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Finite element analysis of circular concrete filled tube connections

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ABSTRACT

A parametric study based on finite element technique is performed to investigate the performance of different connection configurations between circular concrete filled steel tube (CCFT) columns and gusset plates subjected to axial compression loadings. The study focuses on the effect of the pipe and gusset plate dimensions on the connection behavior. The modeling assumptions and techniques used to perform the analysis are detailed. The models are verified using experimental test data performed earlier by the authors. A notable effect was observed on the behavior of the connections due to its detailing changes with respect to failure mode, yield and ultimate capacity, stress distribution and initial and final stiffness.

1. Introduction

Many researchers presented modeling procedures in order to investigate the behavior of different composite systems under both static and dynamic loading cases. Several difficulties arise while dealing with modeling of composite sections that bring together two distinct materials, the ductile steel and the brittle concrete. Modeling of such elements should capture the relative stiffness of each material properly.

Extensive experimental research on moment connections to circular concrete filled tube (CCFT) columns is available in literature. Alostaz and Schneider [1] investigated the moment–rotation behavior of different connection details for wide flange shapes to CCFT columns. The studied parameters included diameter-to-thickness ratios and moment-to-shear values. Elremaily and Azizinamini [2] performed an experimental study in order to comprehend the behavior of through beam connections that showed the capability of through beam connections to develop the full plastic flexural capacity of the beam. Vulcu et al. [3] conducted an experimental program in order to characterize the behavior of moment resisting joints to CCFT columns in multi-storey frames. The specimens were tested under cyclic and monotonic loading. Roeder et al. [4] provided an overview of the seismic demands on the connection of the CFT braced frame systems through an experimental program. Performed tests showed that the effect of bond stresses is less dominant when the diameter of column increases, and that the main load transfer mechanism in connections with gusset plates penetrating through the column is direct bearing. MacRae et al. [5] performed an experimental study in order to evaluate the bearing stress on concrete under the gusset plate at brace–beam–column connections. The authors found that the force was transferred from the diagonal member to the composite column by mainly two mechanisms: the bearing under the gusset plate and friction between steel plate and concrete or steel tube. The percentage of the force carried by the second mechanism is 30% of the total transferred force. However, this part is usually neglected as quantifying the force transferred by friction in actual situations is hard due to the shrinkage of concrete. Moreover, it was observed that the effect of shear studs is negligible in transferring force between steel and concrete.

Bond stresses are present in connections with gusset plate penetrating through the CFT column. Zhang et al. [6] investigated that the factors affecting the bond stresses are found to be dependent on the shape of the steel tube, dimensions of the tube, surface preparation of the interior of the steel tube, shrinkage potential of the concrete, concrete and steel material strengths, and eccentricity of loading. Such stresses are estimated using push-out tests, push-off tests, or connection tests. The performed tests showed that larger diameter tubes and tubes with large D/t ratio are more likely to require mechanical shear transfer mechanisms than smaller diameter tubes. It is also observed that shrinkage of concrete causes severe deterioration of the natural bond capacity. Hajjar [7] reported bond stress values varying between 0.1–1.0 MPa. Typically, the distribution of bond stress is not uniform within the connection zone. The value is expected to reach its maximum estimate at the location where the loading is applied and decays within a certain distance. Leon et al. [8] reported that it is not clear what percentage of the CFT perimeter is typically engaged for transferring the load.

There is a wide range of connection types that can be used with composite construction. The effect of connection flexibility must be considered in the analysis since it affects the distribution of moment between beam and column and the overall drift of the structure. Designers usually face difficulties and insufficient design data when dealing with

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connections of CFT columns. Meanwhile, the used design formulas may yield connections that might have capacities dissimilar to what was anticipated. Connections to CFT columns may be beam-to-column moment connections or beam-brace-column bracing connections. Deciding the appropriate detailing of the connection depends upon the applied straining actions, the construction capabilities, and the type of structural system.

Numerical and analytical methods provide an economical and reliable alternative in many situations. Extensive analytical research work has been conducted in order to arrive at a proper modeling for composite steel–concrete structures that reflects reality. There are many issues concerning the modeling of CFT columns due to material nonlinearities of composite materials since concrete and steel have different characteristics. On one hand, steel is a ductile material with the same response in tension and compression. On the other hand, concrete is a brittle material with different responses in tension and compression.

Hu et al. [9] conducted a numerical study in order to analyze the behavior of gusset plate CFT-to-bracing connections under an axial compressive force. Failure of the connection was generally observed under the connection area. It was found that increasing the thickness of gusset plate or introducing cutouts has a small effect on the ultimate strength of CFT column; yet they cause more local bulged shapes on the steel tube below the connection area. The behavior of composite beam connection to circular CFT column under cyclic loading was investigated by Wang et al. [10].

Modeling of connections usually includes modeling of shear studs. This requires knowing the capacity of shear studs and the load–slip relationship. Several equations have been created expressing the shear connector capacity based on concrete properties and the ultimate tensile strength of stud shear connector [11,12]. Makino [13] found that the cyclic strength of studs is approximately 50% of the ones predicted by Ollgaard et al. [12]. Oehlers et al. [11] derived the stiffness of the stud shear connector under static and dynamic loads from 116 push-out test results using linear regression analyses. Dabaon et al. [14] conducted 22 push-out tests in order to investigate the behavior of different types of shear connectors in normal and high strength concrete. The authors found that the failure mode depends on the shape of shear connector, detailing, and strength of concrete. The size and shape of the gusset plate connection are found to greatly affect the structural response of concentrically braced frames.

In this paper, the finite element analysis of circular concrete filled tube connections was conducted. The analysis incorporated geometric and material nonlinearities. The nonlinear behavior of concrete including crushing and cracking was included in the analysis. Numerical results were verified by comparison to published tests in literature. The verified model was used to investigate the effect of the geometric dimensions and gusset plates as well as connection configuration on the connection behavior including load–deflection curves, yield load, ultimate load, and initial and post-yield stiffness. Numerical results were used also to set design recommendations of such type of connections.

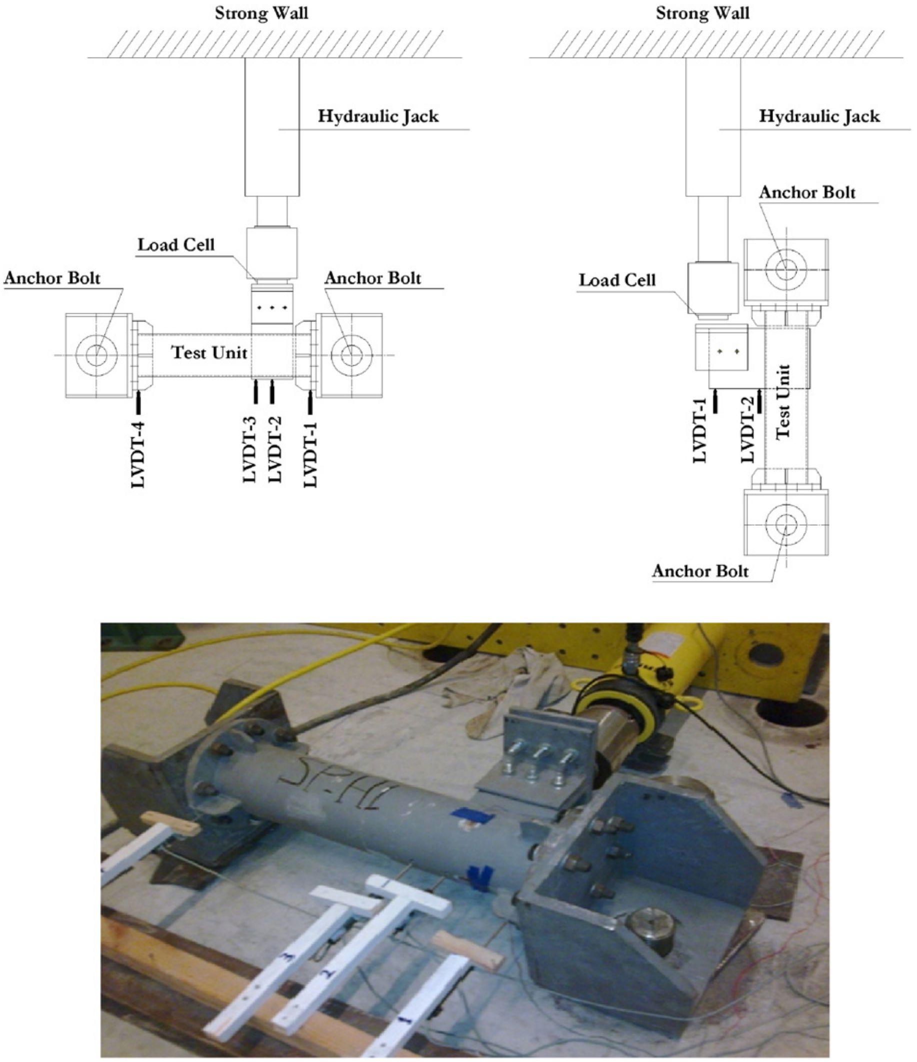

Fig. 1. General view of test set-up.