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Parametric study on moment–rotation characteristics of reverse channel connections to tubular columns

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ABSTRACT

The significance of this parametric study initiates from the need for further understanding of the behavior of semi-rigid/partial-strength I-beam to tubular column connections. This research attempted to gain a qualitative understanding of the influence of the geometrical configurations of reverse channel connections (RCC) on the moment–rotation (M-ϕ) response. Hence, ABAQUS (v.6.12) software was used to develop three-dimensional (3-D) FE models for thirty specimens. The FE models developed were validated against the experimental results available from literature where 268 FE models were used for sensitivity analysis. The main emphasis of this research was on the stiffness, strength, sources of deformability, rotational capacity and failure mechanisms of the RCC. All tests were able to achieve a rotational capacity beyond the minimum 0.03 rad, in most cases more than 0.06 rad and in one case reached 0.16 rad. For the same configuration of RCC, it was found that the channel wall thickness to the flush end-plate thickness ratio is the key to the rotational capacity of RCC. In addition, the deformability of the column face was mainly dependent on the ratio of channel depth to square hollow section (SHS) width and the minimum value of this ratio is recommended to be kept equal to 0.72.

1. Introduction

In recent years, changes in moment-resisting frame design practice have seen increased use of steel hollow sections as structural members instead of conventional open sections. This was partly due to their superior torsional rigidity and hence resistance to flexural-torsional and torsional buckling modes. In addition, when they are employed as columns in long-span steel structures, they can be designed to have similar strength and stiffness about each horizontal axis [1]. This popularity of steel hollow sections is also due to the numerous advantages they provide when compared to conventional open sections. For example; they typically have lower-surface area and lighter weight, which results in cost savings in painting, transportation to site and erection [2]. Being a closed section it is also more resistant to corrosion, particularly when exposed to severe weather conditions.

However, there are difficulties with the detailing of the connections, particularly when I-beams are connected to tubular columns in traditional structures. Accessibility problems seriously affect the use of widely known semi-rigid/partial-strength bolted beam to tubular column connections and current European steel design standards also lack guidance on these types of connections [3]. On the other hand, CIDECT provides design guidelines [4] and Eurocode 3 Part 1-8 [5] proposes rules for determining the resistance of beam-to-tubular column fully-rigid/fully welded connections [6].

The failure of welded connections (Northridge connections) in numerous steel moment resisting frames during the 1994 Northridge Earthquake raised many questions regarding the validity of the design and construction procedures used at that time. After the earthquake, a comprehensive research effort funded by the Federal Emergency Management Agency (FEMA) through the SAC Joint Venture contributed greatly to the understanding of the seismic behavior of steel moment resisting frames. As a result, practical design guidelines were published in a series of FEMA documents, which cover details of a number of pre-qualified connections. The pre-qualified connections are only for I-section (W) column since tubular (Box) columns were not considered because they were not very common in US design practice at that time [7]. The tubular column is the column-of-choice in Japanese steel building design practice [8] and [9]. The detailing of the connections and the design of Japanese tubular columns are sufficiently different from European practice. Hence, the necessity for more investigation on beam to tubular column connection behavior has encouraged researchers to find out suitable connection configurations and to ensure that they are feasible for practical application. Therefore, various types of connections were proposed either by fitting a structural section, such as, longitudinal plate, double angle, tee, reverse channel, top and bottom angle, to the tubular column face by fully welding or by employing blind-bolts with sleeves that expand inside the tube.

For the past few decades, extensive research had been carried out to understand the actual behavior of beam-to-tubular column connections

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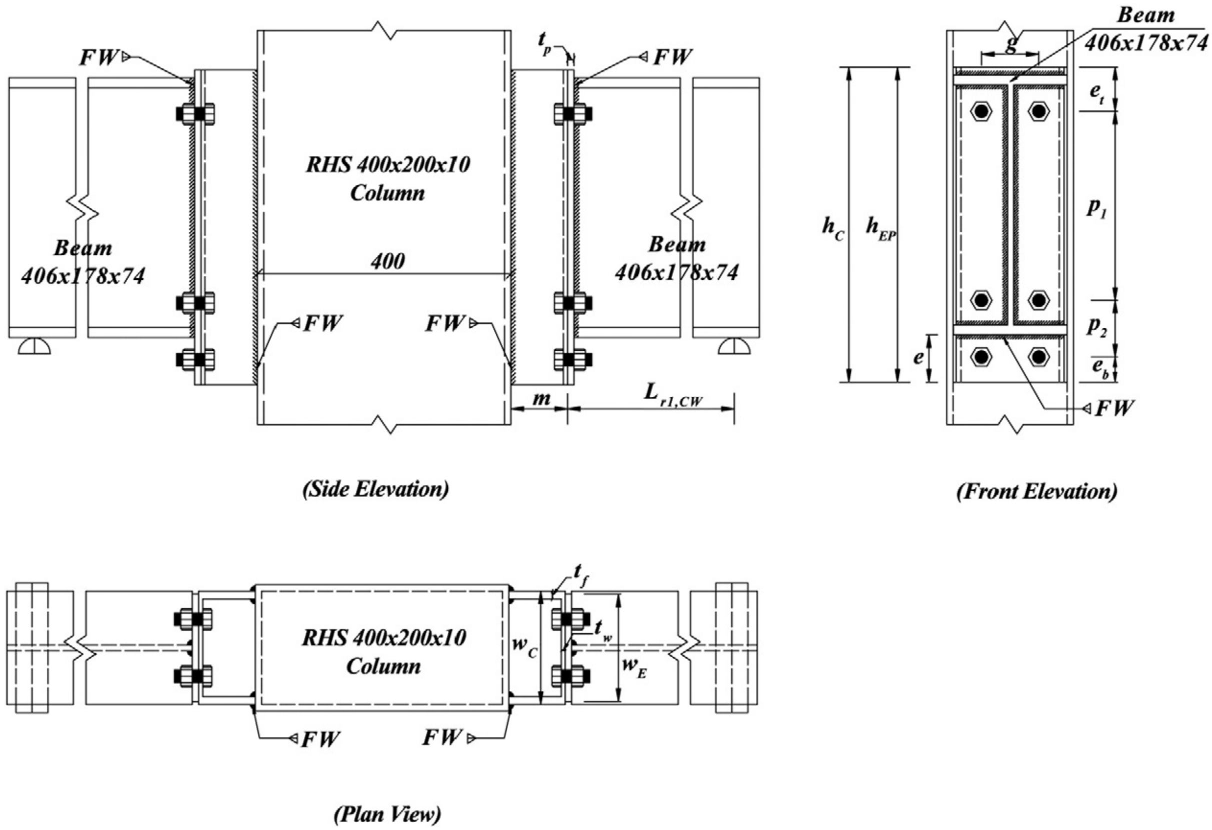

Fig. 1. Reverse channel connection geometries.

and to establish the moment–rotation relationship for the completeness of the new simplified analysis and practical connection design. The connection classification is mainly dependent on the moment–rotation characteristics.

In 2007, Ding and Wang [10] suggested the use of reverse channel connection (RCC) to connect I-beam to tubular column (Fig. 1), where the reverse channel is welded in shop to the tubular column, the flush/extended endplate is welded to the beam and the beam is connected to the reverse channel on site by using bolts. This assembly overcomes the difficulty of access to the internal face of tubular columns by giving access from inside of the channel. Since then numerous researches [3,6,10–18] have been carried out, which were mainly concentrated on the fire and earthquake resistance of RCC and very limited research on its basic structural behavior. The most relevant to this research is the work done by Wang and Xue [18] and [19]. They carried out a limited number of experiments on RCC where all the tested connections were able to reach a rotational capacity of at least 0.03 rad, commonly found to be sufficient for plastic design. They considered a number of parameters, such as, connection type (extended or flush endplate), reverse channel dimensions (thickness, width), orientation of the rectangular tube with or without concrete infill and their effect on the moment–rotation response of RCC. The mentioned parameters found to have significant effect on the connection stiffness, moment resistance and the rotational capacity. It was concluded that these connections can be designed to achieve semi-rigid/partial strength connections.

Nevertheless, there is still need for further investigation of the abovementioned parameters and additional geometrical parameters which may affect the behavior of RCC. Since experimental research is lengthy and expensive process for understanding such behavior then the availability of powerful computer facilities can be a suitable alternative for modeling structural behavior of complex and lengthy parametric studies [20–22]. Therefore, the finite element modeling was used to carry out the parametric studies based on computer simulation in this paper.

The main objective of this research is to capture and monitor the effect of the geometrical configurations of reverse channel flush end-plate connections on the moment–rotation (M-ϕ) relationship under

Table 1
Schedule of test specimens [18].

Test	Channel section	Endplate dimensions	Number of bolts	Dimensions (mm) (Fig. 1)														
	(S275)	(mm)		$L_{r1,CW}$	h_C	w_C	m	t_f	t_w	h_{EP}	w_E	t_p	e_t	p_1	p_2	e_b	e	g
1	180 × 90 × 26	500 × 10 × 170	12	810	500	180	90	12.5	6.5	500	170	10	70	300	90	40	75	90
2	180 × 90 × 26	500 × 5 × 170	12	600	500	180	90	12.5	6.5	500	170	5	70	300	90	40	75	90
3	180 × 75 × 20	500 × 10 × 170	12	825	500	180	75	10.5	6.0	500	170	10	70	300	90	40	75	90
4	150 × 90 × 24	500 × 10 × 170	12	810	500	150	90	12.0	6.5	500	170	10	70	300	90	40	75	90
5	180 × 90 × 26	440 × 10 × 170	8	600	440	180	90	12.5	6.5	440	170	10	70	300	–	70	15	90

Note: Beam Section (Grade S355, UB 406 × 178 × 74 (flange width 179.5 mm, overall depth 412.8 mm, flange thickness 16 mm, web thickness 9.5 mm)); Column Section (Grade S355, Rectangular Hollow Section (RHS) 400 × 200 × 10 mm) were used for all specimens.