Journal of Constructional Steel Research 141 (2018) 118–131

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Numerical estimation for initial stiffness and ultimate moment of T-stub connections

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ARTICLE INFO

Article history:
Received 4 January 2017
Received in revised form 23 May 2017
Accepted 12 November 2017
Available online xxxx

Keywords:
T-stub connections
Finite element method
Initial stiffness
Collapse mechanism
Size factor
Ultimate moment

ABSTRACT

The work in this paper presents the results of a series of finite-element simulations aiming at the prediction of initial stiffness and ultimate moment for T-stub connections. The developed finite element models using ABAQUS software are verified by comparison with previous experimental tests by others. Several parameters, such as the material properties, flange thickness, web thickness, flange length, and web height of T-stub, gage distance, height of column, and depth of beam are considered in the analysis. An improved model for the initial stiffness is proposed, and it agrees well with the various test data. The types of collapse mechanisms for T-stub connections are also established. The model of ultimate moment capacity is proposed, and good agreement between the proposed model and the various test data is shown.

1. Introduction

A T-stub connection consists of two T-stubs welded or bolted to the beam and column flange. This type of connection is popularly used in steel structures because of its high flexural resistance, as shown in Fig. 1. In steel structures, T-stub connections exhibit semi-rigid behavior affecting the overall force distribution in the members of steel frames. Therefore, the moment-rotation relationship of T-stub connections must be known firstly, and then their influence of the connections should be incorporated in the structural analysis and member design. As a result, accurate modeling of moment-rotation relationship for T-stub connections is necessary for engineering application. The object of this work is to develop accurate models for estimating the initial stiffness and ultimate moment of T-stub connections, which is subjected to bending moment and shear loads.

In the past, several researchers conducted experiments to investigate the moment–rotation characteristics of T-stub connections. In 1999 and 2000, Swanson carried out experiments on bolted connections under monotonic and cyclic loading [1,2]. In 2003, Wang and Duan et al. investigated initial stiffness and ultimate moment of semi-rigid connections [3,4]. In 2006, Xu et al. reported the results for two full-scale tests of T-stub connections [5]. In 2011, Yi analyzed the effect of several parameters on the initial stiffness and ultimate moment [6]. Guo et al. conducted a series of tests on the moment-rotation behavior of several types of connections, including T-stub connections [7]. In 2012, Huang and Wang investigated the ultimate strength under static load [8,9].

Some researchers have also derived different design equations to calculate the initial stiffness or ultimate strength of T-stub connections based on various analysis models. In 1977, Packer and Morris proposed the types of collapse mechanisms of T-stub and suggested the equation of the ultimate moment of T-stub connections [10]. From 1999 to 2002, Swanson, Faella et al, Piluso et al., and Kulak et al. proposed different equations of the ultimate strength based on Packer and Morris's theory [1,11–14]. In 2004, Coelho et al. proposed a simplified model to predict the behavior of T-stub connections [15]. From 2005 to 2011, Wang and Chen suggested a spring element and derived the formulation of the initial stiffness [16]. Duan et al. and Guo et al. also derived different analytical equations of the initial stiffness based on different beam models [4,7]. In 2014, Shin and Park also proposed a simplified model to estimate the characteristics of T-stub connections [17]. Yang et al. analyzed the effect of prying action and gave the formulations for calculating the initial stiffness and ultimate moment [18]. In 2016, Francavilla et al. suggested an analytical model to predict the whole force-displacement curve of bolted T-stubs [19].

Besides the above methods, some researchers also used the finite element method (FEM) to obtain the moment-rotation characteristics of T-stub connections. In 1997, Bursi et al. analyzed the behavior of bolted connections using FEM [20]. Mistakids et al. proposed an effective 2-D numerical model and predicted the moment-rotation behavior using MARC

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https://doi.org/10.1016/j.jcsr.2017.11.008
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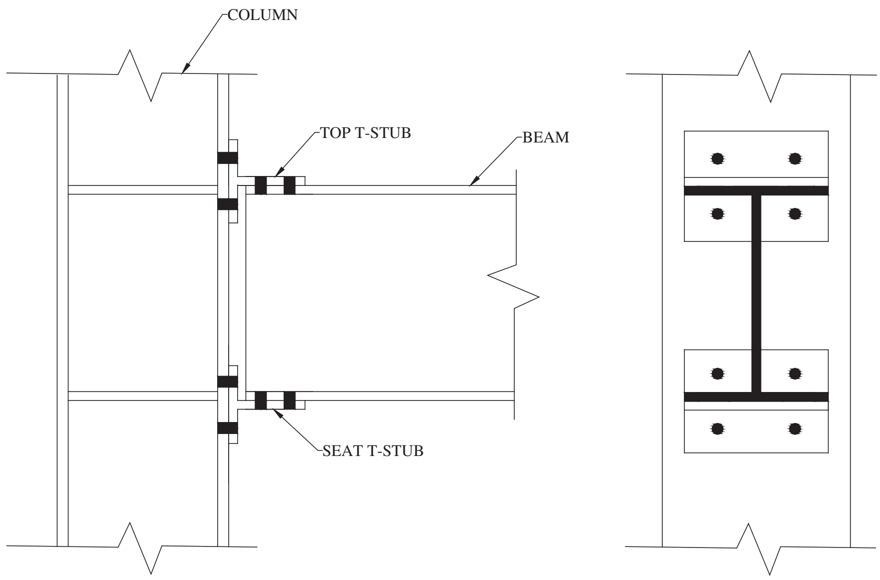

Fig. 1. T-stub connections

software [21]. From 2002 to 2003, Swanson et al. and Gantes et al. performed finite element analysis and investigated the behavior of T-stub connections [22,23]. From 2004 to 2010, Coelho et al. studied the behavior of T-stub connections with two different types of T-stubs (i.e., rolled and welded T-stubs) [24]. Hu, Zhao and Xu investigated the effect of different parameters on the moment-rotation behavior using FEM [25–27]. From 2012 to 2014, Herrera et al. used FEM to study the performance of built-up T-stub for double T moment connections [28]. Hantouche et al. reported the results of a series of finite-element simulations on the strength in thick-flange T-stub [29,30]. Abidelah et al. studied the effect of the flexural rigidity of the bolt on the behavior of T-stub connections using FEM [31]. In 2015, Francavilla et al. proposed a simplified finite element model and predicted the moment-rotation behavior using SAP2000 computer program [32]. Ceniceros et al. used a numerical-information approach to study the ductile behavior [33,34].

As described above, there are numerous publications discussing the moment-rotation behavior of T-stub connections. However, these formulations predicting the initial stiffness and ultimate moment have some limitations as the accuracy of these models are not ideal [18].

In Eurocode 3, the types of joint models are divided into simple, continuous, and semi-continuous models. When a connection is classified as semi-continuous model, the connections flexibility should be estimated and included in the structural analysis for analyzing the inner forces and displacement. For design, the moment-rotation model of a connection may be adjusted to a bi-linear curve for simplification, as described in Fig. 2 [35,36]. In this figure, R_{ki} is the initial stiffness of a connection; M_u is the ultimate moment of a connection; θ_r is the rotation capacity; and S_m is the stiffness modification coefficient. However, this bi-linear curve cannot accurately represent moment-rotation relationship of T-stub connections.

In AISC, three types of joint of are suggested: simple connections, partially restrained (PR), and fully restrained (FR). When PR connection is chosen for a connection, the moment-rotation behavior of connection must be considered in the structural analysis in order to analyze the inner forces and displacements of structure. Hence, the moment-rotation characteristics should be known before structural analysis and member design. As pointed out by AISC, the moment-rotation characteristics for many types of connections can be established from several databases, such as Goverdhan (1983), Ang and Morris (1984), Nethercot (1985), and Kishi and Chen (1986) [37]. However, these databases have some limitation as they only collect limited experimental data, and they don't cover all parameters.

Although previous studies have made significant progress, design equations in the current state-of-the-art and state-of-practice technology lack sufficient accuracy for a wider range of parameters. For accurately estimating the initial stiffness and ultimate moment of T-stub connections, three-dimensional nonlinear finite element analysis is carried out using ABAQUS software. Validity of the finite element model is examined by comparing the results of FEM with the experimental results of Huang and Yi. Then, a parametric study using the validated finite element models is performed, and design-basis equations obtaining in this study are compared to previous models. Since the column stiffener, widely used in construction, is utilized in this study, the deformation of connection but not panel zone is mainly considered.

2. Initial stiffness

The initial stiffness of T-stub connections is an important parameter affecting the force distribution in the structure. For accurately estimate the initial stiffness, seven major parameters (i.e., the length, flange thickness, web thickness, and web height of T-stub, gage distance, height of column, and depth of beam) are investigated in this work.

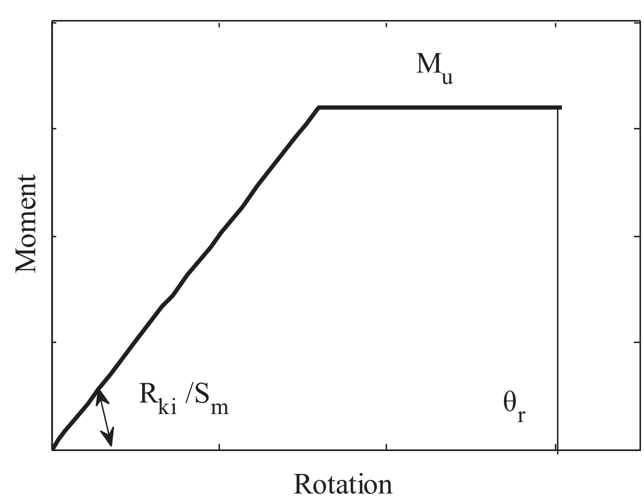

Fig. 2. Design moment-rotation characteristic