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Numerical study of Slotted-Web–Reduced-Flange moment connection

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ABSTRACT

Reduced Beam Section (RBS) and Slotted Beam Web (SBW) are two types of seismic resistant moment connections that were introduced after the 1994 Northridge earthquake. These connections have been tested under cyclic loading and have had acceptable performance. In this paper, a new hybrid connection is introduced that is composed of RBS and SBW and is named Slotted-Web–Reduced-Flange (SWRF). Nonlinear finite element analyses are performed on SWRF under cyclic loading. It is shown that the new connection in some cases performs better than its RBS and SBW predecessors. The effects of panel zone strength, continuity plates and slot length are also investigated.

1. Introduction

Steel moment frames were considered an appropriate solution to stability of buildings in seismic regions because of their perceived ductility. After the 1994 Northridge earthquake, when many steel buildings with moment frames were seriously damaged, this notion proved to be wrong. The scientific community realized that more research is necessary to better understand the behavior of these connections under cyclic loading.

The “pre-Northridge” moment connections consisted of bolted or welded web shear plates and complete joint penetration (CJP) beam flange welds. These connections proved to be susceptible to brittle failure under seismic loading.

Researchers have suggested two solutions to improve ductility of moment connections after the Northridge earthquake. First, increasing the strength of the connections by using stiffeners and appropriate welds in order to prevent premature connection damage, and second, making a beam section weak at a section away from the column face, so that a plastic hinge is forced to occur at this section without damaging the column. The idea of connections with Reduced Beam Section (RBS) and Slotted Beam Web (SBW) is based on the latter concept.

RBS connection relies on the selective removal of beam flange material adjacent to the beam-to-column connection, typically from both top and bottom flanges, to reduce the cross sectional area of the beam. This reduction in cross sectional area will reduce the moment capacity at a discrete location in the beam and so plastic hinge occurs in the beam [1,2].

In SBW connection, slotted beam design allows the beam flanges and the beam web to buckle independently. This circumvents the beam lateral-torsional buckling mode that occurs in non-slotted beams. Therefore, the torsional moment and torsional stresses in the beam flanges and welds at the column flange that result from this buckling mode are omitted. The separation of the beam web and the flange results in a biaxial rather than triaxial stress and strain states in the region of the connection, which increases its fatigue life [3,4].

One of the parameters which can considerably influence the failure mode of the beams with RBS moment connections is the column panel zone (PZ) ductility. Krawinkler [5] and Popov [6] indicated that the beam-to-column joints with weak PZs encounter high shear deformation, resulting in brittle fracture within the weld connecting the beam flange to the column face. As a result, in spite of the weak PZ ability to dissipate a large amount of energy, using very weak joints is not recommended. On the contrary, in the presence of strong PZs, the fracture potential is reduced, but the possibility for beam instability rises, especially for RBS connections. Tsai et al. [7] and Jones et al. [8] experimentally illustrated that balanced PZs show appropriate performance.

Studies also show desirable performance of SBW connections. Richard et al. [3] conducted successful experiments on these connections. The Slotted Beam Web connection designs reduce the stress concentration factor at the beam-to-column flange interface at the column web from typical values ranging from 4.5 to 5.5 in non-slotted beams down to a typical value of about 1.4 by providing a nearly uniform beam flange/weld stress and strain distribution. The SSDA [4] slotted web design develops the full plastic moment capacity of the beam, moves the plastic hinge region in the beam away from the face of the column, and results in nearly uniform tension and compression stresses, strains across and through the beam flanges from the face of the column

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to the end of the slot. It eliminates the lateral-torsional buckling mode that occurs in non-slotted beams, and enhances ductility by reducing the residual weld stresses.

Considering the advantages of RBS and SBW connections, an innovative hybrid connection is examined in this paper in which both beam flanges are reduced in section (like RBS) and the beam web is cut with two slots (like SBW). The connection is named “Slotted Web–Reduced Flange” or SWRF, for short. In this way, the plastic moment forms away from the column face and the web slots reduce stress concentrations and eliminate lateral-torsional buckling modes. A series of nonlinear finite element analyses are performed on this connection using the cyclic load pattern suggested by AISC Seismic Provisions [9] which is similar to the recommendation of SAC committee [10]. The effects of panel zone strength, continuity plates and slot length are also investigated for this new connection. The results are compared with RBS and SBW connections.

2. Analytical study of the SWRF moment connection

An analytical study is conducted on the slotted web–reduced flange (SWRF) connection to investigate the cyclic non-linear behavior of the connection and to find the moment–rotation curves and critical locations of stresses. Subassemblies with a general configuration as shown in Fig. 1 are considered for analyses. Each subassembly consists of an IPE300 beam and an HE200B column, which are rolled European sections. The column is supported at the base by a hinge, while a vertical roller is used at the other end. The beam flanges are laterally braced at a distance of 150 cm from the column face. This distance satisfies the AISC seismic provisions [9] recommendation. Nonlinear material behavior is considered in all analyses.

Nine specimens of SWRF connection are analyzed. The PZ effects are considered by varying the PZ thickness. Three cases of weak, balanced and strong PZs are analyzed. The continuity plates are also added to the 3 PZ cases above to examine their contribution. Four different web slot lengths are also considered. The details of these subassemblies are described in sections to follow.

2.1. Panel zone variation

The IPE300 beam and the HE200B column are pre-selected so that they can produce a weak column panel zone (PZ) at the intersection. Further, for evaluating the effect of PZ thickness, the column web in some specimens is reinforced with 6 and 10 mm thick doubler plates in order to provide balanced and strong PZs, respectively. The three specimens analyzed are shown in Table 1.

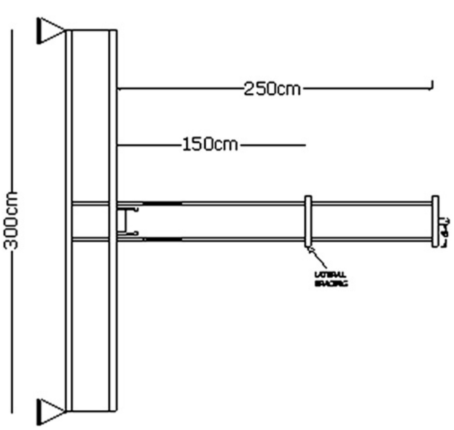

Fig. 1. Subassembly model of SWRF connection.

Table 1
Details of SWRF specimens.

Specimen	Column section	Beam section	Doubler plate thickness (mm)	V_y (kN)	V_r (kN)	V_r/ V_y
Weak	HE200B	IPE300	0	337.5	404.6	1.20
Balanced	HE200B	IPE300	6	517.5	404.6	0.78
Strong	HE200B	IPE300	10	637.5	404.6	0.63

To determine the required strength (V_r), and the design shear strength of the panel zone (V_y), the recommendation of AISC Seismic Provisions [9] are used. They are computed as follows:

$$V_y = 0.6F_y d_c t_{pz}\left(1 + \frac{3b_{cf}t_{cf}^2}{d_b d_c t_{pz}}\right) \quad (1)$$

$$V_r = \beta_E M_P\left[\frac{1}{0.95d_b} - \frac{L_b + \frac{d_c}{2}}{L_b}\cdot\frac{1}{H}\right] \quad (2)$$

in which F_y = yield stress of the PZ material; M_P = plastic moment capacity of the beam section; L_b = beam length from the column face to the beam tip; and H = column height. Dimensions d_c, d_b, b_{cf}, t_{pz} and t_{cf} correspond to column depth, beam depth, column flange width, panel zone thickness and column flange thickness, respectively. In Eq. (2), $\beta_E M_P$ is the flexural demand imposed at the column face. The suggested value of β_E is between 0.85 and 1[11]. Here, β_E = 0.85 is used throughout. These are calculated in Table 1 for the three PZ varying specimens.

2.2. Continuity plate variation

In addition to the panel zone strength, the effects of continuity plates are investigated on the seismic performance of the SWRF connection. In analytical models with continuity plates, the plate thickness is set equal to the beam flange.

2.3. Details of RBS region

The radius cut shown in Fig. 2 was employed for the RBS region. The RBS connections are detailed according to the recommendations of AISC 358 [12]. The dimensions used are shown in Table 2.

2.4. Details of web slots

The beam web slot is designed according to recommendations of reference [4]. Four slot lengths, as shown in Table 3, are used in analyses. In normal cases, the length of slot is 175 mm (LS2) according to the design procedure for this type of connection [4]. However, various lengths for web slots are considered to examine the effects of this parameter. These lengths are shown in Table 3 and correspond to slots extending to the end of shear plate (LS1), to the middle of beam flange reduced section (LS3) and to a distance away from the reduced section (LS4).

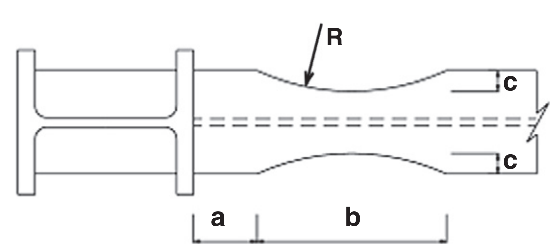

Fig. 2. RBS connection detail.