PROGRESSIVE COLLAPSE PERFORMANCE OF STEEL CONNECTION WITH EFFICIENT SEISMIC DESIGNS

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Abstract - *Corrugated plates are utilized in place of the flat web of the beam at the region near to the column face, known as the curved corrugated web RBS, in order to reduce the beam's flexural strength and assure hinge formation in this area. The corrugated web's application lowers the beam's flange width-to-thickness ratio while boosting lateral and torsional stability in the lowered section zone. To describe the design process and determine the resistance to progressive collapse, FEM is employed. Several models are built using the provided details of the beam and column sections after the numerical model's validation. Then, taking into account the three possible depths for the corrugated cells, these models are examined under cyclic loading. Connections without RBS and with RBS such as flange cut (FC-RBS), are used for comparison. The findings demonstrate that the proposed connection induces the formation of plastic hinges in RBS zone, preventing failure at the beam column junction. This recommended connection performs better than the conventional FC-RBS connection in terms of yield strength, rotation capacity, ductility, and load bearing capacity.*

Key Words: **RBS connection, Corrugated web, Cyclic loading, Seismic behavior**

1. INTRODUCTION

Steel moment frame connections can be secured against brittle failure by using Reduced Beam Section (RBS) connections, which include weakening the beam near to the column face. This technique makes sure that the beam has less flexural strength in the RBS zone than in any other adjacent regions, causing plastic hinges to develop here. By preventing nonlinear behavior from spreading to the connection, this aids in reducing brittle failure in this location. Researchers have proposed a number of methods for reducing the beam's moment capacity at the area where the plastic hinge is gradually developed. The most common RBS connection, referred known as 'dog bone connection', is made by cutting off the beam's flange just beyond the column face in order to ensure flexural yielding there. This cut can be made using a straight cut, a tapered cut, or a radius cut. Due to its enhanced seismic performance, the Radius Cut RBS (RC-RBS) connection has been included to the AISC 358-16.

When considerable deformation occurs, connections with flange or web reduction may affect the mechanical characteristics and produce structural displacement. In particular, the web-reduction created a discontinuous force transmission path, which subjected the beam web to an additional concentrated force. Because of this, it is necessary to evaluate the load carrying capacity, deflection, and cracking of beams with flange and web reductions, which can be evaluated indirectly by their ability to sustain progressive collapse.

Prior research concentrated mainly on how connections performed with or without RBS. In this study, a new type of RBS connection is created to allow for connections with better ductility, load carrying capacity and energy absorption. It has been feasible to compare the common weld connections (W-RBS), traditional RBS connections (FC-RBS), and the new RBS connection (CW-RBS) using numerical validation. The deformation, failure modes, load carrying capacity, rotation capacity, moment capacity, ductility, yield point, stress concentration, and strain distribution are explained and analyzed in detail.

1.1 Corrugated Web RBS

It is possible to construct steel moment frames with more acceptable seismic responses by using corrugated web RBS connections, which have advantages over traditional RBS connections. The corrugated web's geometry in the RBS zone can also be changed in order to further enhance these connections' seismic performance. In this study, a novel corrugated web RBS connection, the curved cell web RBS (CW-RBS) is presented. In the proposed connection, a full-capacity rigid connection is made by welding the beam using Complete Joint Penetration (CJP) to the column's flange. In a region close to the column, the beam's web is cut, and the removed portion is replaced by a cell formed of two corrugated plates. The cell is constructed using two curved plates, known as the curved cell web RBS (CW-RBS) connection. The paper goes into considerable detail in the next part to describe both the design approach and the suggested connection. The development of a finite element model and its validation using the available empirical data are then covered in the following parts. The model was created for assessing the resistance to progressive collapse. The examination of the beam's inelastic behavior in the RBS zone and the energy dissipation capacity of the suggested connection in comparison to conventional RBS is shown at the end of the paper.

1.2 Review on Literature

Using radial cuts in the beam flange and circular aperture in the beam web, Huiyun Qiao et al. (2020) [1] described a new reduced beam section (RBS) connection that enables more ductile connections. Nine distinct specimens were built and evaluated in the investigation under a scenario of removing the central column, without an RBS (RBS-0), with flange reductions (RBS-1), and seven with web and flange reductions (RBS-2). According to the findings, the RBS-0 specimen with brittle failure was ineffective at resisting progressive collapse. While RBS-1 outperformed RBS-0 in terms of ductility and resistance, it still needed to be strengthened in order to withstand progressive collapse after fracture. RBS-2 with web apertures created an arch structure to release energy through ongoing deformations. The diameter and the distance of the web opening, which were associated with the emergence of arching and catenary action, were also two significant elements in RBS-2 that affected its mechanical property.

2. MODELLING, ANALYSIS AND PARAMETRIC STUDY ON NOVEL CURVED CELL WEB REDUCED BEAM SECTION

This chapter deals with the analysis and parametric study on novel curved cell web reduced beam section and finding the optimum performance. Four models are created using ANSYS as per the AISC provisions. The different models used are CW-RBS 75x170x80mm, CW-RBS 50x130x80mm, CW-RBS 75x130x80mm and CW-RBS 50x170x80mm. The dimension details and material properties of the curved cell web RBS are in Table 1 and 2 respectively.

Table -1: Dimension details

Section	Dimension
Beam	200 × 100 × 5.5 × 8 mm
Column	250 × 250 × 9 × 14 mm

Table -2: Material properties

Steel	Young’s modulus (E) =2 ×10^5 MPa
	Poisson’s ratio (μ)= 0.3
	Density (ρ) = 7850 kg/m3

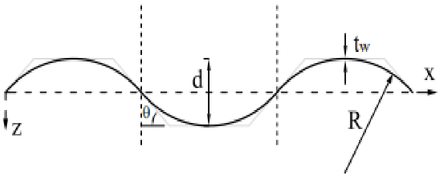

Fig -1: Geometric notations of CW-RBS

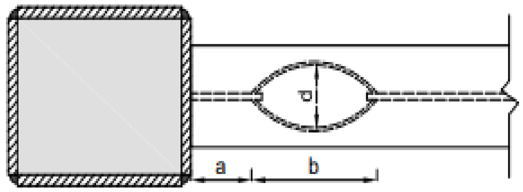

Fig -2: Geometric dimensions of RBS zone

Table -3: Limits for the geometric dimensions

Limits	Max	Min
0.5 bf ≤ a ≤ 0.75 bf	50mm	75mm
0.65db ≤ b ≤ 0.85db	130mm	170mm
0.1 bf ≤ c ≤ 0.25 bf	10mm	25mm
d = 0.4bf, 0.6bf ,0.8bf	40mm,60mm,80mm	

CW-RBS is modelled in ANSYS with different specimen dimensions like CW-RBS 75x170x80mm, CW-RBS 50x130x80mm, CW-RBS 75x130x80mm and CW-RBS 50x170x80mm. Modelling is done by using element type SOLID186. CW-RBS is modelled using hexahedral which is a 20-noded mesh. Programme controlled coarse mesh is adopted for meshing the column and beams. Load is applied as displacement of 10mm according to displacement convergence method.

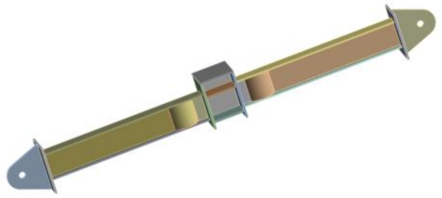

Fig -3: Model of CWRBS

Analysis is carried out to study the performance of CW-RBS with different dimensions. Nonlinear static structural analysis is carried out in ANSYS. Load carrying capacity and deformation is studied. The deformation diagrams are shown in Fig 4 to 7.

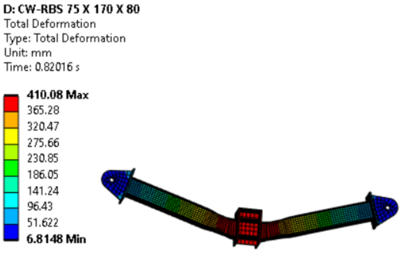

Fig -4: Deformation of CW-RBS75x170x80

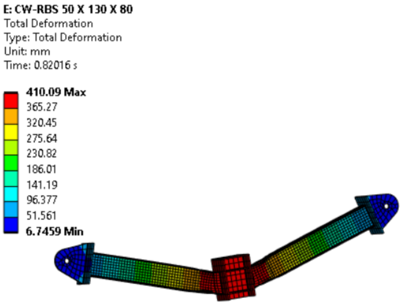

Fig -5: Deformation of CW-RBS50x130x80

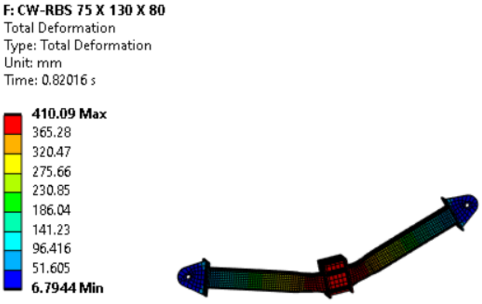

Fig -6: Deformation of CW-RBS75x130x80

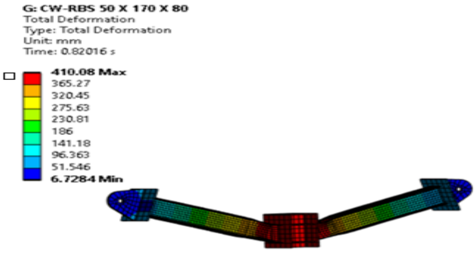

Fig -7: Deformation of CW-RBS50x170x80

1.2 Results and discussion

The result obtained from the Nonlinear static structural analysis of curved cell web RBS like CW-RBS 75x170x80mm, CW-RBS 50x130x80mm, CW-RBS 75x130x80mm and CW-RBS 50x170x80mm are compared with flange cut RBS.

Table -4: Comparison of results

Section	a mm	b mm	d mm	Wmax mm	Pmax kN	%
RBS-FC	-	-	-	246.06	225.31	-
CW-RBS75X170X40	75	170	40	308.12	329.17	46.10
CW-RBS75X170X60	75	170	60	341.05	426.6	89.34
CW-RBS75X170X80	75	170	80	401.05	502.72	123.12
CW-RBS50X130X80	50	130	80	437.35	523.2	132.21
CW RBS75X130X80	75	130	80	407.84	522.79	132.03
CW RBS50X170X80	50	170	80	405.67	493.4	118.99

Section	Θmax = Wmax/L	%	Mmax = Pmax x L	Yield Point mm	%	Ductility = Wmax/ Yield Point
RBS-FC	0.1871	-	296.28	60.07	-	4.10
CW-RBS 75 X170X40	0.2343	25.23	432.86	100.09	66.62	3.08
CW-RBS 75X170X60	0.2594	38.62	560.98	100.09	66.62	3.41
CW-RBS 75X170X80	0.3050	63.00	661.08	100.09	66.62	4.01
CW-RBS 50X130X80	0.3326	77.76	688.01	100.09	66.62	4.37
CW RBS 75X130X80	0.3101	65.76	687.47	100.09	66.62	4.07
CW RBS 50X170X80	0.3085	64.88	648.82	100.09	66.62	4.05

Table -5: Stress concentration and strain distribution in beam and column

section	stress concentration in beam (MPa)	strain distribution in beam
RBS-FC	484.93	1.05
CW-RBS 75x170x40	485	1.846
CW-RBS 75x170x60	485	1.7747
CW-RBS 75x170x80	485	1.6503
CW-RBS 50x130x80	485	1.4062
CW RBS 75 x130x80	485	1.5619
CW RBS 50x170x80	485	1.677

section	stress concentration in column (MPa)	strain distribution in column
RBS-FC	93.81	0.00060
CW-RBS 75x170x40	119.6	0.00107
CW-RBS 75x170x60	123.97	0.00113
CW-RBS 75x170x80	129.47	0.00113
CW-RBS 50x130x80	137.96	0.00106
CW RBS 75 x130x80	128.02	0.00111
CW RBS 50x170x80	127.29	0.00108

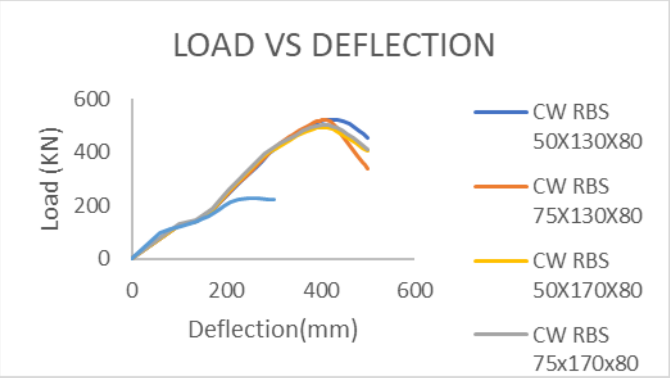

Fig -8: Load deflection comparison

3. CONCLUSIONS

- Since the maximum load and deflection was obtained for the specimen CW-RBS 75x170x80, the optimum value for d is 80 mm and the maximum load carrying capacity and rotation capacity is obtained for the specimen CW-RBS 50x130x80.
- From the study of implementing novel curved corrugated web reduced beam section when compared with FC-RBS, it was found that,
    - Load carrying capacity was increased by 132.21%
    - Rotation capacity was increased by 77.76%
    - Yield strength was increased by 66.62%
    - Considerable increase in ductility is also observed.
    - Stress concentration in beam is 485 MPa and in column is 137.96 MPa
    - Strain distribution in beam is 1.4062 and in column is 0.00106
- Since stress concentration in beam and strain distribution in beam is more than column, the proposed connections cause plastic hinges to emerge in the RBS zone, thereby preventing failure at the beam column junction.
- Beam column connection with RBS shows better performance than beam column connection without RBS because the load carrying and rotation capacity were increased by 42.56% and 185.86% respectively.
- Delaying the rotation capacity and force capacity increases the progressive collapse life of the connection.

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