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STUDY OF STEEL MOMENT CONNECTION WITH AND WITHOUT REDUCED BEAM SECTION

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Abstract
This paper presents test results of two connections tested under cyclic loading. The testing program addressed connection with reduced beam section (RBS) versus without RBS moment connection. RBS connection is widely investigated and used in US, Japan and Europe. However, design of such type of connection is not presented and used in India. This study is conducted to learn, the advantages and usefulness of RBS connection against connection without RBS for Indian profiles. A theoretical model is also created with the finite element method and the results are compared with those obtained from the experimental study. The analysis observed that specimen without RBS performed poorly due to cracks started at the bottom flange weld. The specimen with RBS reached rotation capacity of 0.02 radians without damage in the welds.

Keywords
Steel structures, moment connection, welded joints, reduced beam section, cyclic loads

Introduction
The RBS (Figure 1) connection is one of the most popular and most economical type amongst post Northridge (1994) and Kobe (1995) connections. Number of analytical and experimental studies have been performed on RBS moment connection to examine: flange cut reduction geometry, beam web to column flange connection detail, behavior of panel zone, requirement of continuity plate, lateral and local instability of beam, effect of composite slab, and usefulness for retrofitting...etc. Further, prequalified RBS connection details and guidelines are described in FEMA (Federal Emergency Management Academy) 350-351,355-D [1-3] and ANSI/AISC (American Institute of Steel Construction) 341-10 [4], ANSI/AISC 358-10[5], ANSI/AISC 360-10 [6], National Institute of standards and Technology-NEHRP Seismic Design Technical Brief No. 2 [7], EC8, Part 3[8] AISC Steel design guide series -13 [9], NIST GCR 11-917-13[10] and PEER/ATC 72-1[11].

According to, Indian Standard (IS), IS 12778-2004 and IS 12779-1989 [12,13], hot rolled parallel flange I beam sections are classified into 3 types namely as narrow parallel flange beams (NPB), wide parallel flange beams (WPB) and parallel flange bearing pile sections (PBP). Although, Parametric analysis by R. Goswami et al.[14] has shown that Indian hot rolled I sections having yield stress 250 MPa do not meet compactness requirements specified in Indian standards as well as of those countries with advanced seismic provision for frames used in high seismic zones. However, hot rolled I beam sections having yield stress 250 MPa are most commonly available and used for steel structures in India. As RBS connection is studied and used widely in US, Japan and Europe, however its study is quite limited with respect to Indian profiles and so not found mentioned in any Indian Standards for steel design IS800-2007, IS808-1989, IS1852-1985, IS 2062-1999, IS8500-1991, IS12778-2004 & IS12779-1989, [15-19,12,13] It can be adopted in India for better performance in strong and intermediate earthquakes [20]. Considering the advantages of RBS moment connections and lack of knowledge of the performance of this connection with
respect to Indian profiles led to a study on this topic. The objective of this study was to investigate experimentally the cyclic behaviour of welded moment connections with and without RBS. Two external joint specimens were tested to compare and observe connection behavior. Nonlinear finite element analysis of the connection models performed using the computer program, ANSYS/Multiphysics.

**Design of specimen**
Sections with 250MPa grade were considered for this study. Two specimens were studied, designated as, connection without RBS as ‘WRBS’ and with RBS as ‘RBS’. RBS connection was designed based on specifications given as per AISC and FEMA codes. For panel zone as well as continuity plates, design shear strength, required shear strength & column web/flange thickness limits were studied. The connection was representing an exterior strong-axis connection. Height of the column considered was 975mm and length of the beam from the centre of the column was 1000mm. Other, geometrical details are mentioned in Table 1. Table 2 shows the strength of the connection calculated according to AISC/FEMA formulae. The $\frac{M_f}{R_u Z_i F_r}$ ratio was within the limit (0.85 to 1) suggested by Engelhardt et al. [21]. Table 3 shows normalized limit states for CP and PZ.

From normalized values (>1) (Table 3) it can be observed that doubler plates as well as continuity plates are not required. Therefore, RBS moment connection without doubler plates and continuity plates was considered for the study.

**Experimental Study**
Specimens were fabricated at Focus Robotomation Ltd. Pune, India and experimental procedure was carried out at Composite Research Centre labs at R&D Engineers, Pune, India. Physical observation of members showed that, geometrical sizes and weights were as recommended by with Indian Standards IS 808-1989[16] and IS12778-2004[12]. The sizes/weights of the members considered to model the exterior connection are listed in Table 4. Coupon testing was performed for steel shapes to establish the mechanical properties at Perfect Laboratory Service, Pune, India (see Table 5).

Each beam flange and web was welded at the face of the column using fillet welds. It should be noted that there were no web access holes. The welds' throats were 8 mm for all the specimens. Welds' throat and quality were checked during fabrication. Test setup shown in Figure 2, consisted of: Supporting frame, Test specimen (external subassemblage, Hydraulic actuator (force rating ±100kN and stroke length ±125 mm), Data acquisition system and strain gauges YFLA-5 of gauge resistance120Ω. For the test specimens cyclic loads (Table 6) were applied to the tip of the beam following standard SAC loading history Clark et al.[22].

**Finite Element Study**
The ANSYS Multiphysics [23] finite element software was used to model the specimens for nonlinear analysis. An element SOLID45 from ANSYS element library was used for the 3-D finite element modelling of the RBS moment connection (Figure 3A, B). The fundamental assumptions made to idealize steel mechanical properties are including: Young’s modulus of $2\times10^5$ MPa, Poisson’s ratio of 0.3. Multi-linear stress strain curve are input directly as element material property for cyclic analyses (Figure 3C). The column was assumed as pin connected at both the ends and at the joint beam to column element connection is configured as fully restrained. Each subassembly is loaded at the beam free end in the displacement control as per details given in above section of experimental study.
Performance of the Specimens
Observations of Specimen without Reduced Beam Section ‘WRBS’:
For, specimen WRBS (Figure 4A) column flange buckling was observed and it became more pronounced with each successive loading cycle. From the flaking of the white wash in column panel zone it was observed that column panel zone yielding above elastic limit had occurred in this area (Figure 4B). During the first cycle of the 0.02 radians a crack was developed near weld metal of beam bottom flange, no beam buckling was observed. Figure 4C shows von Mises stress diagram of the specimen. The von Mises contours shown Figure 4C indicate the highest regions of stress contours (435 - 485MPa) occur in panel zone as well in the vicinity of weld element. Reasonable correlation was observed between analysis and experiment for all specimens.

Observations of Specimen with Reduced Beam Section ‘RBS’:
The column panel zone stayed in the upper envelop of elastic state for the specimen as the white wash stayed intact. Column flange or web buckling was not observed. No sign of failure of from welding was observed during the test (Figure 5A, B, C). The von Mises contours shown in Figure 5B & 5C indicate the highest regions of stress contours (358 - 403 MPa) occur in reduced beam section of the beam. This is approximately the upper envelop of an inelastic state. RBS connection reached total interstory drift angle of 0.03 radians, which exceeds the FEMA and AISC requirements for intermediate moment frame of 0.02 radians. Lateral displacement 21mm was observed during cycles of 0.03 radians (Figure 5A, 5B)

Hysteretic Behaviour:
The force-displacement hysteretic responses of the connections resulting from the experimental study are compared with those of the finite element analysis (Figure 6A and 6B). Reasonable correlation between the analysis and experimental results was observed. With cyclic displacement increasing, both specimen share the almost same shape and curve slope decreases continuously until attain the extreme limit loading. It showed that the structures remain elastic before yielding. The area of hysteretic loops gradually increased and residual deformations were observed with the increase of displacement after yielding. Inelastic deformation occurred mainly in RBS area for connection ‘RBS’ creating ductile fuse, whereas as it occurred in panel zone and beam flanges for connection ‘WRBS’

Conclusions
Both the experimental and numerical results observed that cyclic performance of the RBS moment connection was much superior to the connection without RBS. No weld fracture was observed in RBS connection while there was a crack observed near beam bottom flange weld for connection without RBS. A reduction in material and labour cost is possible due to elimination of continuity/doubler plates for RBS moment connection. Numbers of tests conducted in above study are quite limited and more extensive testing is recommended to understand behaviour of RBS for Indian profiles.

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Figure 1 A) RBS connection detail  B) Typical geometry details of RBS

Figure 2 Test setup

Figure 3 A) Specimen modelling B) Finite element mesh C) Idealized uniaxial tensile response

Figure 4 A) Specimen WRBS  B) Panel zone yielding in Specimen WRBS  C) von Mises stress distribution in the WRBS specimen at 0.02 radians

Figure 5 A) Specimen RBS with lateral displacement B) and C) von Mises stress distribution in the specimen 3 at 0.03 radians
Figure 6 A) Force-displacement response of specimen ‘WRBS’ B) Force-displacement response of specimen ‘RBS’
Table 1 Select members for analysis

| Member (Sr. No. as per IS 12778-2004) | Depth $d$ (mm) | Web Thk $t_w$ (mm) | Flange Width $b_f$ (mm) | Flange Thk $t_f$ (mm) | RBS Dimensions(mm) |
|---------------------------------------|---------------|-------------------|------------------------|----------------------|--------------------|
| WPB150(15) Column                     | 162           | 8                 | 154                    | 11.5                 | N.A.               |
| NPB200(9) Beam                        | 200           | 5.6               | 100                    | 8.5                  | 60 160 25 140.5    |

Table 2 RBS moment connection design parameters

| Specimen   | Column (Sr.No. as per code) | Beam (Sr.No. as per code) | $M_{pe}$ (Nmm) | $M_f$ (Nmm) | $M_{pr}$ (Nmm) | $M_f/M_{pr}$ | $\sum M_{pe}^*/\sum M_{pr}^*$ |
|------------|----------------------------|---------------------------|----------------|-------------|----------------|-------------|------------------|
| RBS WPB150(15) | NPB200(9)                     | 67.65×10^6               | 59.68×10^6     | 45.56×10^6  | 0.88            | 3.12        |

Table 3 RBS moment connection design parameters

| Specimen | Column (Sr. No. as per code) | Panel Zone | Continuity Plates |
|----------|-------------------------------|------------|-------------------|
|          | FEMA AISC $t_{pc}$             | LFB LWY WC WCB | FEMA $t_{cf}$ |
| RBS WPB150(15) | NPB200(9)                     | 2.44       | 1.20 1.00 3.46 1.54 2.74 1.02 |

Table 4 Test Specimens

| Test Specimen | Column | Beam |
|---------------|--------|------|
| WRBS          | WPB150(15) | NPB200(9) |
| RBS           | WPB150(15) | NPB200(9) |

Table 5 Steel Mechanical Properties

| Section       | WPB150(15) | NPB200(9) |
|---------------|------------|-----------|
| Yield Strength $F_y$ (MPa) | 334        | 330       |
| Tensile Strength $F_u$ (MPa) | 486        | 484       |

Table 6. Loading Schedule

| Load Cycles (Number) | 6 | 6 | 6 | 4 | 2 | 2 | 2 | 2 |
|----------------------|---|---|---|---|---|---|---|---|
| Interstory Drift Angle (radians) | 0.00375 | 0.05 | 0.0075 | 0.01 | 0.015 | 0.02 | 0.03 | 0.04 | 0.05 |
| Beam Tip Displacement (mm) | ± 3.75 | ± 5 | ± 7.50 | ± 10 | ± 15 | ± 20 | ± 30 | ± 40 | ± 50 |