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Moment-rotation behavior of top-and seat-angle connections with double web angles

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ABSTRACT

The objective of this study is to develop more accurate models to estimate the moment-rotation behavior of top-seat angle connections with double web angles (TSACW). As the characteristics of connections play a very important role in steel structural design, the effects of connections should be considered when an accurate analysis of semi-grid steel frame is desired. Experimental data of TSACW collected is used for evaluating different models, such as the initial stiffness and ultimate moment. Experimental data of top-seat angle connections without web angle collected is used to establish the effect of top and seat angle on the initial stiffness of TSACW. A more accurate equation for the initial stiffness is proposed, and good agreement between the proposed model and various test data is made. The type of collapse mechanism for TSACW is established from Kishi and Chen, Li, and Kong and Kim's analysis. A model of the ultimate moment capacity is proposed, and it agrees well with various test data. A more accurate model of the moment-rotation relation is also suggested.

1. Introduction

A top-seat angle connection with double web angles (TSACW) is a popularly used type in steel structures because of its high flexural resistance, as shown in Fig. 1. In AISC-ASD Specimens, this type of connection is considered as semi-grid connection, which can contribute substantially to the overall force distribution in the structure [1]. As the characteristics of TSACW play a very important role in steel structural design, the effects of connections should be considered in structural analysis. Therefore, it is necessary to accurately estimate the moment-rotation behavior of TSACW.

In past years, some researchers have conducted experiments to investigate moment–rotation behavior of TSACW. In 1985 and 2000, Azizinamini et al. and Calado et al. experimentally evaluated the moment-rotation behavior under static and cyclic loading [2,3]. In 2006 and 2007, Li and Song carried out experiments on the monotonic behavior of TSACW made of cold-formed thin-walled steel [4,5]. In 2009, Wan experimentally investigated the hysteresis behavior of TSACW [6]. In 2011, Guo, Wang et al. studied the rotational stiffness of steel frame beam-column connections, including TSACW [7]. In 2014, Reinosa, Loureiro et al. conducted a test to verify the finite element model of TSACW [8].

Some researchers have also derived different design models to predict the initial stiffness or ultimate strength of TSACW based on various analysis models. In 1987, Azizinamini proposed a beam model and suggested an analytical equation of the initial stiffness [9]. In 1990, Kishi and Chen derived the models of the initial stiffness and ultimate moment capacity based on a cantilever beam [10]. In 2001, Pucinotti proposed a simplified mechanical model and suggested the equations of the initial stiffness and ultimate moment [11].

Besides the above methods, some researchers have also used the finite element method (FEM) to obtain the moment-rotation behavior of TSACW. In 2001, Kishi, Ahmed, and Yabuki used the FEM to estimate the moment-rotation characteristics [12]. In 2002, Citipitioglu, Haj-Ali, and White analyzed non-linear moment-rotation response using the FEM [13]. In 2004, Komuro, Kishi, and Chen performed nonlinear FEM and accurately estimated the moment-rotation relation of TSACW [14]. In 2007, Danesh, Pirmoz, and Daryan used a numerical method to study the effect of shear force on the initial stiffness [15]. In 2008, Pirmoz and Daryan, et al. analyzed the effect of web angle on the moment-rotation behavior using the FEM [16]. In 2014, Abdalla, Drosopoulos, and Stavroulakis performed nonlinear FEM to study the failure behavior of TSACW [17].

As described above, there are numerous publications discussing the moment-rotation behavior of TSACW. However, these moment-rotation characteristics (i.e., initial stiffness, ultimate moment) are accurate only for the limited range of TSACW. Hence, determination of simple and accurate models to predict the moment-rotation characteristics of TSACW connections is a difficult but necessary task.

In Eurocode 3, three different methods of global analysis of elastic, rigid-plastic, and elastic-plastic analysis are suggested [18]. When elastic-plastic analysis is chosen, the moment-rotation characteristics of joints should be used to determine the distribution of internal forces

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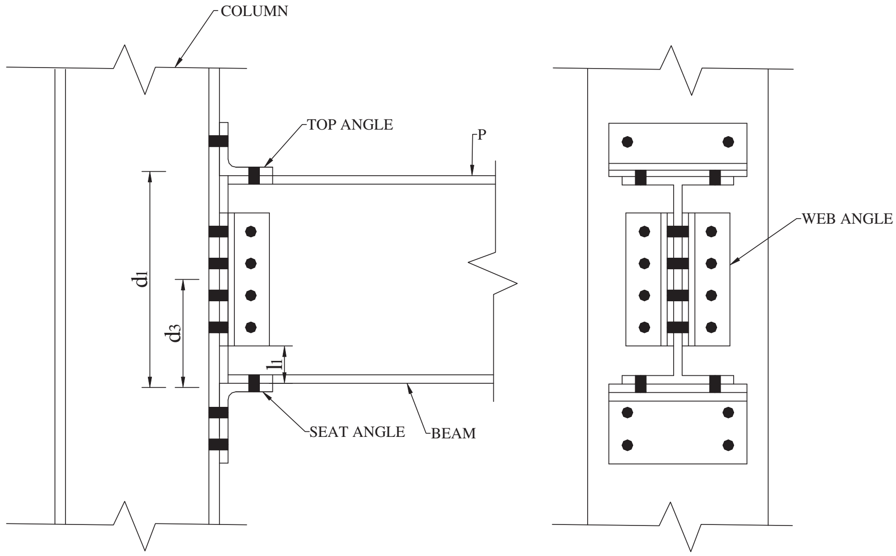

Fig. 1. Top-seat angle connections with double web angles.

and moments. The design moment-rotation characteristics of a joint used in the analysis may be simplified by adopting a bi-linear curve, as shown in Fig. 2. 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. For the design, the equations of the initial stiffness and ultimate moment for connections are given [19]. However, these equations are accurate only for the limited range of TSACW, and the equations are complicated.

In AISC, the types of joint are divided into fully restrained (FR), partially restrained (PR), and simple connections. When a connection is classified as PR connection, the relevant response characteristics of connection must be included in the analysis of the structure to determine the member and connection forces and displacements. Therefore, PR construction requires, first, that the moment-rotation characteristics of the connection be known and, second, that these characteristics be incorporated in the analysis and member design. Typical moment-rotation curves for many PR connections are available from several databases, such as Kishi and Chen [20]. However, these databases don't cover all parameters and all types of connections.

The purpose of this study is to develop new models for accurately predicting the moment-rotation behavior of TSACW.

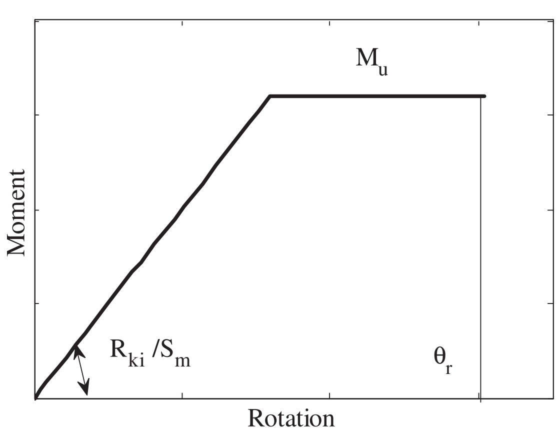

Fig. 2. Simplified bi-linear design moment-rotation characteristic.

2. Collection of experimental data

As pointed out by Cruz et al., a database of test results for connection behavior is important to the development of design methodologies, and it can help researchers to investigate the field without the financial burden of carrying out experimental work [21]. It is also pointed out by AISC that the moment-rotation characteristics of connections should be obtained from databases when an accurate analysis of semi-grid steel frame is desired [20]. Hence, the development of databases is important and necessary.

Experimental results play a crucial role in the development of design equations. As described above, some researchers have conducted experiments to investigate the moment-rotation behavior of TSACW. Therefore, experimental data on TSACW is collected. The data encompass experimental data, published from 1985 (Azizinamini) to the present, on bolted TSACW. All of the 31 tests of TSACW, including geometrical and mechanical characteristics, are shown in Tables 1–2.

3. Initial stiffness

3.1. Previous models

The initial stiffness of TSACW is one of most influential parameters influencing overall behavior of a connection. In 1987, Azizinamini proposed a beam model dividing the angle's leg adjacent to the column flange into two types of beam segments - rigid sections and flexible sections. Then, they suggested the equation of the initial stiffness for

Table 1
References and number of experimental M-θ curves for TSACW.

References for the experimental curves	Number of tests
Azizinamini A. (1985) [2]	18
Calado L. (2000) [3]	3
Song Q. Y. et al. (2007) [4,5]	3
Wan H. Y. (2009) [6]	2
Guo B. et al. (2011) [7]	1
Reinosa J. M. et al. (2014) [8]	4