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EXPERIMENTAL INVESTIGATION OF WELDED T-END CONNECTION TO CIRCULAR HOLLOW SECTION (CHS)

ABSTRACT

This paper presents the results of an experimental investigation into the behaviour of welded T-end connections to circular hollow section (CHS) members subjected to axial tension. A total of 22 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 finite element analysis was used to predict the failure loads and comparison is made with the test results.

Keywords: Connection, Tubular, Welded, Failure, Experimental

INVESTIGATION EXPERIMENTALE DES JOINTS SOUDES EN T A SECTION CREUSE CIRCULAIRE

RESUME

Cet article présente les résultats d'une recherche expérimentale sur le comportement des connexions T-end soudées à profil creux circulaire (CHS) des éléments soumis à une traction axiale. Un total de 22 échantillons ont été testés jusqu'à défaillance. Paramètres pris en compte pour l'enquête ont été la taille du tube et l'épaisseur de la couronne. L'épaisseur de la plaque cale a été maintenue constante pour tous les tests. L'orientation de la plaque cale par rapport au tube a été étudiée et a été retrouvé d'affecter la résistance du joint. Il y avait des preuves de retard de cisaillement en cours. L'analyse par éléments finis a été utilisée pour prédire les charges de rupture et comparaison est faite avec les résultats du test.

Mots-clés: Connexion, Tubulaire, Soudée, Expérimentale

1. INTRODUCTION (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 (CIDECT 1984). 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. One of the most economic solutions is to weld a cap plate to the tube and then weld on to it a cleat plate (Figure 1). The connection could be made entirely in the workshop, thus reducing labour work on site and cost.

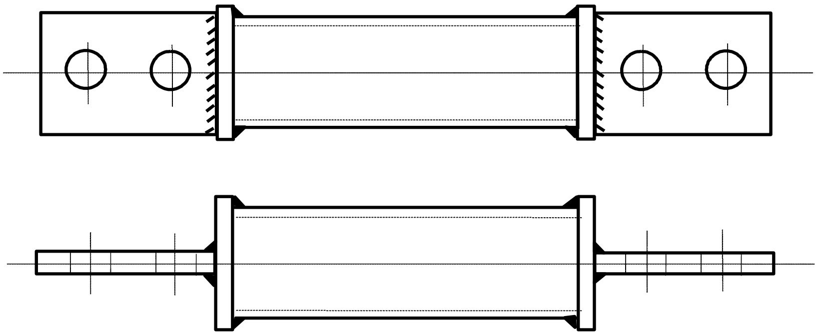

Figure 1. Welded T-end connection
(Figure 1. Connexion soudée)

In the UK there is very little guidance on the design of welded T-end connections. Previous work (Omair 2000) dealt with an investigation of the behaviour of T-end connections to rectangular hollow section (RHS). Elsewhere, research work was mainly carried out by Kitipornchai and Traves (1989) and Stevens and Kitipornchai (1990). Syam and Chapman (1996) attempted to develop design models for T-end connection, as well as for other types of structural steel hollow section connections. Packer and Henderson (1997) 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 (Stevens and Kitipornchai 1990). 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. RESEARCH SIGNIFICANCE (IMPORTANCE DE LA RECHERCHE)

The importance of the research raises from the fact that currently there is very little guidance on the design of T-end connections to hollow sections. It is hoped that this work will aid and form a basis for the development of future design guidelines that may be incorporated in the Eurocode.

3. SPECIMEN PROPERTIES AND EXPERIMENTAL PROGRAMME (PROPRIETES DES ÉCHANTILLONS ET PROGRAMME EXPERIMENTAL)

The testing programme included 22 specimens with varying tube wall and cap plate thickness. Two universal testing machines with capacities 500 kN and 5000 kN were calibrated by independent licensed consultants external, and used for the testing of the specimens. A tensile load was applied in increments up to failure. Strains and deformations were recorded for each load increment.

Two CHS tube sizes of nominal dimensions 114.6X6.3 CHS and 76.1X4.0 CHS were chosen for the test series. The first ten specimens (114.6x6.3 CHS) had bolts in the cleat plate and were tested in the 5000 kN machine because of the limitation in length of the 500 kN machine. The second series of tests with the 76.1x4.0 CHS tube (specimens 11 to 22) were tested in the 500 kN machine and were shorter than the first series specimens (see Figures 2 and 3). Tubes of one size were cut from the same stock length. All tubes used for making the specimens were of hot-finished steel Grade S355J2H to BS EN10210-1 (1994) specification. The plates used for the end cap plates were of steel Grade S355JR to specification BS EN10025-1 (1994).

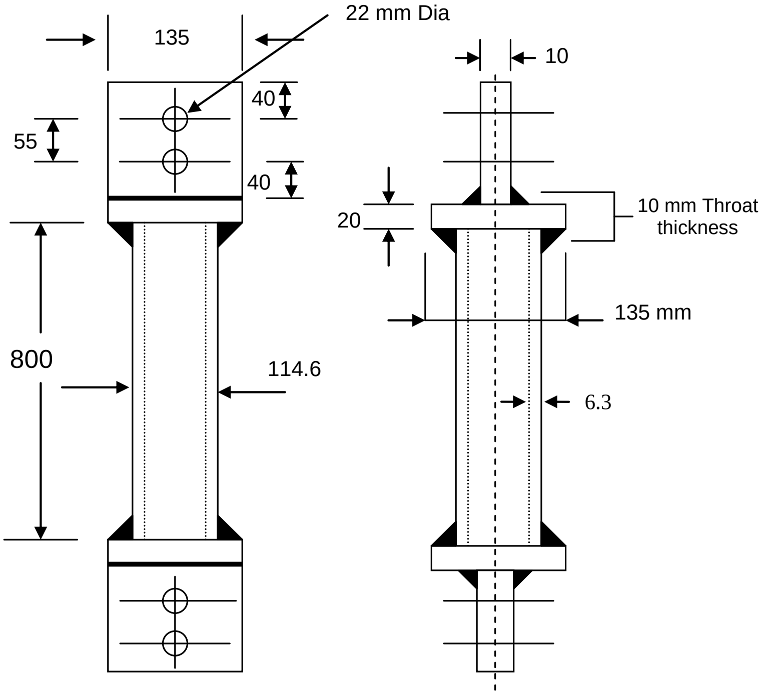

Figure 2. Specimen with 114.6x6.3 CHS
(Figure 2. Specimen avec 114.6x3 SCC)

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 (1994). 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 (1994).

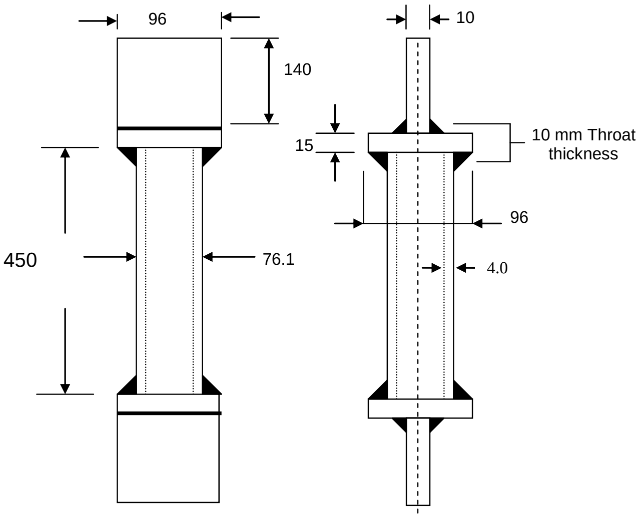

Figure 3. Specimen with 114.6x6.3 CHS
(Figure 3. Specimen avec 114.6x6.3 SCC)

The specimens were loaded in axial tension, taking all necessary precautions to avoid accidental eccentricity, with strain and deformation measurements being recorded (Figure 4).

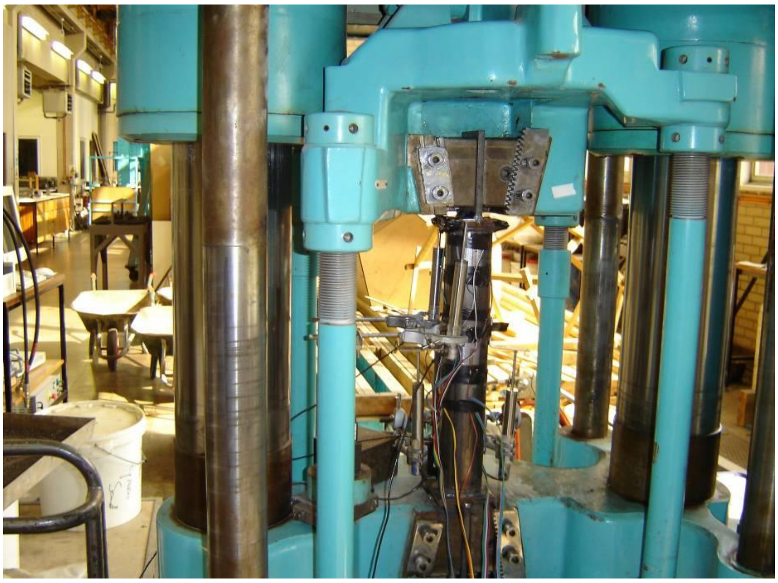

Figure 4. Specimen being tested.
(Figure 4. Specimen testé)

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 (Granstrom 1979).

Strain gauges were located on the tube wall (four faces), the cap plate, and the cleat plate with the aim of closely monitoring strain (stress) variations across the specimen. LVDT's were also used to record readings of the deformations and monitor in-plane and out-of-plane movements of the specimen (see general testing arrangements, Figures 5 and 6). All devises were kept well clear of the welds to prevent any contamination of the strain readings resulting from the

HAZ and residual stresses in and around the location of the welds.

The programme of the tested specimens is summarised in Table 1. The values shown in Table 1 are nominal values. In order to keep the investigation manageable, one cleat plate thickness was used and kept equal at t_p = 10 mm for all specimens.

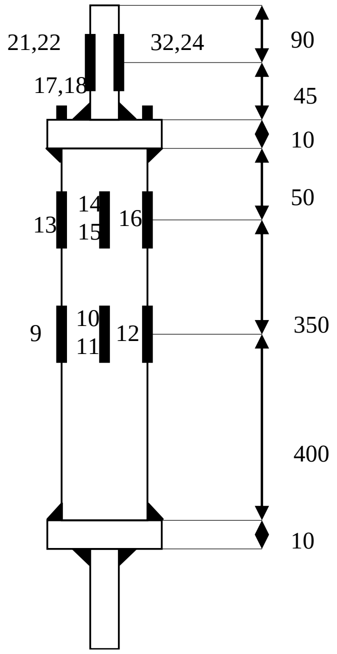

Figure 5. Strain gauges arrangement
(Figure 5. Jauges de contrainte)

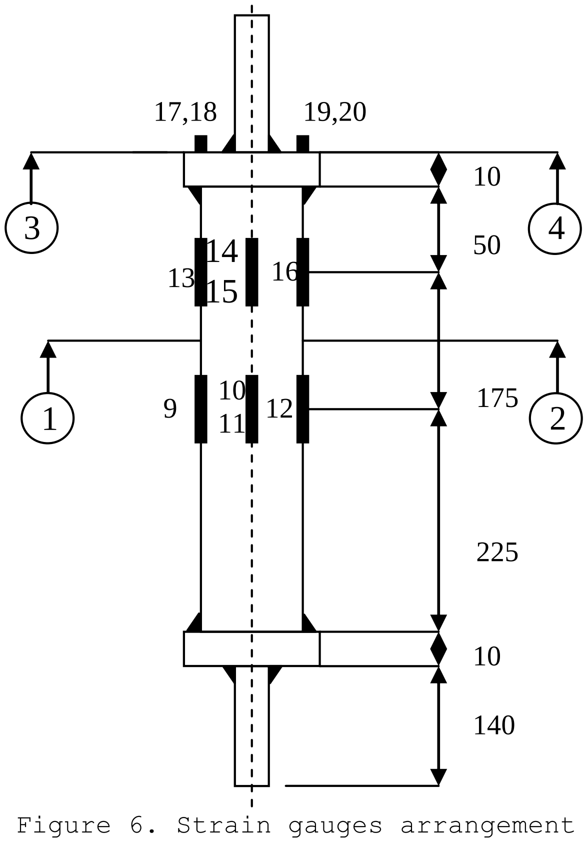

Figure 6. Strain gauges arrangement
(Figure 6. Jauges de contrainte)

Table 1. Specimen size and properties
(Table 1. La taille des échantillons et des propriétés)

No	Tube size mm	Yield stress N/mm^2	Ultimate stress N/mm^2	Cleat plate mm	Cap plate Mm
1	11.6X6.3	436	515	10	6
2	11.6X6.3	436	515	10	6
3	11.6X6.3	436	515	10	8
4	11.6X6.3	436	515	10	8
5	11.6X6.3	436	515	10	10
6	11.6X6.3	436	515	10	10
7	11.6X6.3	436	515	10	12.5
8	11.6X6.3	436	515	10	12.5
9	11.6X6.3	436	515	10	15
10	11.6X6.3	436	515	10	15
11	76.1x4.0	326.0	398.0	10	4
12	76.1x4.0	326.0	398.0	10	4
13	76.1x4.0	326.0	398.0	10	6
14	76.1x4.0	326.0	398.0	10	6
15	76.1x4.0	326.0	398.0	10	8
16	76.1x4.0	326.0	398.0	10	8
17	76.1x4.0	326.0	398.0	10	10
18	76.1x4.0	326.0	398.0	10	10
19	76.1x4.0	326.0	398.0	10	12.5
20	76.1x4.0	326.0	398.0	10	12.5
21	76.1x4.0	326.0	398.0	10	15
22	76.1x4.0	326.0	398.0	10	15

4. EXPERIMENTAL RESULTS AND DISCUSSION (RESULTATS EXPERIMENTAUX ET DISCUSSION)

Examination of output from the LVDT’s and SG’s placed on the sides of the tubes to monitor in-plane and out-of-plane displacements, revealed that these were negligible and could therefore be ignored. This confirms that precautions taken in setting up the specimens in the testing machine were adequate in limiting in-plane and out-of-plane bending stresses interfere with axial stresses from the tensile loading.

Table 2 summarises the failure load (P_{UE}) results from the specimens testing. The first yield load (P_{FY}) of the specimens obtained from the load versus strain graphs, is also shown in the Table. For ease of comparison, the ratio of P_{UE} / P_{FY} is given.

For specimens with bolts in the cleat plate, failure was due to weld fracture (specimens 1, 2, 3, and 4), or, for the remaining specimens, to bearing of the cleat plate and bolts shearing (Figures 7 and 8).

Table 2. Experimental results for CHS joints
(Table 2. Resultats experimentaux pour joints SCC)

Test No	Experimental loads		
	$P_{FY}\,(kN)$	$P_{UE}\,(kN)$	$P_{UE}\,/\,p_{FY}$
1	200	230	1.15
2	175	240	1.37
3	250	300	1.2
4	225	270	1.2
5	280	320	1.14
6	220	300	1.36
7	220	320	1.45
8	220	320	1.45
9	220	320	1.45
10	200	340	1.7
11	100	160	1.6
12	90	160	1.77
13	150	220	1.46
14	170	230	1.35
15	150	220	1.46
16	160	240	1.5
17	250	270	1.08
18	260	300	1.15
19	280	310	1.11
20	280	300	1.1
21	280	310	1.11
22	290	320	1.10

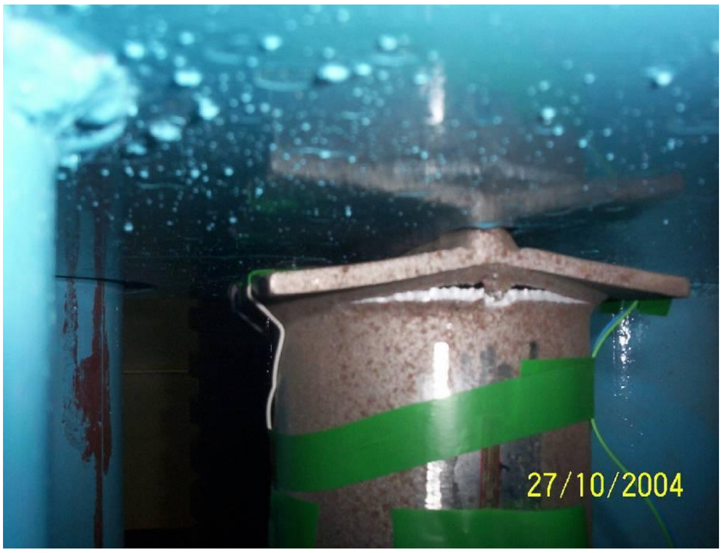

Figure 7. Weld fracture (114.6x6.3 CHS tube)
(Figure 7. Facture de soudure (114.6x6.3 tube)

Figure 8. Cleat plate bearing (114.6x6.3 CHS tube)
(Figure 8. Plaque Taquet (114.6x6.3 tube CHS))

Figure 9 shows a typical load-strain curve for specimen 1. The other specimens (not shown here) exhibited a similar behaviour.

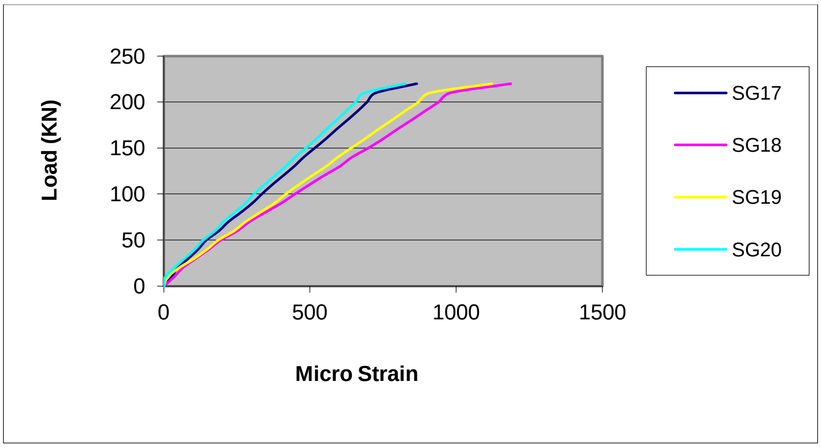

Figure 9. Strain distribution in 6 mm cap plate, 114.6x6.3 CHS tube
(Figure 9. Distribution des contraintes dans plaque de capuchon de 6mm, 114.6x6.3 tube SCC)

The modes of failure that were observed were, for specimens with tube size 114.6x6.3 CHS: (a) fracture of weld between cap plate and tube; (b) bearing failure of cleat plate; and (c) bolts shearing, for specimens with tube size 76.1x4.0 CHS: (a) fracture of weld between cleat plate and cap plate; (b) fracture of weld between cap plate and tube; (c) tube yield failure; (d) tearing in tube. Failure mode (a) would only occur if the welds were the weakest part of the connection, otherwise the bolts would fail by shear of the cleat plate by bearing. Figure 10 shows the axial deformation (LVDT 1 and 2) versus the applied load. It can be seen that the deformation remained linear for load of up to 230 kN, and is linear thereafter.

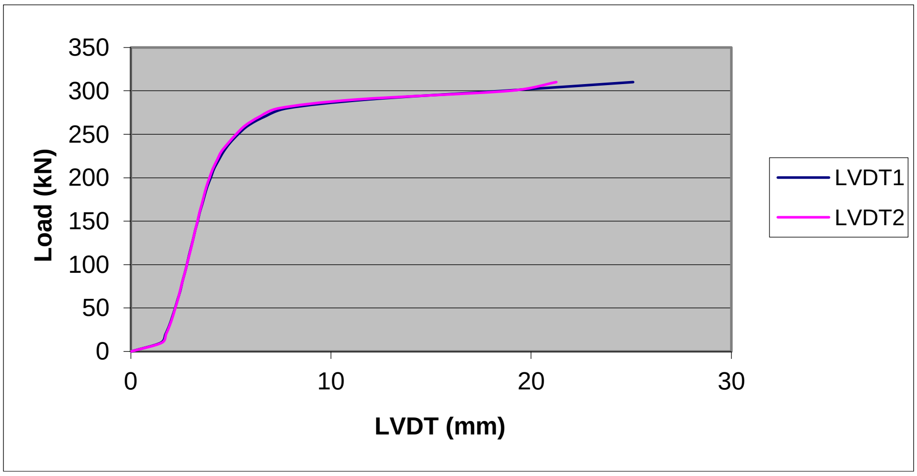

Figure 10. Axial displacements (LVDT 1 and 2) in 76.1x4.0 CHS tube with 10 mm cap plate.
(Figure 10. Déplacements axiaux (LVDT 1 et 2) dans le tube 76.1x4.0 SCC de 10 mm plaque capuchon)

There was evidence of shear lag taking place between the welded cleat plate and the cap plate, in turn, welded to the tube, since specimens failed to achieve their full tension capacity. Shear lag is known to occur in welded elements and has been described by Dowswell and Barber (2005), and also Abi-Saad and Bauer (2006). Micro-cracks in the welds could cause shear lag effects to develop and these will have an impact on the failure load.

5. CONCLUSIONS (CONCLUSIONS)

The behaviour of welded T-end plate connections loaded in tension has been investigated through a series of tests. It was found that different modes of failure could take place: welds fracture, tube yielding or tube fracture at the vicinity of the weld. For those connections with bolts in the cleat plate, other modes of failure were observed, such as bolts shearing and cleat plate bearing.

It was found that the capacity of the joint increases with the cap plate thickness but then seems to cease increasing for cap plate thickness greater than 20 mm, suggesting that excessively thicker cap plates do not necessarily lead to stronger connections. This result could be explained by the HAZ softening in the tube resulting from welding, as a thick and rigid cap plate is welded to a much thinner tube.

The results also suggest that considerable stress re-distribution and strain hardening were taking place after the first yield. In all specimens, the failure load was smaller than the tube tensile strength. This could be attributed to shear lag effects occurring in welded elements, and the fact that the cleat plate will act as a concentrated tensile load causing more micro-cracks in the weld, and hence resulting in a less effective area resisting the applied load.

The advice to designers of such connections is to avoid unnecessary use of very thick cap plates (more than 20 mm) as evidence from this testing programme suggests that this will not necessarily lead to stronger connections, especially when used with thinner tube walls.

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