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Seismic evaluation and upgrading details of plate-reinforced moment-resisting connections

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ABSTRACT

The seismic performance of cover-plate and flange-plate moment connections was evaluated experimentally and analytically in the first phase of the project. Welded flange-plate (WFP) connections met AISC requirements for special moment frames (SMFs); however new constructional detailing was proposed for failed welded cover-plate (WCP) connections and examined experimentally and analytically in the second phase of the project. Eight full-scale tests and 218 numerical finite element (FE) models including joints with unequal beam depth on both sides of the column were studied in this paper. Experimental evidences revealed that relative displacement between cover-plate and beam flange resulted from simultaneous buckling of the bottom beam flange and web, which led to an unfavorable failure mode of bottom flange fracture of the deep beam. The effects of reinforcing plate geometry on the behavior of connections were evaluated in an analytical study and acceptable geometrical limits of reinforcing plate were suggested. Based on crack potential assessment of analytical researches, WCP connections had, on average, up to 63% greater fracture potential at the intersection of the plate end and bottom flange of the beam than WFP connections. In addition, the results confirmed the design suggestions of FEMA-355D and FEMA-350 reports for plate-reinforced connections and made it possible to make some recommendations for new welding detailing and limits for reinforcing plate geometry as well as some suggestions for the case of unequal beam depth to remove the observed unfavorable failure mode and modify WCP connections. Finally, the design procedure for the modified WCP connections was presented.

1. Introduction

Plate-reinforced connection is a type of the moment-resistingconnections. In this connection type, the beam is joined to the flange of the column with top and bottom plates (Fig. 1). Plate-reinforced connections are divided into two types: welded flange-plate (WFP) and welded cover-plate (WCP). In the WFP type, only the plate is welded to the flange of the column by a single-bevel-groove weld, and in the WCP type, both the beam flange and the plate are attached to the flange of the column. The advantages of these connection types are that the stress demand at the column face is reduced and the location of the plastic hinge is moved from the weld lines [1]. In the erection phase of these connection types, greater margins of tolerance of beam length can be considered and a feasible fabrication choice for contractors can be prepared (WFP connections).

Numerous studies of plate-reinforced connections have been performed by SAC joint venture and AISC research teams [2–6] and have been considered as basic references of the FEMA-350 [7] prequalification report and the FEMA-355D connection performance report [8]. Based on FEMA-350 [7], only welded/bolted flange-plateconnections were prequalified, while cover-plate connections were rejected due to observations of undesirable fractures through the beam at the beginning or end of the cover-plate [8]. However, according to some successful experiments, FEMA-355D [8] proposed design guidelines of WCP connections like the prequalified WFP connections of FEMA-350 [7]. Meanwhile, bolted flange-plate connections [9] are still permitted by the relevant connection code, that is, AISC 358–16 [10].

It should be considered that the increased seismic demand of the connection due to new seismic code requirements [10] leads to use flange-plate of WFP connections with large thickness (sometimes >60 mm) and may result in lamination of flange-plate in welding process. In the case of WCP connection, the beam flange is connected to the column flange and the beam flange contributes to the load transferring system accompanied by the load transferred through cover-plate and it can reduce the cover-plate thickness. Meanwhile, greater flange-plate thickness increases the weld volume and results in extending heat affected zone and increases the chance of connection fracture in WFP connection of deep beams. Reducing thickness of the cover-plate by applying modified WCP connection instead of WFP connection,

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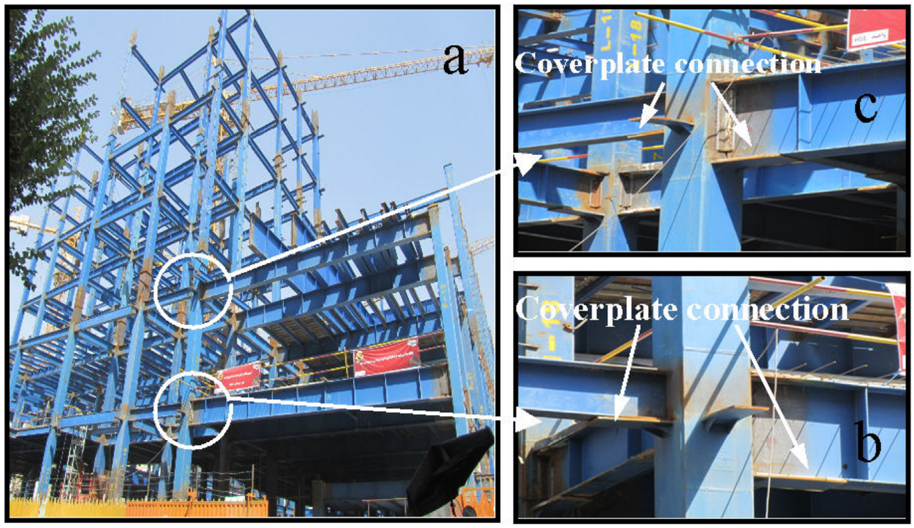

Fig. 1. (a)A shopping complex under construction in Tehran; (b)and (c)interior columns with unequal beam depths and plate-reinforced connections.

decreases the chance of plate lamination and heat input of welding and finally leads to safer welding process. Furthermore, upgrading detail of WCP can be used for retrofitting program of existed buildings with usual WCP connections. Totally, using modified WCP, in order to improve the seismic performance of WCP or to retrofit existed buildings withWCP connections is justifiable compared to using WFP connection especially for the joint with high imposed seismic demand. Besides, plate-reinforced connections are the main choice for weak axis moment-resisting connections of beam-to-column joints [11,12].

Extensive research has been conducted in this area. Gholami etal. [13] experimentally showed the adequacy of WFP connections for use in special moment frames (SMFs). Jazany and Hashemi [14,15] experimentally evaluated the different detailing of plate-reinforced connections in the case of an actual fabrication with unequal beam depth. They evaluated a particular combination of a WFP connection and a bottom haunch connection to eliminate crack initiation on the bottom flange of a deep beam. Jazany etal. [16] analytically studied the effects of different detailing on WFP and WCP connections consisting of continuity plate configuration, flange-plate, cover-plate, and haunch connections [17]. They proposed better connection detailing to provide acceptable ductile behavior. Comprehensive studies about the retrofitting of plate-reinforced connections by T-stiffener and rib plates are available [18–20]. Moreover, some studies of the panel zone behavior of plate-reinforced connections have been performed [21,22]. Some researchers have tried to modify plate-reinforced connections. Ghafari etal. [23] developed seismic specifications for curved WFP connections. Saneei Nia [24] experimentally evaluated WFP connections with finger-shaped plates. Farrokhi etal. [25] experimentally modified plate-reinforced connections by using holes in plates and made them behave as the replaceable fuse of the connection system.

The present research aims to investigate the seismic behavior of WFP and WCP connections experimentally, to assess the unfavorable failure modes of connections, and to develop modified connections or to propose accepted structural criteria for common plate-reinforcedconnections. The presence of unequal beam depths on both sides of the column (Fig. 1) for simulating the real case of fabrication means that a complex detailing must be proposed for the connection. In the first phase of the project, a total of six full-scale experiments [14,15] including beams with unequal depth is considered. In addition, a companion parametric analysis is performed to assess the influences of the geometrical parameters of the reinforcing plates on the unfavorable failure mode of the connection by crack potential assessment. Then, in the second phase of the project, two improved specimens are designed and tested to examine the seismic performance of modified WCP connections.

2. Summary of the experimental investigation of the first phase

In order to evaluate the seismic performance of WFP and WCPconnections, six sub-assemblages for the case of interior columns andbeams with unequal depths were constructed and tested [14,15]. Fig. 2 shows a schematic view of the specimens and connection detail configurations. The welding details and connection types such as the WCP connection, WFP connection, and haunch connection are displayed in Fig. 2. Furthermore, the locations of strain gauges and displacement transducers (LVDTs) are indicated. The dimensions of the sections of the column flange and web were 25×1.5 cm^2 and 32×1 cm^2, respectively. The "deep beam" had section dimensions of the flange and web of 15×1.0 cm^2 and 48×1.0 cm^2, respectively. The"shallow beam" had section dimensions of the flange and web of 15×1.0 cm^2 and 28×1.0 cm^2, respectively. The connections were designed according to FEMA [7,8] and AISC [26,27].

Triaxial strain gauges (rosettes), uniaxial strain gauges, and displacement transducers (LVDTs) were utilized to measure the local nonlinear response of connections. For all specimens, some LVDTs were used to measure the relative deformation between the cover-plate and beam flange according to Fig. 3. Specimens were whitewashed to visually monitor the inelastic deformation of the yielded region during the experiment. In addition, six strain gauges were fixed to the bottom and top plates and the beam flange as depicted in Figs.2 and 3. The letters A, B, C, and D in Fig. 2 refer to the locations of the aforementioned strain gauges. In addition, they show the locations of the installed LVDTs for deep and shallow beams, respectively (see Fig. 3). The letters E and F refer to the locations of the installed strain gauges on the bottom cover-plate and flange of the deep beam, respectively. The quasi-static cyclic loading was applied in the experiments according to the AISC seismic provisions [27].

Fig. 2 specifies that dual/trapezoidal panel zone detailing and WCP, WFP, and haunch connection types are utilized in the construction of specimens, similarly to site fabrication. The specifications of each specimen are summarized in Table 1. Complete information about the test setup, specimen instrumentation, laboratory reaction frame, test geometries, and detailed hysteresis results can be found in references [14, 15]. A summary of the experimental results is presented in Table 1. Based on this table, the values of the story drift angle of failed specimens reach up to 4% rad before bottom flange fracture of the deep beam close to the end of the cover-plate. The dominant failure mode for this special