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Behaviour of welded T-end connection to rectangular hollow section (RHS) in axial tension

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Abstract

This paper presents the results of an experimental investigation of the behaviour of T-end connections welded to rectangular hollow section (RHS) members subjected to axial tension. A total of 19 specimens were tested to failure. Parameters considered for the investigation were the tube size and the cap plate thickness. The cleat plate thickness was kept constant for all tests. The cleat plate orientation relative to the tube was investigated and was found to affect the joint strength. There was evidence of shear lag taking place. The test results also revealed that the use of very thick cap plates (more than 20 mm) does not lead to increased joint capacity. The yield line analysis was used to predict the failure loads and a comparison is made with the test results.

Keywords: Connection; Hollow section; Cap plate; Strength; Modes of failure

1. Introduction

Structural Steel Hollow Section (SSHS) members are known to possess many advantages over equivalent open sections, including better resistance to torsion as well as tension and compression loading, aesthetic appearance and economy in terms of material cost [1]. Connections between SSHS members could be made simple by cutting the ends and welding together. However, depending on joint configuration and number of members connected, this may result in complex and expensive connections. The alternative would be to connect the members together through some other means. Fig. 1 shows the details of types of end connection for hollow tubes that are used in practice. One of the most economic solutions is to weld a cap plate to the tube and then weld on to it a cleat plate (Fig. 2). The connection could be made entirely in the workshop, thus reducing labour work on site and cost.

In the UK there is very little guidance on the design of welded T-end connections. Elsewhere, research work was mainly carried out by Kitipornchai and Traves [2], Stevens and Kitipornchai [3], and Granstrom [4]. Syam and Chapman [5] attempted to develop design models for T-end connections, as well as for other types of structural steel hollow section connections. Packer and Henderson [6] produced a design guide in which design guidelines are given for T-end connection to a tube and gusset plate.

The absence of design recommendations very often leads designers to specify uneconomical solutions. Research has shown that welded T-end connections subjected to uniform tension may fail in different ways [2]. The failure mode is dictated by parameters such as tube wall thickness, cap plate thickness, cleat plate thickness, and weld quality and size.

The possible resulting modes of failure are: (i) Tube yielding; (ii) Local fracture in tube (in the region adjacent to weld); (iii) Fracture of the weld; (iv) Yielding of the cap plate; (v) Shear failure of the cap plate; (vi) Yielding of the cleat plate. A combination of more than one mode of failure is also possible. In a truss environment, commonly in lateral wind bracing members of steel frames, when the connection forms part of the truss assembly and where the cleat plate is bolted to a gusset plate, other modes of failure are also possible.

2. Specimen properties and experimental programme

The testing programme included 19 specimens with varying tube walls and cap plate thicknesses. A universal testing machine with a capacity of 500 kN was calibrated by independent

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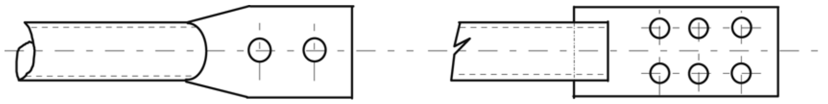

Fig. 1. Types of end connections.

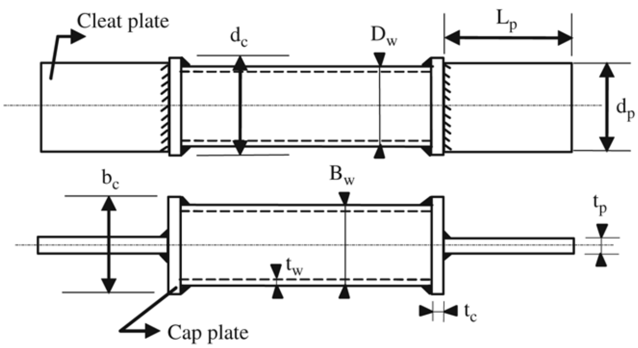

Fig. 2. Welded T-end connection and parameters' definition.

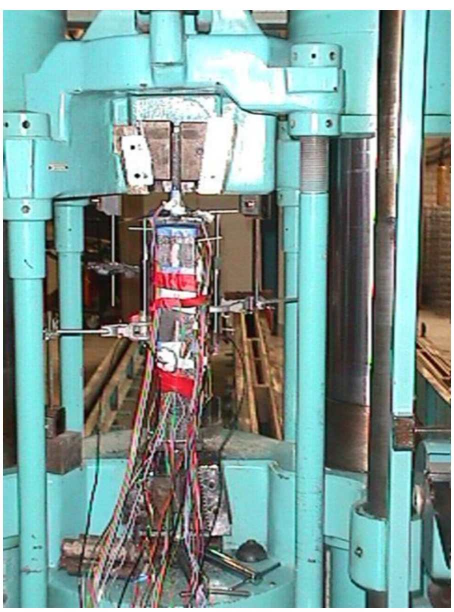

Fig. 3. Testing machine with specimen set-up.

licensed consultants externally, and was used for the testing of the connections. A tensile load was applied in increments of 10 kN up to failure. Strains and deformations were recorded for each load increment (Fig. 3).

Four RHS tube sizes of nominal dimensions 60 × 60 × 4.0; 80 × 80 × 4.0; 60 × 40 × 4.0; and 80 × 40 × 4.0 were chosen for the test series. Tubes of one size were cut from the same stock length, each 500 mm long. All tubes used for making the specimens were of hot-finished steel Grade S355J2H to BS EN10210-1 [7] specification. The plates used for the end and cap plates were of steel Grade S355JR to specification BS EN10025-1 [8]. Tensile testing on samples of the material used in the experimental work was carried out in order to determine Young's modulus, E, the yield and ultimate stress values. The tensile test involved straining a test sample to fracture in order to determine its mechanical properties. Test pieces were obtained by machining samples from an off-cut taken from the same batch of steel used to make the specimen. The samples were tested in accordance with BS EN 10002-1 [9]. The quality and type of weld used received a lot of attention in the preparation of the specimens. All welds were fillet weld with a throat thickness of 10 mm, and were carried out externally by a certified welder to BS EN ISO 15614-1 [10].

The specimens were loaded in axial tension, taking all necessary precautions to avoid accidental eccentricity, with strain and deformation measurements being recorded. The programme of the tested specimens is summarised in Table 1 (read in conjunction with Fig. 2). The values shown in Table 1 are measured values. In order to keep the investigation manageable, one cleat plate thickness was used and kept equal at $t_p = 15$ mm for all specimens. The length of the cleat plate was also kept constant at $L_p = 150$ mm for all specimens.

For specimens with a 'true' rectangular cross-section, i.e. not square (specimens 12, 13, 14, 15, 16, 17, 18, and 19), two arrangements of the cleat plate were adopted. For specimens 12, 13, 14, and 15, the cleat plate was placed parallel to the longer side of the tube. However, for specimens 16, 17, 18 and 19, the cleat plate was placed parallel to the shorter side of the tube. See Table 1.

The test programme was devised to concentrate on the yielding of the tube wall and the deformation of the cap plate as these were found to be the main causes of failure [3]. Strain gauges (SGs) were located on the tube wall (four faces), the cap plate, and the cleat plate with the aim of closely monitoring strain (and stress) variations across the specimen. LVDTs were used to give readings of the deformations and monitor in-plane and out-of-plane movements. LVDTs 2, 3, 4, and 5 gave axial displacement readings of the tube through steel brackets that were glued onto the tube and cap plate as shown in Fig. 4. LVDT 1 was placed at the movable bottom base of the testing machine.

The strain gauges were kept far enough from welds in order to avoid any influence from the residual stresses on the readings. The total length of the tube is sufficiently long (500 mm in this case), again for the same reason. Strain gauges were placed on opposite sides so that in-plane and out-of-plane bending moments could be monitored and calculated. In total, 12 strain gauges and 5 LVDT devices were used to monitor the joint behaviour and obtain the necessary information. The LVDT devices used for testing were calibrated using slip gauges.

3. Experimental results and discussion

Examination of output from the LVDTs and SGs placed on the sides of the tube to monitor in-plane and out-of-plane displacements, revealed that these were negligible and