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Analytical plate approach for the axial stiffness prediction of stiffened angle cleats

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ABSTRACT

In this paper, a plate analytical model for the prediction of the axial stiffness of stiffened angle cleats has been dealt with. In order to support the investigation, an experimental study was carried through on pull test of stiffened angle assemblies, representing some of the common practice design possibilities for top-and-seat angle connections. Additionally, an advance 3D Finite Element model was developed to assess this investigation. The FE model includes the possibility of bolt preloading, reproducing with great accuracy the actual stiffened angle cleat behavior. An equivalent plate analytical model for the prediction of the axial stiffness has been proposed on the basis of numerical parametric studies linked with the definition of an effective width for stiffness calculations. This effective width covers the different possibilities regarding the angle widths and the bolt-to-stiffener positions. This proposal provides satisfactory results in comparison with experimental data from literature and from the tests carried out for this study. It is intended for practical design purposes of stiffened angle cleat connections, and could be used within the EC3 component approach.

1. Introduction

Conventional analysis and design of steel frameworks are usually carried out under the assumption that the connections are either fully rigid or ideally pinned. These considerations radically simplify the analysis and design procedures. Nevertheless, it is a fact, from experimental observations, that all connections used in current practice possess stiffness which fall between those extreme cases [1]. The characterization of the real semi-rigid behavior of connections must be properly modeled in order to reliably predict the response of the frame. Some of the typologies of semi-rigid connections are based on the combination of angle cleats. The use of bolted angle cleat connections is characterized by substantial economical benefits essentially due to the ease in the erection process. On the other hand, this kind of connection preserves the independence of the members, enhancing both deconstructability and reusability [2]. Finally, this typology is more suitable for seismic design than welded moment connections as it was demonstrated by the analysis of the effects of Northridge and Kobe earthquakes [3].

The initial stiffness of this typology could be increased by introducing stiffeners in the joint design [4]. The T-stub analogy is commonly used to model many components of bolted connections. Newly, analytical methodologies based on a frame approach have been proposed to predict the axial stiffness of preloaded [5] and non-preloaded T-stubs [6]. This frame models were conceived for hand calculation, instead of more sophisticated methodologies based on computer implementation [7] or finite element (FE) analysis [8–14]. In these analytical approaches, the response was calculated by means of a beam assembly representing the flanges of the T-stub and the bolts. These frame models considered an effective width for stiffness calculation based on parametric studies using plate FE models.

In this work, the behavior of stiffened angle cleats is dealt with. The main objective of this paper is the determination of the angle axial stiffness. Therefore, the noticeable 3D behavior in terms of deformation is taken into account. In this sense, the analytical approximation proposed for this typology will be pointed to a plate analogy instead of the frame assemblies used for non-stiffened T-stubs [5,6]. First of all, an analytical solution for the stiffness of the simple plate analogy will be numerically obtained by means of shell-based FE models. Once this simplified expression has been stated, the effects of the bolt clamping and the prying force will be included in the stiffness formulation through an equivalent geometrical parameter. This equivalence will be established by way of a more sophisticated FE model, which will include the effects mentioned before. On the other hand, the use of an effective width for stiffness calculations will be also considered and discussed. For the evaluation of this paper's proposal, previous experimental data have been considered. This experimental study consists of two series of tests carried out by Skejic et al. [15,16] at the Civil Engineering Faculty of Zagreb. Besides, an experimental campaign was developed in order to count on additional tests to validate the results of the investigation.

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2. Skejic's et al. experimental work

The specimens of Skejic's et al. experimental study were constituted by two test series of flange cleats labeled as *g0s1* and *g1s1* [15,16]. All the angle cleats were connected through the flanges by means of two high strength grade 10.9 M16 bolts. The flange cleats were made from an L150 × 90 × 10 steel grade S 235 JR profile. It is relevant to point out that the geometries of the shortest angle flange are the same for both series, and the only geometrical difference lies in the bolt holes position of the larger angle flange, as shown in Fig. 1. The experimental tests were carried out under displacement control with a constant speed of 0.01 mm/s up to the collapse of the specimens. Additional detailed information about this experimental work can be found in [15].

3. Developed experimental study

Considering the lack existing in literature on stiffened angle tension tests, an experimental study was carried through. The tests were labeled as *Aangle_thicknessSstiffener_thickness*. Five snug-tightened specimens made of S275J steel with the geometrical properties described in Figs. 2 and 3 and in Table 1 were tested. The tests were carried out through System 7000 data acquisition system that can be controlled using Vishay Micro-Measurements StrainSmart® software. The tests arrangement consisted of two angles attached to rigid supporting plates through the steel assemblage shown in Fig. 4. The tests were instrumented with two load cells with 30 Tons of capacity and a sensitivity of 2 mV/V, placed under the actuators. These actuators possess a load capacity of 30 Tons and maximum stroke of 220 mm. Additionally, two displacement sensors were placed in both sides of the angle assemblage to monitor the load displacement relationship as shown in Fig. 5.

The mechanical properties of the five specimens are summarized in Tables 2 and 3.

The load was applied to the rigid plates, and their relative displacement was measured. In all cases, a preloading step in the elastic range was done and, after that, the load was applied. Since the objective of the study was to analyze the axial stiffness, all tests were loaded until approximately two thirds the angle cleat resistance. This bound resistance was obtained with the assessment of the FE model described in Section 4.

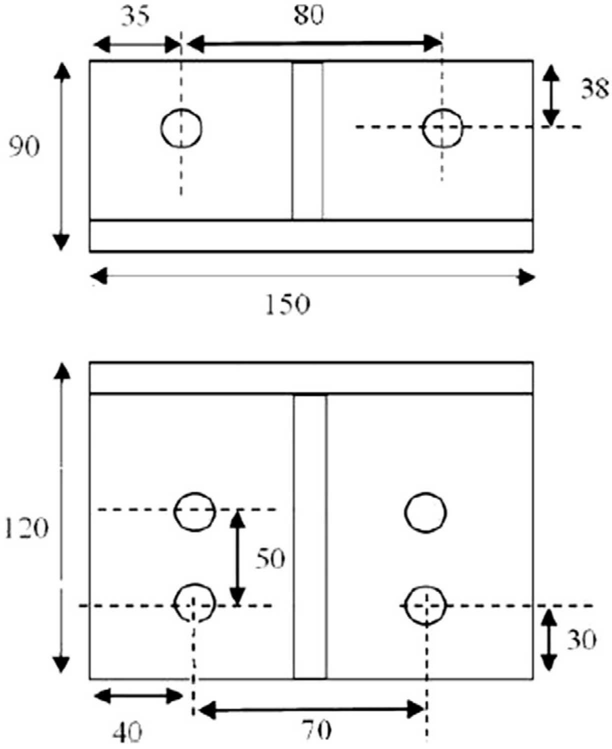

Fig. 2. Experimental test standard dimensions (mm).

There is a variation between the measurements of the two displacement sensors owing to the undesired rotations of the specimen due to geometrical imperfections. Because of this, an average value of the

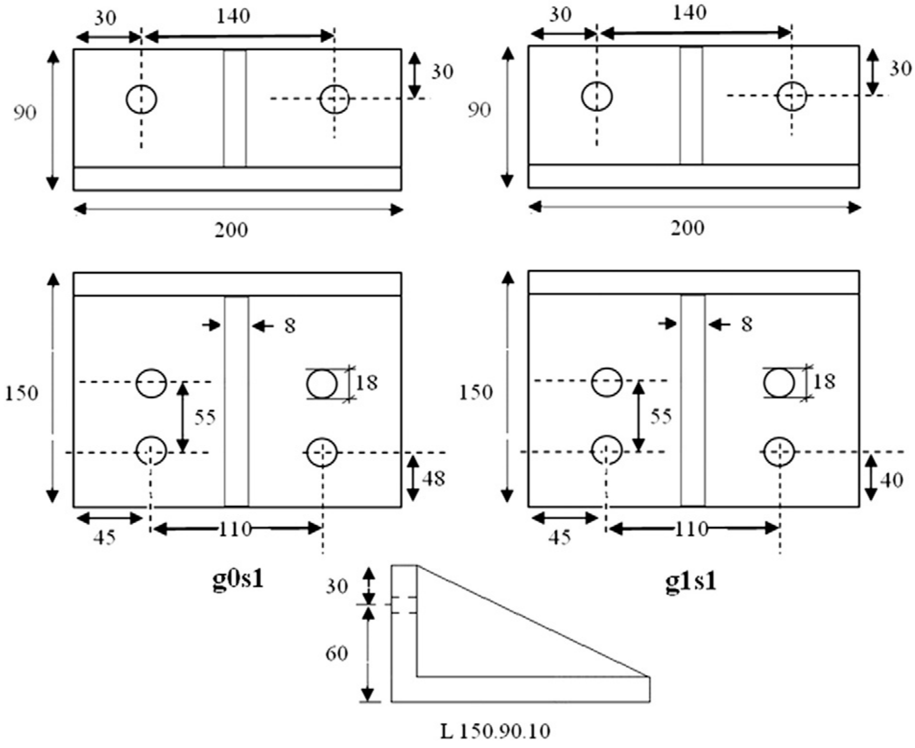

Fig. 1. Skejic et al. specimen geometrical properties (mm).