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STUDY OF THE BEHAVIOUR OF WELDED T-JOINTS IN HOLLOW CIRCULAR STEEL SECTIONS

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ABSTRACT

A study of the behaviour of welded T-joints in circular hollow sections, conforming to Indian Standards, when subjected to static loading was done under the above project head. The study was structured in such a way that the works include design of hollow section T-joint, fabrication of specimens based on the design data and testing them under static loading and studying the various failure modes based on the experimental results. An analytical work is also conducted to validate the experimental programme. The joint strength obtained from experimental works was compared with design strengths obtained from IS 806:1968 and CIDECT GUIDE-1. The results obtained indicated a close correlation between experimental values of joint strength and design strength predicted based on CIDECT GUIDE-1. It was also found that IS 806:1968 overestimates the joint strength and hence can lead to unreliable design.

NOMENCLATURE

N_i	Design of joint strength
f_{y0}	Yield strength
$d_i \& d_o$	Diameter of brace and chord
θ_i	Angle between chord and brace
t_o	Thickness of chord
l_o	Length of chord
α	chord length parameter ($\alpha = 2l_0/d_0$)
β	width ratio between brace and chord
γ	half diameter to thickness ratio of chord ($\gamma = d_0/2t_0$)
f_{wd}	Design weld strength
f_u	Ultimate load capacity of member
Q_f	Chord stress function
N_0	Axial force in member
N_{pl}	Axial yielding capacity of the member
M_0	Ultimate out-of-plane bending moment
M_{pl}	Plastic moment capacity of the member
k_a	Punching shear function
γ_{mw}	Factor safety for material

1. INTRODUCTION

Hollow sections are nowadays being widely used in construction industry by virtue of its ductility, low slenderness ratios, high moment of inertia compared to open sections with same cross sectional area etc. The term joint is used to represent the zone where two or more members are interconnected.The main member is designated as the chord member and the branch member is designated as the brace member. The research works done in the area of hollow sections, especially in joint study is scarce when Indian scenario is considered. Vide this work; an attempt is made to study the behavior of joints in circular hollow sections under static loading condition. Further the joint strength obtained from experimental programme was compared with those obtained from IS 806:1968 and CIDECT GUIDE-1. Experimental work was validated using analytically using finite element software package, ANSYS10.0.

Previous experimental researches have shown that the failure of axially loaded members is under weld cracking in tension and chord plastification in compression. For joints under cyclic-in-plane bending, punching shear and chord plastification can also be identified [1]. Further, the chord thickness has a remarkable effect on the stress distribution along the weld, while the brace thickness is not having any significant effect. The diameter ratio (d_i/d_o) is also having significant effect on the joint strength for both K and T joints [2]. It is also seen from the previous studies that the ductility capacity of the cyclically loaded specimens mainly depends on three factors, viz., yield strength, member slenderness and member width to thickness ratio [3].

2. EXPERIMENTAL PROGRAMME

The schematic view of the T-joint specimen is shown in Fig.1.The elements of the specimens were selected from the list of Indian standard tubes available in IS

1161:1998, based on the actual analysis of a 4 span 48m truss bridge and conforming to CIDECT GUIDE-1. 6mm fillet weld based on IS 800:2007 was provided at the brace-chord joint. The tube specimen was tested for its yield and ultimate strength and the speciimen material properties are listed in Table 1.From the results in Table 1, it can be seen that the specimen materials conforms to YSt 210 grade steel as per IS 1161:1998. Based on the above design data, the specimens were fabrricated to suit the lab requirements.

Four specimens were fabricated and out of which two were subjected to axial compression in the brace (specimens C1 and C2) and the remaining two were subjected to axial tension in the brace(speciimens T1 and T2).The geometrical characteristics and details of all the specimens are listed in Table 2 and Table 3. Strain gauges were fixed at select locations to evaluate the hotspot stresses and LVDT was used to measure the joint displacement as shown in Fig.1. Th e outcome of each test were (a) the strains in chord member and brace member (b) the joint displacement in the direction of loading and (c) the ultimate load capacity of the joint. The modes of failure were also observed. The results obtained from the experiments were compared with the design data.

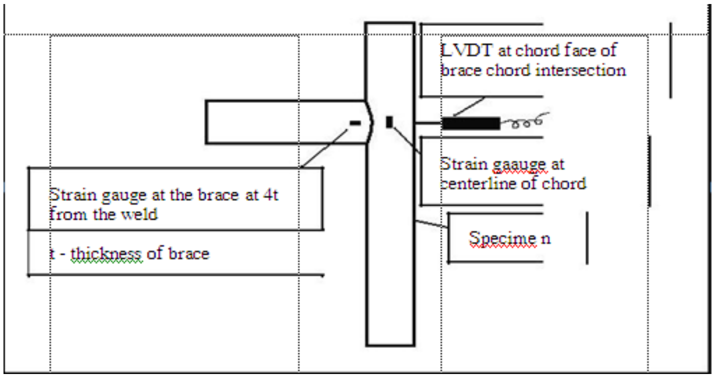


FIGURE 1.SCHEMATIC REPRESENTATION OF STRAIN GAUGE AND LVDT LOCATIONS

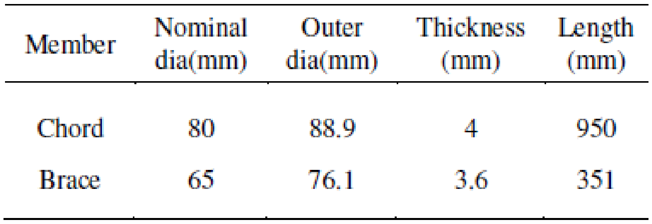
TABLE 1.MATERIAL PROPERTIES OF STEEL TUBES

Member	Yield strength in tension (N/mm^2)	Ultimate strength in tension (N/mm^2)
Chord	320.6	355.3
Brace	317.4	348.0

TABLE 2
GEOMETRIC PROPERTIIES OF SPECIMENS IN AXIAL COMPRESSIVE LOADING IN BRACE

Member	Nominal dia(mm)	Outer dia(mm)	Thickneess (mm)	Length (mm)
Chord	80	88.9	4	950
Brace	65	76.1	3.6	426

TABLE 3.
GEOMETRIC PROPERTIES OF SPECIMENS IN AXIAL TENSILE LOADING IN BRACE



Member	Nominal dia(mm)	Outer dia(mm)	Thickness (mm)	Length (mm)
Chord	80	88.9	4	950
Brace	65	76.1	3.6	351

2.1 Design details

The design of the joints were carried out for various design criteria, such as chord plastification and punching shear, given in CIDECT GUIDE 1, as per equations (1) and (6) respectively. Weld design was carried out based on IS800:2007 guidelines as per equation (8).

$$N_i = Q_n \times Q_f \times \frac{f_{yo} t_o^2}{sin\theta_i} \tag{1}$$

$$Q_f = (1-n)^{C_1} \tag{2}$$

$$Qn = 2.6(1+6.8\beta^2) \times \gamma^{0.2} \tag{3}$$

$$n = \frac{N_o}{N_{pl}} + \frac{M_0}{M_{pl}} \tag{4}$$

$$C_1 = 0.45 - 0.25\beta \tag{5}$$

$$N_i = 0.58 \times f_{yo} \times \pi \times d_o \times t_o \times \frac{k_a}{sin\theta_i} \tag{6}$$

$$k_a = \frac{1 + Sin\theta_i}{2Sin\theta_i} \tag{7}$$

$$f_{wd} = \frac{f_u}{\gamma_{mw} \times \sqrt{3}} \tag{8}$$

TABLE 4
DESIGN SUMMARY AS PER CIDECT GUIDE 1

Design criteria	Joint strength (kN)
Chord plastification	77.15
Punching shear	116.47
Yield strength	172.20

The design summary as per CIDECT GUIDE-1 is given in Table 4.It can be seen froom the above table that the joint strength is 77.15kN. The weld is designed for a minimum axial load of 172.2kN (the axial load capacity of the brace member).

2.2 Specimen testing and Experimental Results

The specimens of dimensions as per Table 2 and Table 3 were fabricated and were tested for axial loading on the brace. The schematic representation of test setup and the actual test setup are shown in Fig.2 and Fig.3.The load was applied by means of double acting hydraulic jack.

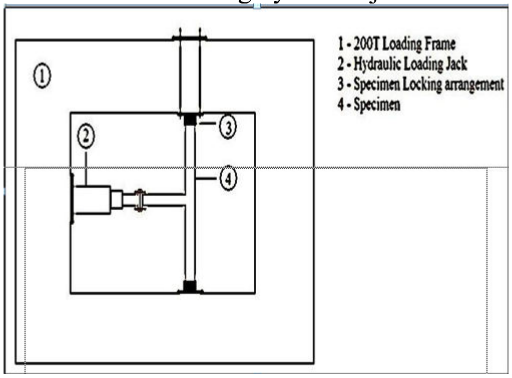


FIGURE 2.SCHEMATIC REPRESENTATION OF LOADING SETUP

FIGURE 3.SPECIMEN UNDER LOADING

The joint strength obtained from the experimental programme and the observed modes of failure are presented in Table 5. Fig.4 shows the failure of the specimen in chord plastification when compressive load is applied at the brace

FIGURE 4.CHORD PLASTIFICATION

TABLE 5.TEST RESULTS – JOINT STRENGTH

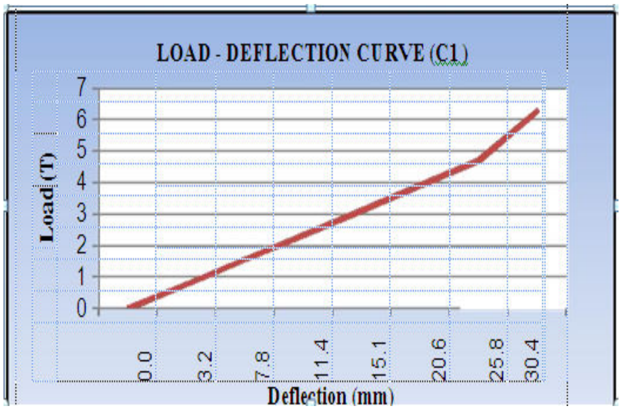
Specimen Designation	Dominant Failure mode	Failure load (kN)
C1	Chord plastification	62.84
C2	Chord plastification	70.70
T1	Chord plastification	72.18
T2	Chord plastification	72.18

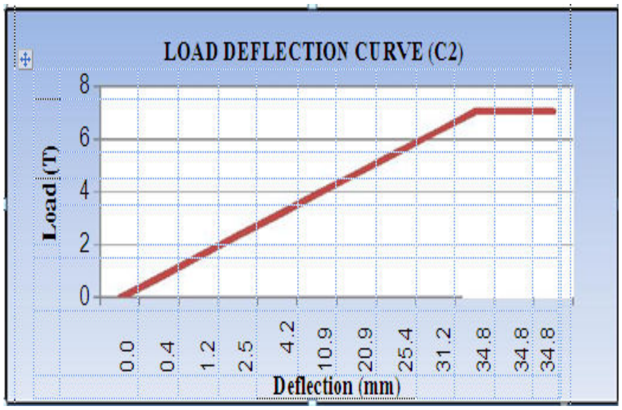
TABLE 6.COMPARISON OF EXPERIMENTAL AND THEORETICAL JOINT STRENGTH

	Average joint strength from experiment	Joint strength as per CIDECT GUIDE -1	Joint strength as per IS 806:1968
Compression tests	66.8kN	77.15kN	102.5 kN
Percentage variation from actual	0%	15.49%	53.44%
Tension tests	72.18 kN	77.15kN	102.5kN
Percentage variation from actual	0%	6.88%	42.00%

The experimentally obtained failure loads are compared with the design joint strengths as per CIDECT GUIDE-1 and IS 806:1968 in Table 6 and it can be seen that the experimental values are 5 - 16% close to the design values given by CIDECT GUIDE-1 and are as much as 40 - 50% less than that given by IS 806:1968. The main reason for this discrepancy is the fact that IS 806:1968 do not consider the chord plastification and punching shear failures, which are being considered as the major failure mode of joints by CIDECT GUIDE-1.

Based on the measurements taken in the experimental programme, the load deflection curves for the specimens were generated and are presented in Fig.5. From the load-deflection curves, the energy absorbed by the specimen till failure, is calculated. The energy absorption characteristics of the specimens in compressive and tensile loading in the brace are averaged and are presented in Fig.6. As indicated by the CIDECT GUIDE-1, the above results shows that the failure load in tension is more than that in compression and further the deflection and hence the energy absorption before failure were found to be more in the case of specimens with brace in tensile loading (T1 and T2). The energy absorption is found to be as much as 25% higher for specimens T1 and T2 when compared to specimens C1 and C2.





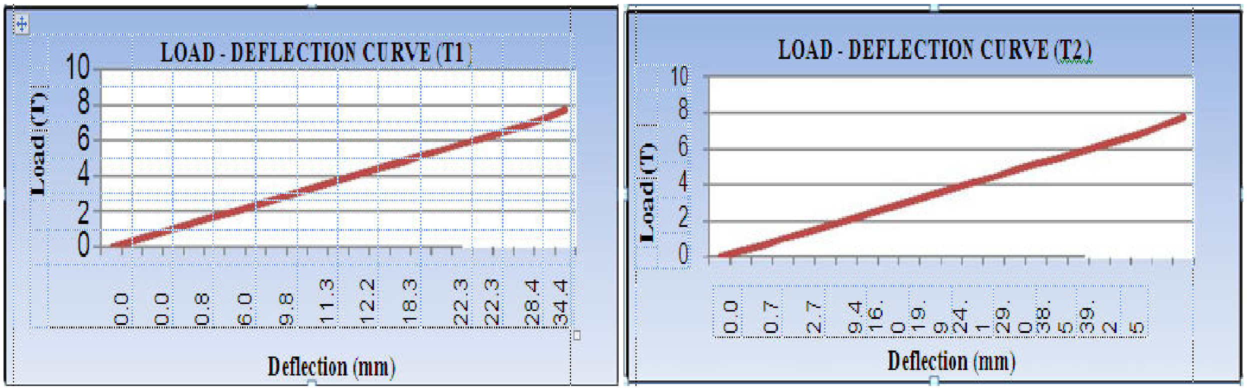


FIGURE 5.LOAD DEFLECTION CURVES FOR VARIOUS SPECIMENS

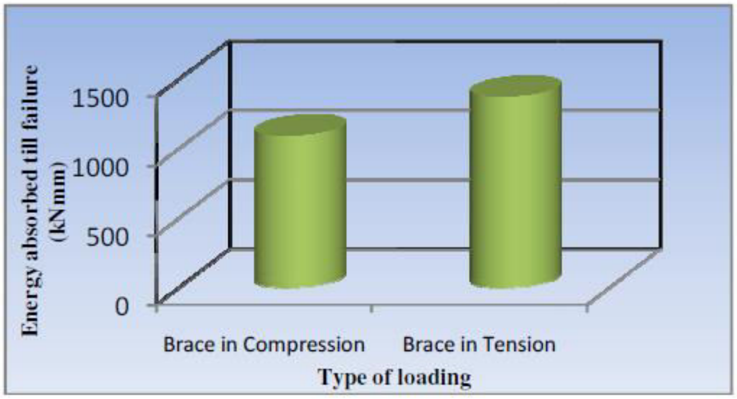


FIGURE 6.ENERGY ABSORPTION CHARACTERISTICS OF SPECIMENS IN COMPRESSION AND TENSION IN BRACE

2.3 Analytical validation

The analytical models of the specimens were generated in ANSYS10.0. The element used for discretisation was a 10 noded "Solid92" element having three degrees of freedom at each node. The failure loads obtained from the experimental programme was applied to the models and the stress response of the specimen to the above loading was studied. The stresses obtained from Finite element analysis are presented in Table 7. From the stress values obtained from the analytical programme is can be seen that the failure of the specimens are initiated at the joints when the failure loads, as obtained from the experiment are applied to the model. From this it can be concluded that the above failure loads obtained from the experimental programme can reasonably be accepted as the actual joint strength.

TABLE 7.VALIDATION OF EXPERIMENTAL WORK USING FINITE ELEMENT ANALYSIS

Specimen Designation	Load applied (kN)	Joint stress obtained from FEA (N/mm^2)
C1	62.84	-515
C2	70.70	-579
T1 & T2	72.18	592

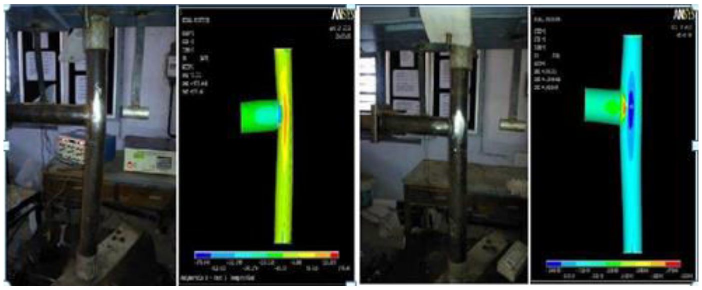


FIGURE 7.FAILED SPECIMENS AND THEIR
ANALYTICAL MODELS

2.4 Comparison of IS 806:1968 design and CIDECT GUIDE-1 design of T-joints

IS 806:1968: This guide relies on working stress method for the design of tubular joints. The code derived its basic concepts from British sttandards, BS 449:1959 and incorporates the various devellopments in the field of steel designs up to 1968. The application of this standard is limited to only hot finished tubes. The joint strength given by this code only depends on the load capacities of the members and the weld strength

CIDECT GUIDE-1: This guide adopts the limit state design procedures. The code is based on the various experimental works on steel tubes done during 1980s – 2008 and was validated by CIDECT Technical commission and AISC. The guidelines are applicable for both hot rolled as well as cold formed structural steel tubes. The joint capacity equations given by this guide mainly depends on chord plastification and punching shear capacity of the chord member. Further the code give stress that the weld at the joint should be provided such that the weld strength should be at least the member load capacity.

3. CONCLUSIONS

From the above work the following conclusions are drawn.

1. The failure of all the specimens subjected to compression in brace was due to chord plastification.
2. The failure of all specimens subjected to tension in brace was also due to yielding of the chord member.
3. The above failure modes were supported by the analytical results obtained from ANSYS10.0.
4. The joint strength obtained from experiments was in good agreement with those given by CIDECT guidelines.
5. IS 806:1968 gives an overestimated joint strength when compared to the joint strength given by CIDECT guidelines.
6. IS 806:1968 gives an overestimated value for joint strength ranging from 40 – 50% more than the actual joint strength and hence can lead to under designed structures.

4. SCOPE FOR FUTURE RESEARCH

The conclusions drawn above are based on the tests conducted on limited number of specimens. Even though the number of specimens was less, the results obtained show a general failure trend, which are in close conformance to CIDECT guidelines. Thus the validity of CIDECT guidelines can be extended to Indian Standard tubes, provided, the various aspects such as cyclic loading, fatigue behavior, seismic response, fabrication procedures etc. are validated based on experimental investigations.

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