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RHS beam-to-column connection with web opening—experimental study and finite element modelling

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Abstract

Rectangular Hollow Sections (RHS) have superior structural performance compared to conventional steel sections. However, the application of RHS in structural steel framework is limited because suitable connection configurations have not been developed between such members. Also adequate information on the moment–rotation characteristics of connections between RHS members is not available for design. To overcome these problems, a new and efficient connection is proposed which is easy to fabricate and convenient for erection. The connection employs channel connectors welded to the column flange and bolted to the beam to transfer beam flange forces into the column webs thereby avoiding the need to provide internal diaphragms in the column. An opening in the web facilitates the installation of bolts and can be used to pass service lines. The bolts are loaded in shear, so as to obtain improved performance of the connection under cyclic loading. By choosing suitable dimensions for the channel connectors, the strength and stiffness of the connection can be varied. The behaviour of the connection is evaluated by cyclic tests and non-linear finite element analysis. Test results are presented in the form of hysteretic curves and failure modes. In the case of channel connectors of high strength, failure occurs at the beam net section away from the face of the column, similar to beams with Reduced Beam Sections (RBS). It is shown that the connection has adequate ductility and hysteretic energy dissipation capacity. The moment–rotation characteristics of the connection can be expressed in terms of the three-parameter power model, for semi-rigid frame analysis.

Keywords: Rectangular hollow sections; Semi-rigid connections; Moment–rotation curves; Web opening; Cyclic tests; Non-linear analysis

1. Introduction

Rectangular hollow sections (RHS) are increasingly being used in steel framed structures due to their higher efficiency in resisting compression, bending, and torsion in comparison with conventional sections and also for architectural reasons. Due to the absence of outstands they are less susceptible to local buckling and so exhibit higher ductility and hysteretic energy dissipation capacities. This makes them particularly suitable for moment resisting frames designed to resist seismic loads. They also possess high strength to weight ratios resulting in lighter structures. RHS columns filled with concrete, popularly known as concrete filled tubes (CFTs), have also been widely used in high rise buildings. The frames with CFTs are light in weight and have high ductility and stiffness. However, the application of RHS in structural steel frameworks is limited because suitable connection configurations have not been developed between such members.

Although sufficient information is available on connections between I-beams and I-columns, very little research work has been done on connections between RHS beams and RHS columns. The current practice is to go for full penetration welds and for larger sections, diaphragms are inserted inside the column at beam flange levels. However, this involves considerable fabrication and cost and has the disadvantage of the field welds introducing potential zones for fracture under seismic loading. The use of bolts gives considerable tolerances in fabrication but conventional bolts require access on the inside to facilitate tightening of nuts. To overcome these problems, a new and efficient connection is proposed which is easy to fabricate and convenient for erection.

In the proposed connection, channel connectors are welded to the column and connected to the beam flanges by high strength friction grip (HSFG) bolts. The channel connectors

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transfer the beam flange forces into the column webs thereby avoiding the need to provide internal diaphragms in the column. An opening in the web facilitates the installation of bolts and can be used to pass service lines. The bolts are loaded in shear, so as to obtain improved performance of the connection under cyclic loading. The behaviour of the connection is evaluated by cyclic tests and non-linear finite element analysis. It is shown that the connection has adequate stiffness, strength, ductility and energy dissipation capacity. The moment–rotation characteristics of the connection can be expressed in terms of the three-parameter power model [1,2]. A parametric study of connection behaviour is presented in a companion paper [3] to facilitate the use of the proposed connection.

2. Review of literature

In view of the several advantages of RHS, some researchers initiated the use of RHS in columns only and carried out the experimental and analytical investigations on connections between I-beam and box-column sections. However, such information is still limited and in particular does not address the problem of connecting two RHS members.

White and Fang [4] carried out experimental investigations on the behaviour and performance of different types of I-beam to box-column top and seat angle connections, using a combination of welding and bolting. They observed that although web cleat connection suffered significant deformation of column flange, the top and seat angle connection behaviour did not depend on the width-to-thickness ratio of the column flange.

Ting et al. [5] presented the results of finite element analysis of I-beam to box-column connections with beam width less than the column width. The connections were stiffened externally with triangular plate stiffeners, angle stiffeners and T-stiffeners. The results indicated that the connections with external T-stiffeners were the most efficient form as they redistribute the stresses more effectively and enhance the stiffness of the connection. They concluded that for effective transfer of stresses to the side walls of the column, the combined width of beam flange and stiffeners at the joint should be equal to the width of the column to allow the transfer of stress to the column side walls. The optimum length of the stiffener which results in minimum stress levels was also derived.

Shanmugam et al. [6] carried out experimental investigations on the cyclic behaviour of I-beam to box-column connections stiffened internally using continuity plates and externally with T- or angle stiffeners. The load–displacement hysteretic loops were found to be stable and connections exhibited ductility values ranging from 5.1 to 10.7, which were considered to be adequate. They concluded that performance of the connection with T-stiffeners was better than the connections with internal continuity plates and external angle stiffeners. The failure modes of the tested specimens were fracture of the welds at joints, excessive yielding of stiffeners followed by buckling of either the column web or beam flange at the joint. They also pointed out that plate slenderness of column webs was

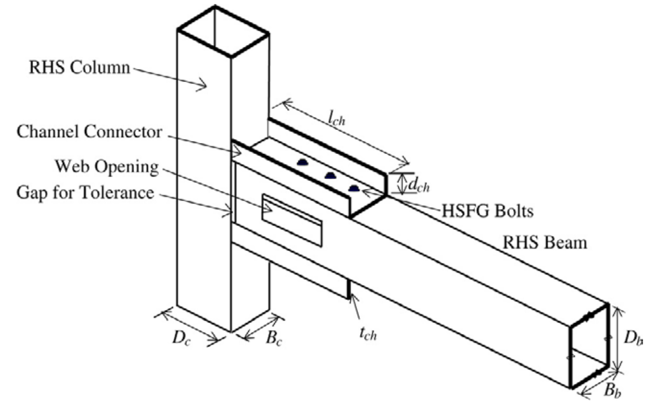

Fig. 1. Proposed RHS beam-to-column connection.

an important parameter affecting connection performance. Another study [7] carried out on interior connection also yielded similar results.

Korol et al. [8] carried out experimental investigations on the performance and failure modes of extended end plate, high-strength, blind-bolted moment connections between I-beams and box-columns, to overcome the problem of lack of access inside the hollow column section to tighten the nut. The specimens were tested under monotonic loading. It was found that the behaviour of the proposed connection was similar to the connection using A325 bolts and possesses good stiffness, moment capacity and ductility.

Wheeler et al. [9,10] reported test results and analysis of connections between RHS using an end plate and pretensioned bolts. The connections failed by tensile bolt fracture or excessive deformation of the end plate.

3. Proposed connection and connection performance

The proposed connection between an RHS Beam and an RHS Column is as shown in Fig. 1. The essential features of the connection are two channel connectors, of uniform thickness, welded to the column in the fabrication shop. These channel connectors transmit the stress resultants of the beam flanges to the column webs by shear-lag action. Rectangular openings were provided in the beam webs so as to allow bolting between the beam flange and the channel connector. Adequate tolerance and end clearance can be provided between the beam end and the column face to facilitate erection. The beam can be erected between two such connections by lowering it to the required level and rotating in plan, to get the required alignment. The main considerations in deciding the size of the opening and the channel connectors are that the connection should attain an ultimate moment close to the full-plastic moment of the beam and the failure modes like shear failure, of the channel connector or of bolts, should be avoided. Connections with HSFG bolts subjected to shear only are known to perform better under cyclic loading.

4. Cyclic tests on connections

The primary objective of the tests was to obtain the moment–rotation characteristics and also to validate the finite