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An experimental study on a novel cold-formed steel connection for light gauge open channel steel trusses

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ABSTRACT

This paper describes an experimental investigation on a novel hollow connector, to be referred to as the Howick Rivet Connector (HRC). The HRC is of diameter of 12.75 mm and thickness of 0.95 mm and can be used to connect cold-formed steel channel-sections with a gap, such as found in the connection arrangement of cold-formed steel trusses and seismic framing units. Laboratory tests on twenty-seven Tee-stub specimens that use the HRC are described; for comparison, another twenty-seven Tee-stub specimens are also tested that use standard bolts. In the laboratory tests, the effect of three different thicknesses of channel-sections and three different end distances are investigated. It is shown that the behaviour of the HRC Tee-stubs is similar to that of the bolted Tee-stubs, but possess a higher capacity and an improved ductility, as shown by a longer yield plateau once the connection becomes inelastic. It recommended that a minimum end distance of 1.5 times the diameter of the HRC is sufficient. Design equations that can be used to predict the bearing strength of the HRC Tee-stubs are proposed; for these equations, the index of reliability calculated was greater than the recommended 3.5.

1. Introduction

The Howick Rivet Connector (HRC) (see Fig. 1), is a novel hollow pinned connector conceptualised and developed by Howick Ltd., New Zealand. It has been developed with objective to overcome two problems commonly associated with cold formed steel connections; a low proportionality limit due to slip, tilting or bearing, and limited post peak strength and stiffness. An initial HRC size, with outside diameter of 12.75 mm and wall thickness of 0.95 mm has been developed for experimental testing to determine its behaviour, modes of failure and load carrying capacity. The experimental testing presented in this paper is based on that size of HRC and different thickness members being connected, so as to determine the characteristics of the HRC with connected members of different thicknesses. It is intended that a wider range of sizes be developed, based around the rules established for this size, with testing of the upper limit sizes to determine the consistency of behaviour across the proposed HRC size range and wider testing if the behaviour is found not to be consistent. The HRC is used to connect open cold-formed steel channel-sections through their flanges, as shown in Figs. 1 and 2, such as found in the connection arrangement of cold-formed steel trusses and seismic framing units.

Figs. 1 and 2 show details of the typical connection arrangement for the HRC. As can be seen, the HRC is a hollow steel tube, with two inner swaged collars, that can be placed in the gap between the channel-sections. Each HRC can connect either 1 or 2 web members to a chord member. In the internal connection of a web to chord member for a Warren truss, either one connector is used to connect two web members to the chord member, or two separate connectors are used, each connecting one web member to the chord member. While the latter case is easier to install, the eccentricity between the adjacent HRC connectors inputs shear and bending moment into the truss chord, reducing the truss stiffness in the elastic range.

Testing of the first series of short span trusses that use the HRC has previously been described by Mathieson [1]. The failure modes observed were 1) bearing of the plies and 2) shear failure of the HRC. Both were ductile, with good post peak retention of strength and stiffness and a high proportionality limit.

During installation of the HRC, the outer swages are formed by pressing using a proprietary tool, also designed and manufactured by Howick Ltd. The HRC shank undergoes outward expansion, which results in a bearing fit between the shank and the holes of the connected plies. The HRC was developed for use in steel trusses and the initial size

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Nomenclature

C	bearing constant;
C_{HRC}	bearing constant proposed for HRC;
C_P	correction factor (5.7) (see Clause F1.1 (c) of AISI S100 [7]);
$C_ø$	calibration coefficient (LRFD, 1.52) (see Clause F1.1 (c) of AISI S100 [7]);
C_{Yu}	bearing constant proposed by Yu and Panyanouvong [2];
d	diameter of fastener;
d_{bolt}	diameter of bolt;
d_{HRC}	outside diameter of HRC;
e	natural logarithmic base;
e_1	end distance;
F_m	mean value of fabrication factor (1.0) (see Table F1 of AISI S100 [7]);
F_u	tensile strength of ply;
m_f	modification factor for type of bearing connection;
M_m	mean value of material factor (1.1) (see Table F1 of AISI S100 [7]);
n	number of shear planes;
$P_{b,AISI}$	bearing strength in accordance with AISI S100 [7];
$P_{b,HRC}$	bearing strength proposed for HRC Tee-stubs;
$P_{b,Yu}$	bearing strength proposed for bolted Tee-stubs without washers by Yu and Panyanouvong [2];
P_{EXP}	experimental peak load;
P_m	mean value of tested-to-predicted load ratio;
P_{mEXP}	mean experimental peak load;
t_{ply}	base metal thickness of connected plies;
$t_{ply.nom}$	nominal thickness of connected plies;
t_{HRC}	base metal thickness of HRC;
V_F	coefficient of variation of fabrication factor (0.15 for HRC and 0.05 for bolt) (see Table F1 of AISI S100 [7]);
V_M	coefficient of variation of material factor (0.10 for HRC and 0.08 for bolt) (see Table F1 of AISI S100 [7]);
V_P	coefficient of variation of tested-to-predicted load ratio;
V_Q	coefficient of variation of load effect (LRFD, 0.21) (see Clause F1.1 (c) of AISI S100 [7]);
$ø_b$	resistance factor for bearing (0.6) (see Clause E3.3.1 (c) of AISI S100 [7]);
β	index of reliability;
η	variation of experimental results.

developed is designed to be used to connect channel-sections of thickness between 0.75 mm and 1.15 mm. Under shear, the inner and outer swaged collars restrain the plies against outward movement.

Laboratory tests on a similar connection arrangement with a gap, but using a bolt instead of the HRC, have previously been described by Yu and Panyanouvong [2]. Compared with such a bolted arrangement, the advantages of using the HRC include:

1. Slip of the connection at low levels of loading is eliminated due to the HRC installation process, raising the proportionality limit.
2. Deformation of the rivet in shear that generates stable behaviour and better retention of load in the post elastic range.
3. Restraint against lateral movement of the truss flanges is provided by both inner and outer swaged collars.
4. Reduced labour and material costs. As the HRC is one component, installation and tightening of nuts and washers are not required. Less steel is also required in the connector as the HRC is hollow. Offsetting these savings to some extent is the cost of manufacturing the HRC connectors, however when this process is fully automated the production unit cost will be comparable to that of a bolt.

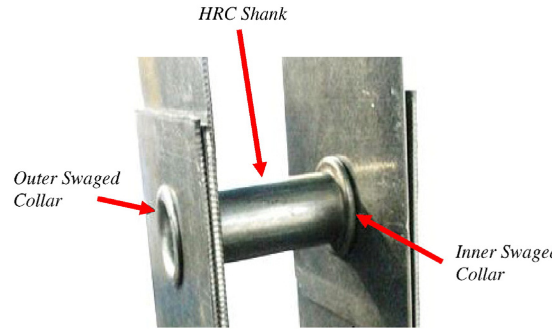

Fig. 1. Photograph of HRC.

Furthermore, when compared with other cold-formed steel novel forms of connection, such as press-joining [3], self-piercing rivets [4], and the Rosette connection [5] (see Fig. 3), the HRC results in a concentric connection.

This paper quantifies the performance of the HRC based on the testing undertaken and generates the necessary information on which to develop larger sizes and thicknesses. Twenty-seven HRC Tee-stub specimens have been tested in the laboratory to determine the failure modes of the connection and the strength/stiffness in the elastic and the inelastic range. For comparison, twenty-seven bolted Tee-stub specimens have also tested. These bolted Tee-stub specimens differ slightly from the arrangement of Yu and Panyanouvong [2] in that outer washers are used; no inner washers or inner nuts are used. The plies therefore remain free to move laterally inwards, as with Yu and Panyanouvong (see Fig. 4). For the case of the HRC, this lateral movement is prevented by the inner swaged collar. In the laboratory tests described, three different thicknesses of channel-sections were used: 0.75 mm, 0.95 mm and 1.15 mm. The effect of three different end distances has also been investigated.

2. Experimental investigation

2.1. Test specimens

Fig. 5 shows general details of the Tee-stub tests. Both chord and web members are assembled from identical channel-sections with nominal dimensions of 45 mm × 65 mm × 10 mm, which refer to the web depth, flange width and lip depth, respectively. The HRC was of diameter of 12.75 mm and thickness of 0.95 mm. Fig. 6 presents the specimen labelling convention. As can be seen, the test specimens are separated into HRC and bolted tests.

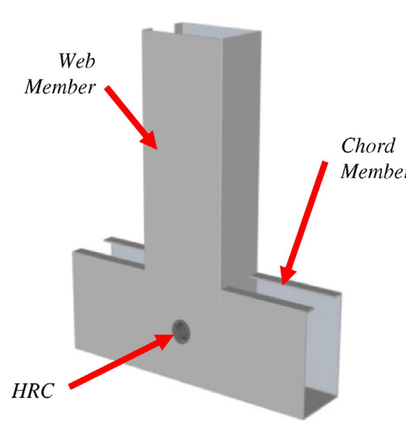

Fig. 2. Chord and web members connected by HRC.