Journal of Constructional Steel Research 140 (2018) 208–221

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Initial stiffness and strength characterization of minor axis T-stub under out-of-plane bending

Beatriz Gil *, Rufino Goñi, Eduardo Bayo

University of Navarra, Department of Construction, Services and Structures, 31080 Pamplona, Spain

ARTICLE INFO

Article history:
Received 29 June 2017
Received in revised form 29 September 2017
Accepted 22 October 2017
Available online xxxx

Keywords:
T-Stub
Semi-rigid connections
Minor axis bending
Out-of-plane bending
Experimental
Finite element
Analytical characterization

ABSTRACT

No research has been performed yet that deals with the characterization of the minor axis of steel joints under out-of-plane bending. As a consequence, a complete description of all the components that become part of a 3D steel joint is not yet available either in scientific journals or current codes. Moreover, it is necessary to identify the behavior of each isolated component that is subjected to in and out of plane effects before studying the interaction among components and the interaction with the loads that act in both the major and minor axis of the joint.

The aim of the research described in this paper is to define the behavior of the T-Stub under out of plane bending attached to the column minor axis. In the proposed kind of joint the minor beam is not attached to the column web but to additional plates welded to the column flanges.

With the purpose of characterizing this component, two experimental tests have been performed that allow validating the finite element models. Then, a parametric study is performed by varying different characteristics of the joint to check their influence. Through the tests and models the additional plate in bending has appeared to be the most influential component, which is not characterized in the Eurocode 3.

Finally, analytical expressions for the initial stiffness and strength of the additional plate of the T-Stub in minor axis under out of plane bending are presented.

1. Introduction and objectives

Extensive experimental, numerical and analytical investigations on semi-rigid steel joints have been carried out that have focused on the bi-dimensional behavior [1,2], the overall three-dimensional behavior [3–8] and that of the isolated components in which the joint can be subdivided [9–12]. These studies have mainly been developed taking into account loads acting in the beams major axis, that is, loads that cause in-plane bending in the beams and the corresponding joints. The column can be either subjected to major axis bending or minor axis bending depending on whether the connection is attached to the column major or minor axis [13–16].

There has been little work dealing with joints or components subjected to loads in their minor axis [17,18], and no research has been done to deal with minor axis joints under out of plane bending. As a consequence, a complete description of all the components that become part of a 3D steel joint is not yet available either in the scientific journals or current codes. In addition, it is necessary to identify the behavior of each isolated component that is subject to in and out of plane effects before studying the interaction among components and the interaction with the loads that act in both the major and minor axis of the joint.

Although out-of-plane bending may take place less frequently than in-plane bending, this situation appears in:

- Internal joints of 3D frames
- Façade joints when subjected to lateral wind loads
- Crane girders subjected to both vertical and transversal loads, particularly when they are designed as continuous beams (EC3-6, CEN 2004 [19]).
- Beams supporting floors with eccentric loads, which induce torsion in the beams
- Joints under fire conditions that induce three dimensional effects

Beam to column connections under out of plane loading conditions are usually considered either pinned or rigid for frame analysis, as well as for resistance and stiffness checks. Furthermore, stability checks require the calculation of a critical buckling load (in case of members under compression) and a critical lateral buckling moment (in case of elements under bending). In both cases, the resulting value depends on three factors: the characteristics of the element, the type of loading, and the boundary conditions. Modern codes, including Eurocode 3 (CEN 2005 [20]), allow the stability checks to be done by either approximated formulations or by means of advanced method of analysis. The latter

* Corresponding author.
E-mail address: bgilr@unav.es (B. Gil).

https://doi.org/10.1016/j.jcsr.2017.10.028
0143-974X/

Nomenclature

b_b	Beam width
b_{eff}	Effective breadth
$M_{ap,Rd}$	Bending moment resistance of the additional plate
$M_{b,pl,Rd}$	Bending moment resistance of the beam
$M_{c,pl,Rd}$	Bending moment resistance of the column
$M_{j,Rd}$	Bending moment resistance of the joint
M_p	End plate or additional plate plastic moment
E	Young modulus for steel
e_l	Distance between the pushing force and the additional plate edge.
e_{ap}	Distance between the bolts and the additional plate edge.
$F_{ap,c,Rd}$	Additional plate strength for the compression side
$F_{ap,t,Rd}$	Additional plate strength for the tension side
g	Horizontal distance between the bolts in a row
I_b	Moment of inertia of beam section
$k_{ap,t}$	Axial stiffness coefficient for the tension side (pulling side)
$k_{ap,c}$	Axial stiffness coefficient for the compression side (pushing side)
L_b	Beam length
$S_{ax,ap,ini}$	Initial axial stiffness of the additional plate
$S_{j,ini}$	Initial stiffness of the joint
S_b	Beam stiffness
$S_{c,T}$	Torsional stiffness of the column
t_{ap}	Additional plate thickness
$T_{c.Rd}$	Torsional strength of the column
t_{ep}	End plate thickness
t_{fb}	Beam flange thickness
w_{ap}	Additional plate width
z	Lever arm. Distance between the pushing and the pulling forces

become much more accurate and rigorous if the correct boundary conditions are provided. For this purpose, the minor axis stiffness and strength of the joint should be characterized.

In view of the above, this paper intends to define the behavior of the T-Stub under out of plane bending attached to the column minor axis. In the proposed kind of joint the minor beam is not attached to the column web but to additional plates welded to the column flanges (see Fig. 1) following a quite standard design that is presented in [3–5,17,18]. The advantages of these additional plates are: first, there is less interaction between the loads of the connections at both sides of the column; second, it is easier to build the joint; and third, the plates increase the stiffness of the major axis joint.

With the purpose of characterizing this type of joint, two experimental tests have been performed. The experimental results serve to validate numerical finite element models carried out with the software Abaqus [21,22]. Then a parametric study is performed by varying selective characteristics of the joint to check their influence. Through the results of the tests and the models, the additional plate in bending has turned out to be the most influential component, which is not characterized in the EC3. Then, a characterization of this component under bending: analytical expressions for the initial stiffness and bending strength, as well as a mechanical model for the complete T-Stub in minor axis under out of plane bending are presented.

2. Experimental program

The experimental program has consisted on testing two specimens that represent a T-Stub made of half a beam welded to an end plate,

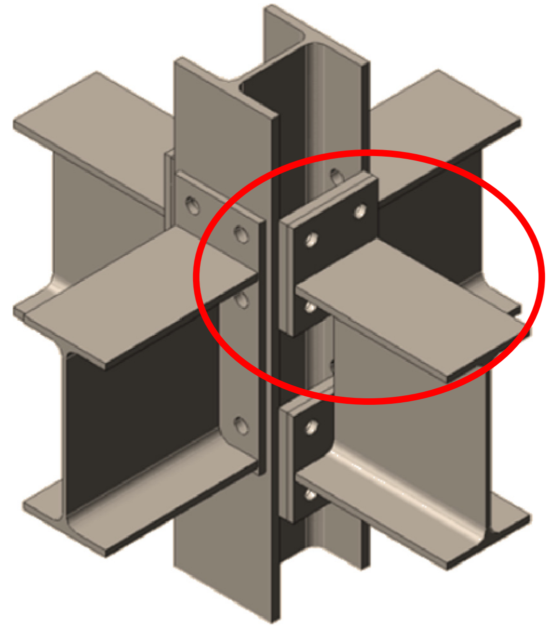

Fig. 1. Joint configuration.

which is bolted to the minor column axis through an additional plate as shown in Fig. 1. The advantages of this kind of additional plates are discussed in Refs. [3–5,17,18]. The load is applied in the beam minor axis so that the T-Stubs is subjected to out of plane bending. The difference with the tests performed in Ref. [17] is that the T-Stubs were attached to the column major axis and, in this case, the T-Stubs are attached to the column minor axis.

Some characteristics vary between the two performed specimens: the beam profile, the plate thicknesses and the bolt diameters. The characteristics of the two specimens are summarized in Table 1. In the first specimen, named TS01m, the flange width of the T-stub is smaller than the distance between the interior faces of the column flanges, inducing an important bending in the additional plate. In the second specimen, named TS02m, the T-Stub flange width is slightly larger than the distance between the internal faces of the column flanges so that the compression in one side of the T-Stub is transmitted directly to the column flange, thus changing the bending moment distribution and deflected shape in the additional plate (see Fig. 2).

2.1. Mechanical properties of the materials

The mechanical properties of the materials used in the specimens are described in Table 2. The steel grade for sections is S275 and for the plates is S355; steel grade for bolts is 10.9 and that for the welds is Fe ER 70S-6 WL G3Si1. The real properties of the steel are obtained by means of tensile coupon tests for every kind of section, that is, for the HEB160, IPE 200, IPE 300, 10 mm plate and 6 mm plate. The true stress–strain curves will be used later in the finite element models for the calibration process. However, nominal values will be used in the parametric study.

Table 1
Tested specimens.

Test	Column	Beam	End plate	Additional plate	Joint
TS01m	HEB 160 (S275)	IPE 200 (S275)	6 mm (S355)	6 mm (S355)	4 bolts M12 (10.9)
TS02m	HEB 160 (S275)	IPE 300 (S275)	10 mm (S355)	10 mm (S355)	4 bolts M16 (10.9)