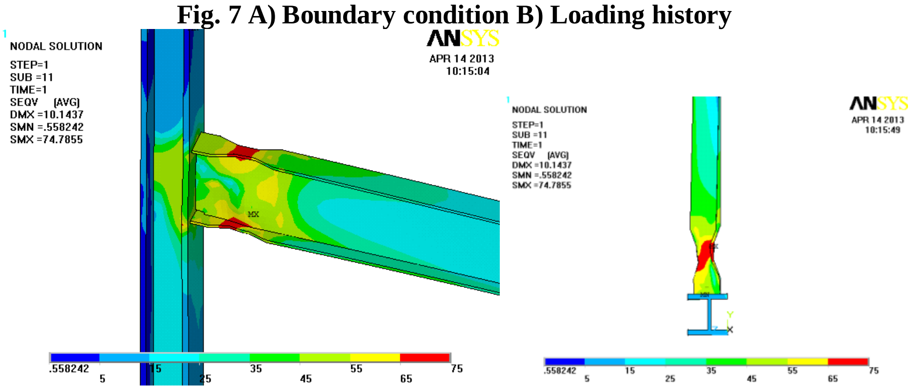

Fig. 8A, B Von Mises Stress distribution at 0.05 radians for straight cut RBS

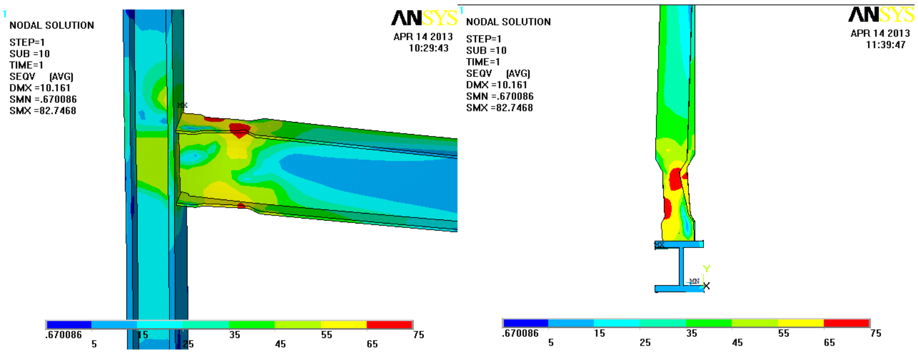

Fig. 9A, B Von Mises Stress distribution at 0.05 radians for taper cut RBS

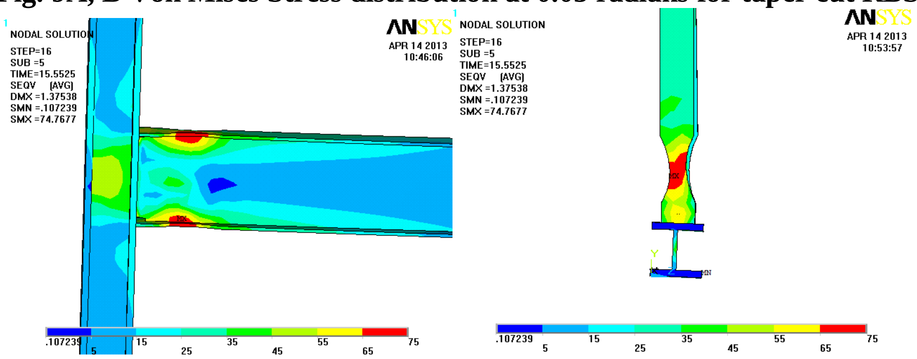

Fig. 10A, B Von Mises Stress distribution at 0.05 radians for radius cut RBS

IV. Discussion And Conclusion

This study is pilot exercise done to learn behavior of different cut profiles and to compare them. From the above Von Mises stress diagrams, it can be observed that:

1. Maximum Von Mises stress intensity for all connections is in between 65 to 75 ksi for 0.05 radians. Stress intensity in panel zone is in between 35 to 55 ksi for all connections.
2. Stress contours are of uniform nature for the radius cut RBS. For the trapezoidal and straight cut RBS connections stress concentration is observed at the re-entrant corners eventually may lead to fracture of the beam flange.
3. At 0.05 radians beam lateral torsional buckling and column flange twisting was found almost same in all cases.
4. RBS connections are not studied with respect to Indian profiles study can be made to learn its various parameters.

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