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Experimental and numerical study on moment-rotation relations of welded end-plate tubular connections

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ABSTRACT

Ductile behaviour of steel structures depends on mechanical properties of steel materials and steel structures are designed so that plastic deformations occur on beams particularly in beam-to-column connections under cyclic loads. Details on moment-resisting beam-to-column connections are given only for I-profiles in the Turkish Earthquake Code (TEC, 2007) and no details about beam-to-column connections consisting of box or circular hollow sections is available in the relevant code. That is why there is an uncertainty in the definition of the ductility level of the structural system consisting of box and circular hollow sections. The purpose of this study is to prevent local buckling effects to occur under bending in welded connections of circular hollow sections. In this context, the contribution of cover stiffness plates of different sizes to the behaviour and the effect of plate sizes on the capacity were investigated numerically and experimentally. Results obtained from experimental analysis are given comparatively supported by ANSYS program.

1. Introduction

The two most important features of steel in a structure designed using steel construction are ductility and energy absorption capacity under cyclic loading. In ductile structures, seismic energy is absorbed by plastic hinges before the occurrence of collapse mechanism. The feature of steel to cause large deformation without break and its high strength makes the material an ideal material for structures to be built in earthquake zones.

The earthquakes occurred in Northridge (Los Angeles, USA) in 1994 and in Hyogo-ken (Kobe, Japan) in 1995 have changed the outlook on the structural performance that steel frame systems exhibited under the earthquake. Although no total collapse occurred in any steel building in both the earthquakes, brittle fractures and cracks were observed on beam-to-column connections. This poor performance observed despite high ductility capacity of steel structures showed that the current knowledge about these frame systems was not enough. The need to perform detailed investigations on connections in moment-resisting frame systems has arisen after this experience and accordingly, many connection types have been examined in terms of stiffness, strength and ductility. These investigations have been included in FEMA reports and caused many countries to review the earthquake-resistant structure design criteria according to their own conditions and to renew their codes in this direction.

Many examples in the literature demonstrate that circular hollow sections have outstanding behaviour characteristics under the effects of compression, tension, bending and torsion. The circular hollow sections are the best section types that resist wind, water and wave loads especially in coastal structures. Further, the circular hollow section combines these characteristics with an architecturally attractive shape. Therefore, it has been widely used in many structural applications in buildings, halls, bridges, barriers, masts, towers, offshore and special applications, such as glass houses, radio telescopes, sign gantries, parapets, cranes, jibs, sculptures, etc. [1].

It is important that designers are aware of behavioural principles of joints and have knowledge about the effect of certain parameters on joint in terms of making a good design using circular hollow sections. In this context, design formulas in the recommendations of IIW International Congress 2008 (IIW IC 2008) were rearranged based on the results of researches performed after the first edition of Design Guide (CIDECT) [1,2] and additional analyses carried out. However, these arrangements have not yet been incorporated into various international standards such as Euro Code 3 [3].

Lee and Parry [4] conducted a study on a strengthening method in order to prevent deformations occurred on circular hollow section columns and beams that are commonly used in marine structures under bending and axial load. The researchers observed that

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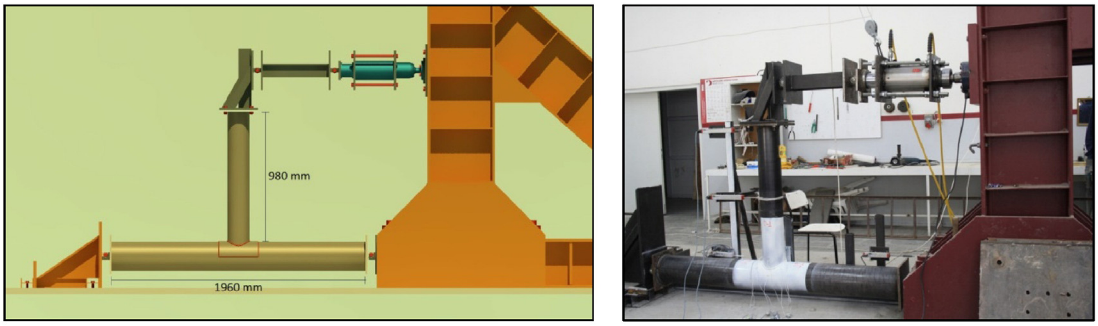

a) Dimensions of the experiment apparatus setup b) Overview of the experimental model

Fig. 1. Overview and dimensions of the experiment apparatus setup. (a) Dimensions of the experiment apparatus setup. (b) Overview of the experimental model.

stiffening plates to be placed inside the area of effect into a beam/brace connected on a column positively affected the seismic performance of the joints. Mashiri and Zhao [5] carried out an experimental study on the welded T-joints of circular and rectangular hollow sections. The numerical model was designed with the help of the yield line theory obtained as a result of the study. Wang and Chen [6] studied the behaviour of the circular hollow section T-joints under cyclic axial load and cyclic in-plane bending. Eight experiments in total were carried out. Four of the profiles were exposed to cyclic axial load and the other four were exposed to bending load on a cyclic plane. It was concluded that the energy dissipating mechanism for tubular joints under different load conditions showed significant differences. Yang and Kim [7] examined the behaviour of fully welded (FW) and high-strength bolted (TSD and DWA) joints under cyclic loads. In the study, three test specimens were exposed to cyclic rotations until a failure occurred. It was found out as a result of the study that the values of the moment–rotation relationship of high-strength bolted joints (TSD and DWA) were 39% and 4.4% for initial stiffness and 28.3% and 58.6% for ultimate moment respectively, compared to welded junctions.

D'Aniello et al. [8] investigated the effect of the current criteria that are used to classify flexural behaviours of steel beam in buildings on the overall performance in their study. It was concluded that rotation capacity had a significant effect on loading condition. In their study, Sharaf and Fam [9] developed a non-linear finite element analysis in order to analyse beam-to-column T-joints of rectangular hollow sections strengthened with through-wall bolts inside. As a result of the study, it was observed that attaching the bolts to beam walls by welding significantly increased ductility and affected strength at moderate level. Kımıllı [10] studied the structural behaviours of rectangular hollow section beam and circular hollow section column connections. As a result of the study, it was discovered that end-plates attached to connection in this type of joints prevented deformations occurring in the column and ensured rigidity of the joints.

The aim of this study is to investigate ductility details of end-plate welded moment-resisting beam-to-column connections of steel frame systems made of circular hollow sections. An experimental as well as numerical study was performed to determine end-plate sizes of beam-to-column connections to achieve 0.04 rad relative story drift angle so that system could be identified one with the high ductility level in the TEC 2007 [11]. Numerical analyses of all the experimental models were performed using the ANSYS program and the results obtained therefrom were compared to the results from experimental analysis. Main factors affecting the rotational capacity, such as sizes of elements, material characteristics, moment changes, buckling types and number of cyclic loading, were taken into account in the analysis and experiments.

The specimens in this study, was conducted at Süleyman Demirel University Steel Structures Laboratory. Details information can be found in Ref. [12].

2. Material and method

2.1. Material and experimental setup

Experimental models were designed as shown in Fig. 1. The vertical and horizontal elements was designed respectively as a beam and a column and modelled in full scale. The condition of strong columns and weak beam was sought for the selection of the cross sections of the column and beam. Circular hollow section profiles of Ø219.1 mm with a wall thickness of 5 mm were used for columns and of Ø168.3 mm with a wall thickness of 4 mm for beams. The column and beam lengths were set at 1960 mm and 980 mm, respectively. The profiles were assembled using the gas metal arc welding method and the thickness of the welding was 6 mm.

In the study, different sizes of end-plates were used in connections in order to prevent local deformations likely to occur on columns and to increase joint stiffness. The beam and column connection was made directly without using any end-plate to see the contribution of the end-plates to the behaviour. The model created in this way was considered as reference specimen as shown in Fig. 2.

In this study, it was aimed to prevent local deformations likely to occur on columns under bending in particular and to increase the stiffness and capacity of joints with the end-plate (stiffening plate) to be attached to the joint. Two different end-plate thicknesses, 6 and 8 mm, were used in this study. Dimensional parameters of the end-plate used for the study were given in Fig. 3. Accordingly, the V_a length was accepted as 66 mm, 91 mm and 116 mm and the V_b length as 300 mm, 350 mm and

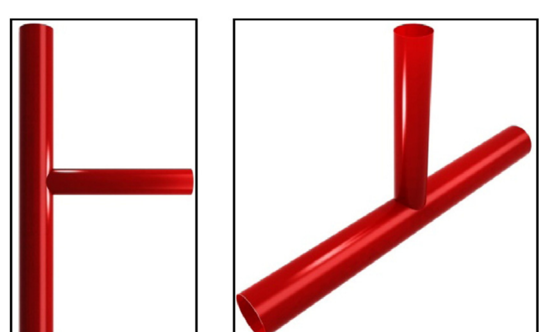

Fig. 2. Overview of the reference specimen beam-column connection details.