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Modified stiffness model for thick flange in built-up T-stub connections

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ABSTRACT

The results of the finite element simulations are used to develop a modified stiffness model to predict the behavior of thick-flange in built-up T-stub connections with Complete Joint Penetration (CJP) and fillet welds. Using ABAQUS, three-dimensional finite element (FE) models are developed for the selected cases. The performance of the FE model results is compared to experimental results for validation. The FE model results are used to develop the modified stiffness model that characterizes the behavior of thick-flange in built-up T-stub connections. The model is based on a combination of finite element and a stiffness modeling approach that incorporates the overall flange deformations of key component elements, and it includes nonlinear material behavior of both tension bolts and base material, accounts for pretension of fasteners, and contact interactions. The modified stiffness model consists of linear and nonlinear springs which model deformations from tension bolt elongation, T-stub flange, and prying force. The model predicts the force-deformation curve of the whole T-stub flange taking into account flange-partial-yielding and accounting for the contact force encountered. A new failure limit state is highlighted, which is partial-yielding at the K-zone followed by bolt fracture, with or without prying. The behavioral characteristics of the flange in T-stub connections are examined including strength, stiffness, and deformation capacity. Comparisons of model predictions with FE and experimental data show that the modified stiffness model accurately predicts the response of thick-flange built-up T-stub connections with CJP or fillet welds and accounts for flange-partial-yielding followed by tension-bolt-fracture, with and without prying.

1. Introduction

Previous research work on the behavior of T-stub connections dealt with estimating the strength, stiffness, and deformation of flange in T-stub connection using experimental and analytical work [1–8]. Stiffness models and finite element models have been suggested to predict the force–deformation curve of the flange of the T-stub connection. The validity of these models is demonstrated to be acceptable by comparing the results predicted with experimental results. Well established finite element and stiffness models exist to account for the behavior of T-stub connections with thin and medium flange in which $g_t/t_f \geq 4.00$, where g_t is the flange gage distance and t_f is the flange thickness. In these models, a flange of a T-stub is defined to be thin if its capacity is limited by the formation of only 2 plastic hinges (one at the K-zone and one at the bolt line), whereas the flange is defined to be of medium thickness if its capacity is limited by one plastic hinge at the K-zone [2,9,10]. However, for thick flange T-stub connections where $3.00 \leq g_t/t_f \leq 4.00$, similar methods are not available to predict the response and in particular the force–deformation curve. T-stubs in which $g_t/t_f \leq 3.00$ are not possible based on current fabrication and code practices [11]. A typical built-up T-stub connection associated with deep beam is shown in Fig. 1.

Stiffness models for predicting the force–deformation curve of flanges in T-stub connections are reported in the literature and the important ones include those suggested by Swanson [1], Swanson and Leon [2], Lemonis and Gantes [5], Piluso and Rizzano [6], Hu et al. [8], Eurocode [10], and Coehlo et al. [12]. These stiffness models are based on component linear spring theory, and incorporate deformations contributed by tension bolt elongation and bending of the T-stub flange. Swanson and Leon [2] proposed an elastic–yielding–plastic flange model to predict the behavior of relatively thick flange ($g_t/t_f = 4.00$). The model considered weighted averages of the fully plastic states and the elastic states to determine the partially plastic stiffnesses and prying gradients. However, this elastic–yielding–plastic flange model does not accurately predict the behavior when compared with experimental results obtained as part of this research for stiffer flanges in which $3.00 \leq g_t/t_f \leq 4.00$. This is because when partial yielding occurs across the T-stub flange, the theoretical partially plastic stiffness and gradient have a nonlinear behavior and result in a nonlinear force–deformation relationship, which the previous model [2] fails to simulate.

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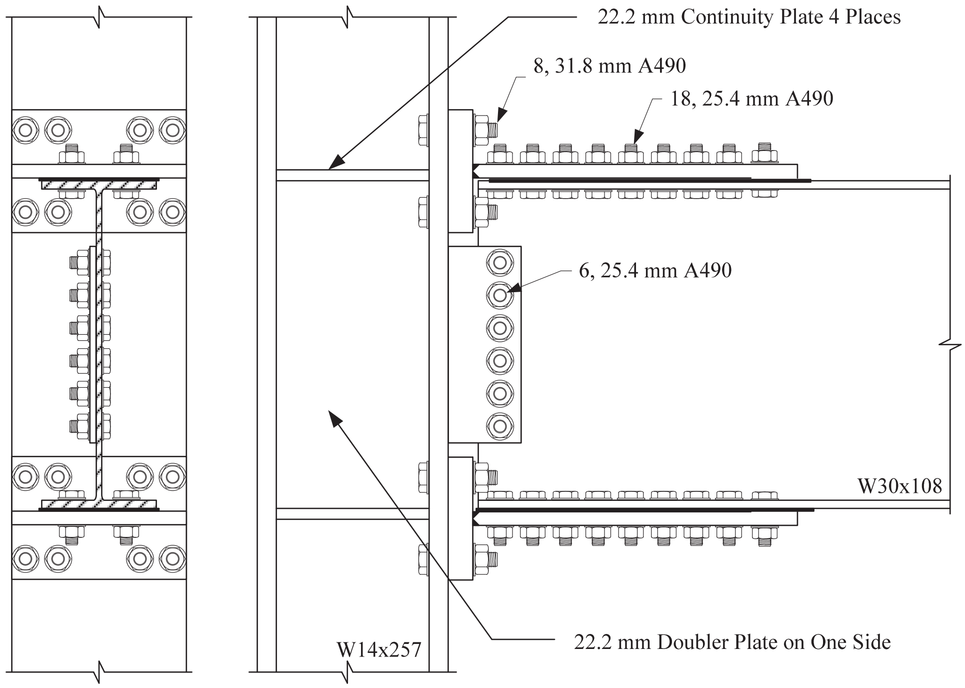

Fig. 1. Typical built-up T-stub moment connection.

Finite element modeling studies for predicting the force–deformation curve of the flange of a T-stub connection are reported in the literature; the most important ones include those suggested by Swanson [1], Swanson et al. [3], Popov and Tahirov [4], Piluso and Rizzano [6], Kasai et al. [7], Hu et al. [8], and Coehlo et al. [12]. In these studies, finite element analysis was conducted to model the full-scale (beam, column, and T-stub) and the component behavior

(T-stub) of the connection is as close as possible to the experimentally observed behavior. Also, finite element analyses were performed to study the prying action in the flange–bolt system for various flange thicknesses [4]. It was found that the gage to thickness ratio (g_t/t_f) has a major impact on the amount of prying encountered in T-stub connections.

In summary, besides the experimental tests of rolled and built-up T-stub connection mentioned in the literature, finite element modeling of various T-stub connections with thin, medium and thick T-flange have been reported in the literature. Also, successful stiffness models have been suggested by Swanson and Leon [2] and Lemonis and Gantes [5] to predict the behavior of T-stub connection with thin and medium T-flanges ($g_t/t_f \geq 4.00$). These stiffness models predict accurately the behavior of thin and medium T-flange for both built-up and rolled T-stubs, but less accurately when used for thick T-flanges where $3.00 \leq g_t/t_f \leq 4.00$. Thus, a similar stiffness model is needed to predict the behavior of thick T-flanges which needs to be validated using both experimental test results and finite element model predictions. The stiffness model predicts the capacity of the connection for the failure limit state of tension flange partial yielding followed by bolt fracture. This study is limited to the case of thick-flange T-stubs that are associated with deep girders ranging from W24 to W36 sections where the slenderness ratio is $3.00 \leq g_t/t_f \leq 4.00$.

In the study reported, the behavioral characteristics of thick flanges in T-stub connections are examined including strength, stiffness and deformation capacity. The complexity of thick T-stub connections is presented by quantifying the contact phenomenon that occurs between the T-flange and the column flange, the onset of yielding of the flange, and partial yield penetration into the flange thickness as the external load acting on the connection increases. Some assumptions are taken into consideration to avoid these difficulties.

2. Nonlinear finite element modeling of thick flange built-up T-stub connections

Nonlinear finite element analysis results are used to develop a modified stiffness model for thick flange T-stub connections built-up using either CJP or fillet welds to connect the T-stem to the T-flange. Using the experimental results from a pilot study presented in [13,14], the geometric and force related variables that impact the connection behavior are identified, and a range of variation based on current design and fabrication practices are established. Considering the T-stubs as three dimensional systems, 14 finite element models are developed for T-stub connections using a solid element available in the software package ABAQUS [15] (7 T-stubs with CJP welds and 7 with fillet welds). These cases are selected based on the findings of a parametric study [13]. The finite element results are used to develop a modified stiffness model for thick built-up T-stub connections, with either CJP or fillet welds.

2.1. Three-dimensional solid thick T-stub

Using ABAQUS [15], three-dimensional (3-D) finite element models were developed for typical T-stub connection test specimens which incorporate the following characteristics: (1) nonlinear material behavior for base material and bolt material; (2) full pretensioning of the fasteners; and (3) contact interactions between the T-stub and column flanges, bolt head and column flange, and bolt nut and T-stub flange. The finite element models are used to conduct virtual tests of T-stub components with thick flanges ($3.00 \leq g_t/t_f \leq 4.00$).

The FE model includes both the T-stub connection and the W12 × 136 stiffened column stub used in the experiment [13,14]. The W12 × 136 column stub is stiffened with web stiffeners plates. The length of the column stub is 965 mm. In the research reported only the T-stub connection element deformations are considered to develop the desired modified stiffness model and any contributions from the column stub side are ignored. In this study, all nodes of the top flange of the column stub were fully constrained. The column stub was kept for a future study in which contributions from the column side will be considered. The FE model of the T-stub connection contains: (1) 4686