Research on Design of Through-Diaphragm Connections between CFRT Columns and HSS Beams

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Abstract
The through-diaphragm connection detail has been identified as a good choice for attaching HSS beams to concrete-filled rectangular tube columns in engineering applications. In this research program an analytical study was conducted to comprehend the behavior of this detail and develop the accompanying design guidelines. The experimental results are presented elsewhere. In this paper two analytical models were established to predict the shear stiffness and yield shear strength of the HSS beam and panel zone, respectively. Theoretical results based on the proposed model well agreed with the experimental data. Finally, design provisions were introduced to check the strength in the connections.

Keywords: through-diaphragm connections, concrete-filled rectangular tube column, HSS beam, mechanical model, shear strength, shear stiffness, design

1 Introduction

Concrete-filled rectangular tube (CFRT) columns have been widely used in practical applications these days due to their benefits of excellent mechanical behavior and architecturally pleasing advantages. Hollow structural sections (HSS) beams continue to be an attractive choice because of their good tension resistance and high strength-to-weight ratio.

A large amount of research has been conducted on the connections between CFRT columns and steel H-beams. Previous investigation on the panel zone of these connections has included that of Kamba \textit{et al.} (1991), Kawaguchi and Marino (1994), Morita \textit{et al.} (1995), Sasaki \textit{et al.} (1995), Kawano \textit{et al.} (1998), Koester (2000), Lu \textit{et al.} (2000), Morino and Tsuda (2002), Fukumoto and Morita (2005), Park \textit{et al.} (2005), Choi \textit{et al.} (2009), Nie \textit{et al.} (2009), Qin \textit{et al.} (2014a, b). Theoretical models for the flexural strength and shear strength were proposed by these researchers. A perceived drawback of these mechanical models is the need for accurate material constitutive laws in order to properly characterize the behavior of the connection. This perception is not entirely correct, as the accuracy of the model does not hinge so much in the ability to identify each material accurately but on recognizing and properly modeling all the relevant deformation components.

Study on the seismic behavior of H-beam-to-CFST column connections has been conducted by Shanmugam and Ting (1995), Kang \textit{et al.} (2001), Ricles \textit{et al.} (2004), Shin \textit{et al.} (2004), Choi \textit{et al.} (2010), Qin \textit{et al.} (2014c, d, e). Additionally, various connection alternatives have been proposed and explored by researchers, such as the application of blind bolt (Tizani \textit{et al.}, 2013), combined channel angle connections (Málaga-Chuquitaype and Elghazouli, 2010), and through-bolt connections (Wu \textit{et al.}, 2005). Several state-of-the-art reports and papers also presented a large number of research results on CFRT column-to-H-beam connections (Shams \textit{et al.}, 1997; Shanmugam and Lakshmi, 2001; Nishiyama \textit{et al.}, 2002; Kurobane \textit{et al.}, 2004; Gourley \textit{et al.}, 2008).

However, few studies have considered the viability of through-diaphragm connections between CFRT columns and HSS beams, which are beneficial because of their reduction in surface area and decrease in lateral bracing requirements compared with open sections. Moreover, connections with HSS beams can be a challenge. The complex, unusual configuration of connections can pose...
geometrical and access difficulty for fabricators, and reinforcement such as horizontal stiffeners may not be feasible to include on closed sections. Therefore, both theoretical analysis and experimental data need to be expanded on the mechanical behavior of these connections.

In this paper, the HSS beam to CFRT column connection detail was used to identify the force transfer mechanism within the connection. Two models to estimate the elastic shear stiffness and the yield shear strength of the HSS beam and panel zone, respectively, were proposed. The reason that the research here focuses on the elastic shear stiffness and the yield strength is because these two parameters were found to be the most influential parameters affecting connection behavior from the results of many studies. The method presented herein trades off the need for a complex description of the constitutive laws for a number of deformation components. Design guidelines were introduced for the CFRT column-to-HSS beam connection with through-diaphragm.

The model presented in this paper is based, for most part, on sound engineering principles and experimental results. It is important, though, to stress at this point that the theoretical prediction of the shear transfer mechanism of the connections is an extremely complicated matter. In fact, both geometrical and mechanical nonlinearities arise. In some cases, simplifications and assumptions were made to reduce the model’s complexity to a reasonable level. As will be evident from the derivation of the formulations given in the following sections, the theoretical approach is based on the following approximations:

- Both steel and concrete contribute to the shear stiffness and shear strength of the beam-to-column connection. They are assumed to have independent behaviors and the total performance of the connection is equal to the sum of contributions from different components.
- Geometrical nonlinearity is disregarded, as one of the aims of the model is to provide methods and procedures intended for hand computation.
- Deformation of the holes for bolts was neglected in the model. While these deformation were deemed insignificant for the present work, larger hole sizes or other situations may amplify the importance of this component.
- Compatibility between bolt and hole displacements is not considered. The holes in the beam web was assumed to be perfectly aligned with the holes in the shear tab, and the bolts were assumed to exactly fit the hole locations.
- The behavior of the connection under shear force was assumed to be in a sequence of the yielding of the steel tube web, the yielding of the steel tube flange and through-diaphragm, and the yielding of the concrete.

As a result, some limitations exist. The model cannot provide the deformation corresponding to a random shear force and significant future work remains. Meanwhile, it should be mentioned that, there is no perfect design approach available for the through-diaphragm connections between the CFRT columns and the HSS beams yet. However, the results of this study can provide a good understanding of the behavior of this connection, and therefore, should prove useful in design. Although the model presented in this paper may at first appear to be overly complicated, it must be recognized that the behavior of this type of connections is not simple.

2 Experimental Program

2.1. Test specimen

The test specimen was constructed in a tee shape to simulate the external connection of a steel moment-resisting frame. The height of the column and the span of the beam were 4200 mm and 3600 mm, respectively. The specimen detailing is shown in Fig. 1. The 500×500×36×36 CFRT column was made of four steel plates vertically seamed by complete joint penetration (CJP)