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Promotion of cyclic behavior of reduced beam section connections restraining beam web to local buckling

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ABSTRACT

This paper is to find out a convenient method to mitigate buckling severity in the beams with reduced beam section (RBS) connections. A new detail was proposed to enhance the RBS performance by delaying beam buckling. The efficiency of the proposed detail was investigated by a large scale laboratory testing under cyclic loading. The results showed that the proposed RBS connection had superior performance as compared with the conventional one. The proposed detail increased plastic rotation capacity of the conventional RBS connection by 40%. Moreover, some numerical and analytical analyses were provided to better justify how the proposed detail works.

1. Introduction

The novel cyclic behavior of the reduced beam section (RBS) moment connections has been verified by a variety of experimental and numerical research. Most of the laboratory specimens exceeded a minimum plastic rotation of 0.03 rad prescribed in the design codes [1–6]. However, there are two features that necessitate more attention

(a) According to the performance-based design method [7], the RBS frames should provide a plastic rotation of 0.03 rad for Life Safety (LS) level. While, as shown in the next section, the minimum plastic rotation needed for Collapse Prevention (CP) level is 0.045 rad, approximately. Satisfying this provision is of more importance in the Maximum Probable Earthquake (MPE) level [7]. However, the plastic rotation of 0.045 rad has rarely been reported for RBS connections.
(b) The laboratory RBS specimens had mostly undergone excessive out-of-plane deformation before reaching the required inelastic ductility [8–10]. The out-of-plane deformation is due to the web local and lateral modes of buckling followed by the flange local buckling. The severe beam buckling may also result in the column twisting especially for deep columns [11,12]. Although the notable out-of-plane deformation is a ductile mode of failure by itself, it can cause brittle fracture due to the subsequent secondary stresses. Moreover, the significant residual deformation that remained in the members after a severe excitation may bring the structural post-earthquake serviceability into question. The undesired excessive deformation in the beams and columns increases dramatically the cost of post-earthquake retrofitting process.

Consequently, some researchers have made effort to mitigate the buckling severity of the beams with RBS connections. Yu and Uang [5] investigated the effect of providing extra lateral bracing near the RBS region. Their study showed that the lateral bracing reduced the rate of strength degradation, resulting in more plastic rotation capacity. Uang and Fan [9] studied the effect of floor slab on the behavior of the RBS connections. They concluded that the floor slab increases the strength and the rotation capacity of the RBS beams under positive bending. However, under negative bending, the slab does not provide efficient bracing to the beam bottom flange. Lee [13] tested the behavior of RBS connections reinforced by vertical ribs. The reinforcement can diminish the stress concentration at the beam-to-column weldment. The use of RBS including void in the web [14] or corrugated web [15] is still in its early stages.

This paper aims to assess the ability of RBS connections to behave in a sufficiently ductile fashion that they may be used for steel frames in high seismicity regions. A new detail was proposed to enhance the RBS performance by delaying the beam web local buckling. In this method the beam web within the RBS region was

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strengthened by two added plates to protect it against local buckling.

A large scale laboratory program was set up to investigate influence of the proposed detail on the behavior of the conventional RBS connections. The test results are reported in detail to compare the performance of specimens with the conventional and the proposed RBS connections. The results verified effectiveness of the proposed detail.

Thereafter, a numerical study was conducted to gain more insight into how the added plates affect performance of a beam with RBS connection. The numerical results were in agreement with the test data. Finally, the results of the simplified stability analysis developed in this paper may be used to quantify efficiency of the added plates.

2. Description of the objective

This research was primarily outlined to promote the seismic performance of an existing moment frame. For this purpose, the frame was specified to satisfy the LS performance due to the normal seismic hazard level (known as DBE in Ref. [7]), and the CP performance due to a higher seismic hazard level (known as MPE in Ref. [7]). The existing frame included two typical fully welded moment connections as shown in Fig. 1. Previous observations confirmed that the existing connections were not able to meet the minimum plastic rotation specified in FEMA356 [7]. Two strategies were chosen to modify the connections performance

(a) Trimming off the beam flanges to reform the existing connections to the RBS ones, as shown in Fig. 2. The advantages and disadvantages of this type of connection are mentioned in Introduction. This connection was not supposed to satisfy the requirements needed for the CP-leveled structures in higher seismic hazard levels. The minimum plastic rotation specified in FEMA356 [7] for CP level is 0.05–0.000012 d_b (d_b is the beam depth in mm) for RBS connections. This value equals, approximately, 0.045 rad for the current case. Accordingly, the second strategy was proposed.

(b) Using a new detail to delay the beam instability: In the new detail, two extra rectangular plates were added to the beam web within the RBS region to postpone out-of-plane deformation. These plates were attached to the beam web with four high strength bolts. The long-slot holes were provided in the added plates, while the standard ones in the beam web. The slot holes were directed along the beam longitudinal axis to avoid increasing of the web in-plane resistance (Fig. 3). In addition, to make more adequate attachment between the added plates and the beam web, a plug welding was used at the center of each plate. Since the plug welding was placed on the neural axis of the beam section, no increase of the in-plane resistance of the web was expected.

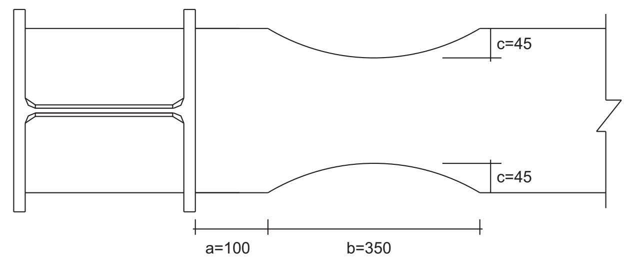

Fig. 2. RBS geometry.

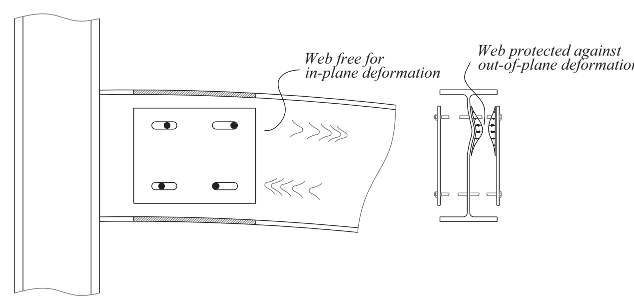

Fig. 3. Performance mechanism of the added plates.

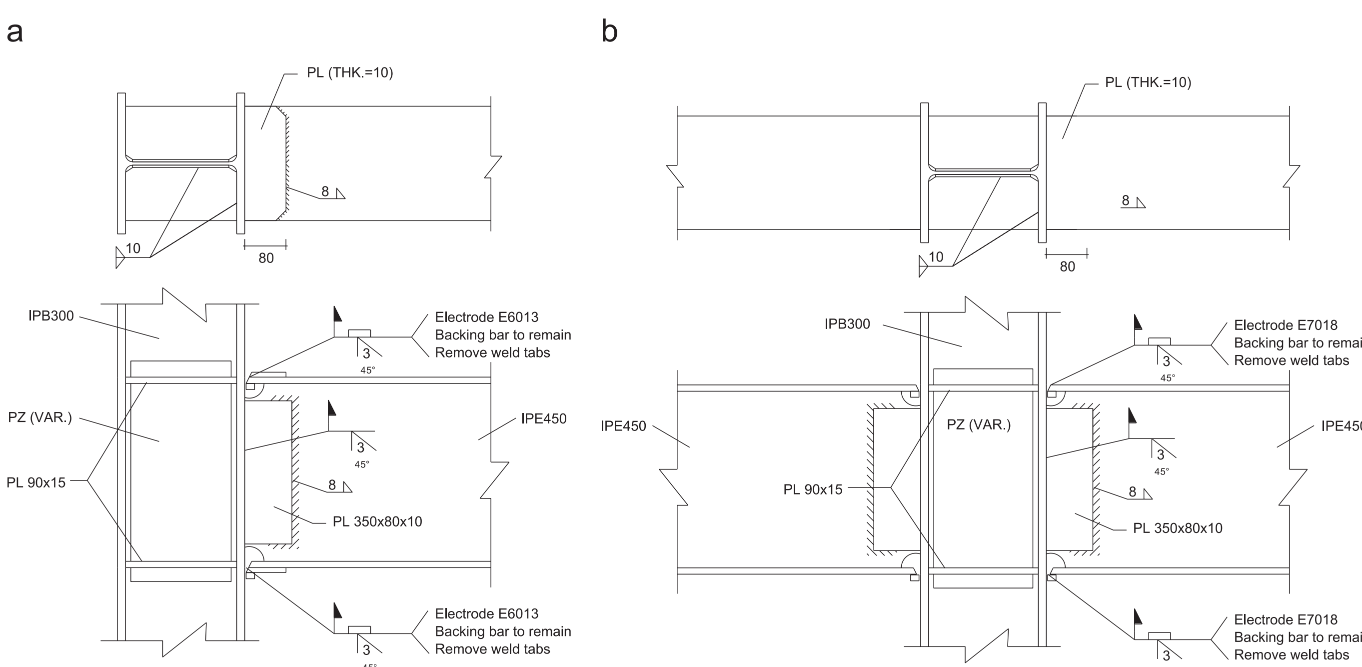

Fig. 1. Typical existing connections: (a) exterior connections and (b) interior connections.