Journal of Constructional Steel Research 114 (2015) 338–348

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental assessment of the semi-rigid connections behavior with angles and stiffeners

Abdulkadir Cüneyt Aydın [a,*], Mahmut Kılıç [a], Mahyar Maali [a], Merve Sağıroğlu [b]

[a] Ataturk University, Faculty of Engineering, Department of Civil Engineering, 25240 Erzurum, Turkey
[b] Erzurum Technical University, Faculty of Engineering, Department of Civil Engineering, Erzurum, Turkey

ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 19 June 2015
Accepted 4 August 2015
Available online xxxx

Keywords:
Top-and-seat angle connections
Minor column axes
Experimental testing
Resistance
Stiffness
Steel beam-to-column

ABSTRACT

Experimental investigations were done on statically loaded beam-to-column connections that were designed with top-and-seat angles in minor column axes. This study was undertaken to analyze the influence of angles with and without stiffeners on the behavior of the beam-to-column connections. The aim was to provide necessary data to improve the Eurocode 3. While the rotation stiffness and capacity of the entire stiffener used beams decreased, the resistance moment increased. Moreover, the rotation capacity increased with the increased thickness of the top-and-seat angles.

1. Introduction

Taking into account the behavior of the connections in the analysis and the design of steel frames is important when presenting the actual behavior of such frames. Thus, the behavior of the connections must be well-understood. The connections form various moment–rotation (M–θ) curves according to the type of connection, elements of the connection, and placement of the connection. These curves are the visual expressions of the actual behavior discovered in experiments. In 1917, Wilson and Moore [1] performed the first experiment to assess the rigidity of steel frame connections at the University of Illinois. Since then, experimental testing has continued. The data banks from experiments have been obtained partially. The four most important data banks are: 1. Goverdhan data bank. The first one to be developed, in 1984 [2], has the results of 230 tests from the United States of America (USA) carried out between 1950 and 1983. 2. Nethercot data bank. The first European data bank on steel connections was developed in 1985. Nethercot [3,4] examined more than 70 experimental studies that involved collecting more than 700 individual tests by other researchers [5]. 3. Steel connection data bank. In the USA, the work of Goverdhan [2] was followed by that of Kishi and Chen [6,7], who prepared a data bank collecting experimental tests carried out from 1936 to 1986 all over the world. They compiled the results of more than 303 tests [8,9]. In 1995, Abdalla and Chen [10] added the results of 46 additional experimental tests of steel beam-to-column joints. 4. SERICON data bank. Developed by Arbed Recherches [11] and Aachen University [12], it includes only European test results [13].

These databanks have completed classification and the formation of mathematical models to express the behavior of connections. However, classification is limited to seven types of beam–column connections. The seven connection types are called: 1 — single web angle, 2 — double web angle, 3 — header plate, 4 — top-and-seat angle, 5 — end plate without column stiffeners, 6 — end plate with column stiffeners, and 7 — T-stub. These connection types were experimentally tested between 1958 and 1990 [14–33]. However, there are many different types of beam–column connections in steel structures today that aren't defined in data banks. de Lima et al. [34] investigated the experimental and mechanical models for predicting the behavior of minor axis beam-to-column semi-rigid joints. The investigation motivated the development of a mechanical model for assessing the connections structural response. The mechanical model is based upon the component method of design, in accordance with the Eurocode 3 specifications. This philosophy implies that each joint component is represented by a spring possessing a non-linear force versus displacement (F–Δ) curve.

Coelho et al. [35] investigated the assessment of the behavior of bolted 32 T-stub connections made up of welded plates. Although T-stubs have been used over many years to model the tension zone of bolted joints, the research mainly focused on rolled profiles as T-stub elements. To extend this model to the case of welded plates as T-stub elements, a test program was undertaken and reported.

* Corresponding author.
E-mail address: acaydin@atauni.edu.tr (A.C. Aydın).

http://dx.doi.org/10.1016/j.jcsr.2015.08.017
0143-974X/

Coelho et al. [36] investigated the ductility of the extended end-plate connections. An experimental investigation of eight statically loaded extended end-plate moment connections was undertaken to provide insight into the behavior of this joint type up to collapse. The specimens were designed to confine failure to the end plate and/or bolts without the development of the full plastic moment capacity of the beam. Coelho and Bijlaard [37] researched the experimental behavior of high-strength steel end-plate connections. The major contributions to this study are (i) the characterization of the nonlinear behavior, (ii) the validation of current Eurocode 3 specifications, and (iii) the ductility analysis of high-strength steel moment connections. The test results show that the tested connections satisfy the current design provisions for stiffness, resistance, and rotation demands. Cabrero and Bayo [38] researched the semi-rigid behavior of three-dimensional steel beam-to-column joints subjected to proportional loading. An experimental investigation of statically loaded extended end-plate connections in both major and minor column axes was undertaken. The aim of the research was to provide insight into the behavior of these joints when a proportional load is applied to both axes (three-dimensional loading). The rotational stiffness of the joints increased in this type of three-dimensional loading. The findings also showed the increasing end-plate thickness as an increase in the connections flexural strength and stiffness and as a decrease in its rotation capacity. Shi et al. [39] investigated the experimental and theoretical analysis for the moment–rotation behavior of stiffened extended end-plate connections. A new theoretical model for evaluating the moment–rotation (M–Φ) relationship for stiffened and extended steel beam column end-plate connections was derived. Based on a specific definition of the end-plate connection rotation, the end-plate connection was broken down into several components, including the panel zone, bolt, end-plate, and column flange. The complete loading–deformation process of each component was then analyzed.

Recently, Abidelah et al. [40] researched the experimental and analytical behavior of bolted end-plate connections with or without stiffeners. The experimental results of eight specimens of steel bolted beam-to-column and beam-to-beam connections with flush or extended end plates were investigated. Four of the connections had the end plates reinforced with stiffeners in the extended parts. The low-resistance column was used to observe the failure modes in the tension and compression zones. The results were analyzed on the basis of global moment–rotation curves and the evolution of the tension forces in the bolts. The main parameters observed were the failure modes, the evolution of the resistance, the stiffness, and the rotation capacity. Experimental results were used as a basis for comparison with the analytical results given by the component method of Eurocode 3, leading to code specifications that enabled the calculation of the moment–rotation characteristics of major axis beam-to-column joints, beam-to-beam joints, and column bases, as stated in the current draft version of Eurocode 3, Part 1.8 [41]. When beam-to-column joints to the column minor axis were considered, the adopted design process generally assumed these joints to be pinned; however they did not behave as though they were pinned [34]. Given that no code provisions currently exist for semi-rigid minor axis joints, a mechanical model was developed in accordance with the general principles of Eurocode 3 [41] to evaluate the connections structural behavior. Authors investigated [10] beam-to-column minor connections with or without stiffeners in top-and-seat angles and web of the beam in two groups.

The conventional usage of stiffeners can be designed to present local bending, local yielding, and local buckling of the beam or column. However, the usage of stiffeners with angles is not mentioned and investigated either in Eurocode 3 or in the literature as in this research. Thus, the aim of the study was to analyze the influence on the beam and joint stiffeners and lengths (L) of top-and-seat angle joints on the behavior of connections and to provide the necessary data for improving Eurocode 3. Moment–rotation curves were used to evaluate the main parameters characterizing the behavior of the tested connections, such as the stiffness, the resistance, the failure mode, and the deformation capacity of the joints.

2. Description of the experimental program

2.1. Test details

Two series of 10 bolted beam-to-column connections were investigated throughout this study, the experimental program is shown in Fig. 1. The joints were fabricated from a minor axis connection, as shown in Fig. 1 and detailed in Table 1. Each of the minor axis beam-to-column connections had a control specimen (without a beam stiffener) to compare its behavior within each group (A60 and A50). All stiffeners with a thickness equal to 5 mm and 10 mm were welded to the beam and to the top-and-seat angle by means of a continuous 45° fillet weld. The fillet welds were prepared for the workshop in a down-hand position. The manual metal arc welding type of procedure was involved with a consumable electrode. The chosen steel grade for the top-and-seat angle, plate stiffener, and profile section was S235. The column IPE300, the beam IPE120, and hand-tightened full-threaded grade 8.8 M8 bolts in 10 mm drilled holes were kept constant for all tested specimens.

2.2. Mechanical properties

The test program included one steel grade for the beam; the column and stiffeners were S235 with nominal values of yield strength f_y, n and ultimate tensile strength f_u, n equal to 235 MPa and 360 MPa, respectively. The coupon tension test on the structural steel material was performed according to the appropriate UNE procedures [42]. The real mechanical characteristics were obtained using tensile tests on coupons cut from the flange and web of the beam and column and from the top-and-seat angles 50 and 60 and the stiffeners. For each component, three tests were performed. Table 2 gives the values for the static yield and tensile stresses, f_y and f_u. Each bolt was tested under tension in order to determine the mechanical properties of the bolt material, in accordance with UNE-EN 10002-1 [42]. The average properties are set out in Table 2.

2.3. Test arrangement and instrumentation

The specimens were subjected to a static force applied by a 250 kN hydraulic jack with a maximum piston stroke of 200 mm. Tests were performed under displacement control with a constant speed of 0.016 mm/s up to the collapse of the specimens. The test arrangements are shown in Fig. 2. In order to prevent the lateral torsional buckling of the beam while loading, a two-column guidance device near the beam was provided. In fact, from the experiments, it was observed that lateral torsional buckling of the beam with the course of loading did not occur. The instrumentation plan is described in Fig. 2. The lengths of the beam and column (1500 mm) were chosen to ensure that a realistic stress pattern was developed at the connection, on the one hand, and that fracture of the several specimens, i.e., ultimate load, was attained with the specific testing machine.

The full instrumentation plan is described below. The primary requirements of the instrumentation were the measurement of:

1. the applied load (P), which is obtained directly from the hydraulic jack;
2. the displacements (DT) of the connection, beam, top-and-seat angle, and web of the column, which are directly predicted by using linear variable displacement transducers (LVDTs); and
3. the strains at the stiffener of the beam and at the top-and-seat angle connections, which are obtained directly from the strain gauges.

The results were collected using a data logging device that recorded all measurements and the load cells at one-second intervals. All of the