Journal of Constructional Steel Research 112 (2015) 242–251

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Shear capacity of 3D composite CFT joints subjected to symmetric loading condition

Jiansheng Fan [a,*], Cheng Liu [a], Yue Yang [a], Yu Bai [b], Chao Wu [b]

[a] Department of Civil Engineering, Tsinghua University, Beijing 100084, China
[b] Department of Civil Engineering, Monash University, Melbourne, Australia

ARTICLE INFO

Article history:
Received 30 December 2014
Accepted 8 May 2015
Available online 5 June 2015

Keywords:
Composite joint
3D joint
Panel zone
Shear capacity
CFT column

ABSTRACT

Shear capacity analysis of the panel zone in a composite joint of concrete-filled steel tubular (CFT) column and steel beam is important for avoidance of premature shear failure of the joint. This paper reviews 2D shear capacity models for joints between CFT column and steel beam. Then a 3D model is proposed for consideration of joints subjected to symmetric beam loadings in two planes and compared to the existing 2D shear capacity models. The effects of encased concrete on the shear capacity of the joint are taken into account for 3D composite joints through an additional compression strut model. A shear force and deformation relationship with four linear segments is thus achieved for a composite joint. To evaluate the corresponding ultimate shear capacity, the modeling results are compared with experiments where specimens fail through shear mode at the joints. It is found that the shear–deformation relationship and ultimate shear capacities predicted for 3D composite joints agree well with the experimental results.

1. Introduction

A concrete-filled steel tubular (CFT) column is a structural element in which steel tube and encased concrete carry load by composite action between them. The strength and ductility of the encased concrete are improved by the confinement effect of the steel tube while the local buckling of steel tube is delayed by the encased concrete. Due to advantages such as high strength, excellent ductility and convenience for production and construction, CFT columns are widely used in civil infrastructure. In high-rise buildings, a typical structure system is formed by CFT columns connecting with horizontal structural members (such as beams and floor panels). To ensure structural ductility, premature shear failure of a composite joint should be avoided, especially in structural seismic design. Resistance to earthquake loading in such structural systems depends largely on the capacity of beam-to-column composite joints. Therefore, reliable estimation of the mechanical performance of composite joints between CFT column and beam is essential for structural design.

Extensive experimental and theoretical studies have been performed to understand the performance of the panel zone in a composite joint between CFT column and steel beam and to develop corresponding mechanical models. Analytic formulations for joint shear capacity have also been developed [1–5], but only a 2D configuration (i.e. with CFT column and steel beam in the same plane) has been considered. Research has shown that for a composite joint with internal diaphragms, the steel plates in the joint region and the encased concrete both contribute to the shear capacity of the joint. Using the superposition principle, equations have been formulated to estimate the shear capacity of 2D composite joints by the Architectural Institute of Japan (AIJ) [6]. In the latter research, however, the effects of axial compression on the shear capacity of the panel zone were not considered. Also, it was required that the nominal compression strength of the encased concrete should not be higher than 36 MPa, which largely limited its applicability for high-strength concrete. Koester [1] conducted a series of experiments on split-tee through-bolted moment joints between CFT columns and wide-flange steel beams. In this configuration, the shear capacity of the panel zone of the composite joints was estimated through regression analysis of experimental results without mechanism-based modeling. This limitation therefore restricts the applicability of the proposed shear capacity equation for other forms of composite joints with different connection configurations. Cheng et al. [2,3] proposed an innovative stress–strain model for the panel zone of a composite joint based on the compression strut mechanism, in which the shear force transfer was taken into account through a truss mechanism. The shear capacity formulation developed in this way considered the effects of axial compression on the steel wall and the encased concrete of the column; however, the model became complicated and was not convenient for design purposes. Nishiyama et al. [4] carried out a series of experiments on beam-to-column joints of CFT columns made of high-strength steel and concrete. Their experimental results showed that the design formula given in AIJ [6] was applicable for unconfined compression strength of concrete up to 110 MPa

* Corresponding author.
E-mail address: fanjsh@tsinghua.edu.cn (J. Fan).

http://dx.doi.org/10.1016/j.jcsr.2015.05.005
0143-974X/

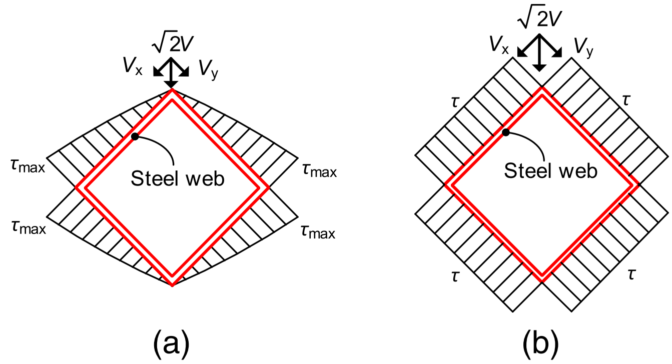

Fig. 1. Distribution of shear stress (τ) along webs of a steel tube in (a) elastic and (b) plastic stage under bi-directional loading ($V_x = V_y$).

and tensile strength of steel up to 809 MPa. Similar experiments were conducted by Fukumoto and Morita [5] on the joints of high-strength CFT columns and steel beams to investigate structural elastoplastic behavior. A new compression strut mechanism was proposed, where a tri-linear shear–deformation relationship was derived for description of the full shear deformation of the panel zone, and the effects of axial force on the behavior of the steel tube were also considered. In that study, the shear deformation at the ultimate strength of the encased concrete was defined as the ultimate shear deformation of the composite joint. Since the ultimate shear strain of concrete is much lower than that of a steel tube, the shear capacity at yielding of the webs of the steel tube was considered in the calculation of the ultimate shear capacity of the joint. In another words, the shear capacity of the joint was provided by the yielding strength of the steel tube plus the ultimate strength of the encased concrete.

Existing formulations of joint shear capacity only consider the shear forces in one plane, corresponding to a 2D composite joint configuration. For realistic composite joints under seismic action, the joint panel zone is actually subjected to shear forces in two planes, corresponding to a 3D joint configuration. For such cases, no mechanical modeling has yet been done to describe joint stiffness and to predict joint shear capacity. In this paper, the 2D load transfer mechanism is extended to a 3D construct to analyze the shear capacity of composite joints in CFT column systems. A 3D load transfer mechanism is analytically modeled and the contributions from both steel column and encased concrete to the shear capacity of the joint panel zone are investigated. In this 3D model, a shear–deformation relationship with four linear segments is considered and its reliability and applicability are verified against previous experimental results including scenarios of composite joints with normal strength concrete [7] and with high-strength concrete [4].

2. Analytic shear capacity model of a 3D composite joint

Composite joints in building structures are often under 3D loading conditions, such as those for interior columns, exterior columns and corner columns. In a CFT column system connected by orthogonal beams, the core zone of the 3D composite joint is actually subjected to shear forces from two orthogonal planes, the mechanism of which may be different from that of a planar composite joint. In this section, we establish analytic models of the shear–deformation relationship of steel tube and concrete core. Classical plastic theory is applied to derive the yield and ultimate shear strength of the steel tube. Two forms of strut mechanism are considered to model the ultimate shear capacity of the concrete core. The joint shear–deformation relationship is obtained by the superposition principle, considering the contributions from both steel webs and concrete core. It should be noted that the 3D loading conditions considered in this paper are limited to the scenario where the shear forces from two orthogonal directions are equal (resultant shear force in 45° direction) and the planar shape of the concrete panel is square, since this scenario is the most typical for 3D loading conditions.

2.1. Shear capacity and deformation of steel tube at joint region

The shear capacity of a steel tube at the joint region has two components. One component derives from the shear strength of the webs of the steel tube and the other derives from the shear capacity of the steel tube–inner diaphragm system. In 3D composite joints, the latter component derives mainly from the deformation of the diaphragm system from cubic to parallelepiped shape (similar to a frame mechanism) and it has been reported that this contribution to the total shear capacity of the steel tube at the joint region is very limited [8]. Therefore, only the contribution of the webs to the overall shear capacity of the steel tube is taken into account in this study.

In 3D joint panel zones subjected to shear forces from both x and y directions, the shear stresses in the webs of the steel tube can be determined by principles of material mechanics. Fig. 1 shows the distributions of shear stresses along the webs of steel tube in the elastic (Fig. 1a) and plastic stage (Fig. 1b) under bi-directional loading. If $V_x = V_y$, the resultant shear force V acts in a 45° direction to V_x or V_y.

In the elastic stage, the maximum shear stress within the webs of the steel tube (see Fig. 1(a)) can be calculated as:

$$\tau_{max} = \frac{\kappa_s V}{A_w} \tag{1}$$

where τ_{max} is the maximum shear stress within the webs of the steel tube; A_w is the shear area of the webs of the steel tube; κ_s is the shear coefficient, which equals 1.2 for a square hollow section according to Fukumoto and Morita [5].

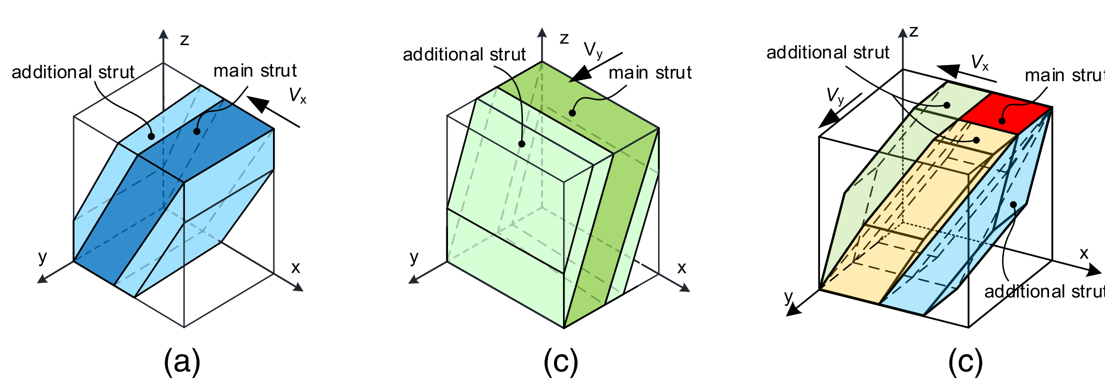

Fig. 2. Compression strut model for concrete at panel zone of a composite joint under loading in (a) XZ plane, (b) YZ plane and (c) 3D loading (bi-directional loading).