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Experimental study discussion of the seismic behavior on new types of internal/external stiffeners in rigid beam-to-CFST/HSS column connections

Omid Rezaifar *, Adel Younesi

Department of Civil Engineering, Semnan University, Semnan, Iran

HIGHLIGHTS

- Investigated three types of connection with internal stiffeners and two types of connection with external stiffener.
- Effect of concrete on the behavior of connections has been investigated too.
- Investigated external stiffeners to replace continuity plate, results confirmed the issue.

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ABSTRACT

The use of box columns has been increased due to the rigidity of rigid orthogonal moment resisting frames. On the other hand, the installation and welding of necessary horizontal continuity plates inside the columns are both labor-consuming and costly tasks. In this paper, an experimental study of the seismic behavior of internal/external stiffeners in rigid beam-to-Concrete Filled Steel Tube (CFST) and Hollow Steel Section (HSS) column connections is presented respectively. In this study, four hollow steel section specimens and six concrete filled steel tube section specimens are investigated. The results show that specimens with external stiffener in both cases (HSS and CFT) provide seismic parameters and they move the plastic hinge away from the column face due to their specific geometry. Therefore external stiffeners proposed in this study can be a good alternative for connections with continuity plates (suggested connection of design codes).

1. Introduction

Steel tube columns with or without concrete filled are widely used in steel buildings due to their good seismic performance. In order to provide rigidity in these connections, continuity plates are commonly used in Panel Zone (PZ), but the installation and welding of necessary horizontal continuity plates inside the columns are both labor-consuming and costly tasks. Hence, the use of external stiffeners is enormously noticed by researchers.

Wide experimental and analytical studies have been carried out since 1970 [1–3], in order to examine the behavior of PZ under monotonic and cyclic loadings. Three types of traditional connections to rectangular CFT columns have been widely used in Asian countries such as China, Japan, and South Korea. Each type employs an internal, external or a through diaphragm. These connections offer practical and economic advantages and their performance have been extensively studied. For this reason in previous investigations, some studies have been conducted on the experimental behavior of these traditional connections [4–15]. The analytical study on the performance of these connections has been conducted by some researchers [16–19]. It has been demonstrated that the use of diaphragms in column locally, does not only stiffen the connection, but also results in strain concentration and fracture of the beam flange at their weld access holes. Meanwhile, discontinuities of welds arise from both the presence of weld access holes and difficulties in performing the welds, especially when sitting on the top flange of a deep beam. Furthermore, strain concentrations develop at connection details that lack a gradual transition in geometry and lead to a reduction in connection ductility.

Kang et al. in their paper [20] compared the previously proposed equations for joint shear capacity, discusses the shear deformation mechanism of the joint, and suggests recommendations for obtaining more accurate predictions. Finite element analyses of

* Corresponding author.
E-mail addresses: orezayfar@semnan.ac.ir (O. Rezaifar), a.younesi@students.semnan.ac.ir (A. Younesi).

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internal diaphragm connections to CFT columns were carried out in ABAQUS. Results show that:

(1) shear deformation of the steel tube dominates the deformation of the joint; while the thickness of the diaphragms has a negligible effect; (2) in OpenSEES simulation, the joint behavior is highly dependent on the yielding strength given to the rotational spring; and (3) axial force ratio has a significant effect on the joint deformation of the specimen analyzed. Finally, modified joint shear force-deformation relations are proposed based on previous theory.

According to a study by Wenliang et al. [21], Shear failure and core concrete crushing at plastic hinge region are the two main failure modes of bridge piers, which can make it impossible to repair the bridge and cause the collapse of it. To prevent the two types of failure of pier, a composite pier was proposed, which was formed by embedding high strength concrete filled steel tubular (CFT) column in reinforced concrete (RC) pier. The seismic performances of the composite pier were studied through cyclic loading tests. The experimental results show that the CFT column embedded in composite pier can increase the flexural strength, displacement ductility and energy dissipation capacity, and decrease the residual displacement after undergoing large deformation. Qin et al. [22] a numerical study of axially loaded concrete-filled steel tubular columns with T-shaped cross section (CFTTS) based on the ABAQUS standard solver is presented in this study. Two types of columns with T-shaped cross section, the common concrete-filled steel tubular columns with T-shaped cross section (CCFTTS) and the double concrete-filled steel tubular columns with T-shaped cross section (DCFTTS), are discussed. The numerical results indicate that both types have the similar failure mode that the steel tubes are only outward buckling on all columns' faces. Furthermore, a new beam-to-box column connection by trapezoidal external stiffeners and horizontal bar mats is presented to provide seismic parameters and studied behavior of connections with types of internal and external stiffeners [23–26].

A nonlinear force-deformation model is proposed by Cheng and Chung to simulate shear transfer behavior in the panel zone of CFT beam-column connections. In this model, the influence of axial load on the shear transfer behavior is accounted for. Test results showed that all specimens failed by the welding fracture while entering nonlinear stage. It is found that the higher the axial load was applied, the better the ductility of connections was obtained. Comparison of analytical and experimental results shows that the proposed prediction for panel shear falls in a reasonable range for higher axial load tests, but tends to be conservative for lower axial load tests [27]. Two analytical models are presented to predict the flexural and shear strengths of through-diaphragm connections between concrete-filled rectangular steel tubular (CFRST) columns and steel beams, respectively. The use of the proposed theoretical equations led to good agreement between predicted and experimentally measured strength. As the second phase of the research program, an analytical model for shear strength was presented according to the simplified tri-linear shear–deformation relationship for connections. A theoretical method was proposed to evaluate the shear strength of the concrete compression strut at the yielding point of the steel tube. In addition, the contribution of steel frame mechanism in the panel zone was taken into account in the proposed model. Excellent agreement was found between theoretical and experimental results for both yield and ultimate shear strengths for connections [28].

In present study, the experimental study of the behavior of types of connections with external and internal stiffeners will be discussed. In this paper 10 specimens with monotonic and cyclic load were studied and the seismic parameters of connection investigated to achieve the alternative external stiffener for connection with continuity plate. The experimental data and the project is performed by O. Rezaifar and et al. [25,26].

2. Experimental program

2.1. Test specimen

In general, ten specimens are designed for testing to investigate the seismic behavior of connections as shown in Table 1 and Figs. 1–10.

The columns and steel beams were identical for ten specimens. The column was made of four steel plates vertically seamed by complete joint penetration welds. It is believed that it will enhance the versatility and practicality of HSS/CFT connections due to the wider range and larger size available in tubular sections.

The height of column and the length of beam in all models are chosen 1500 mm and 1000 mm respectively. In order to build columns plates with 200 mm width and 6 mm thickness has been used. Furthermore, for construction of the beam a plate with 150 mm width and 6 mm thickness and in web of the beam 6 mm thick, 77 mm wide and 200 mm long shear stiffeners are used.

For making the specimens, at first four-sides ($4 \times 1500 * 200 * 6$ mm) of column are attached together by welding, but in specimens with continuity plate three-sides of column are attached together and after that the continuity plates(Or bar mats) are welded to the sides and the assemblage of the fourth dimension of column is performed in the next step (Figs. 3 and 4). It should be noted that continuity plates (Figs. 3 and 4) and bar mats (Four bars #12 in each direction) (Fig. 5) are along the flanges of the beam. In specimen with four bar mats two additional bar mats are also embedded at equal distances along panel zone. After that, beams are made of three $1500 * 200 * 6$ mm plates in I-shaped form to strengthen the beams by placing the vertical shear stiffeners on both sides of beam's flange at distances of 200 mm. In HSSE1VP and CFTE1VP (Figs. 9 and 10) specimens, the vase plates are initially welded on the upper flanges and under the lower flanges and then Rectangular plates ($310 * 50 * 6$) are installed horizontally in two sides of column (Sides of perpendicular to the beam), but in specimens with surrounding plate at first the rectangular plates of $210 * 100 * 6$ are welded on the upper flanges and under the lower flanges and after that lateral plates of $410 * 200 * 6$ will be welded in two sides of column (Parallel to beams) to rectangular plates ($210 * 100 * 6$) (Figs. 7 and 8). In specimens with concrete after making the steel parts of specimens, the

Table 1
The introduction of specimen.

Row	Specimen (Nick name)	Full name (HSS/CFT-Internal/External-Number-Type of stiffener)	Address
1	HSS0000	Hollow Steel Section-0-0-00	Fig.1
2	CFT0000	Concrete Filled Tube-0-0-00	Fig.2
3	HSSI2CP	Hollow Steel Section-Internal-2-Continuity Plate	Fig.3
4	CFTI2CP	Concrete Filled Tube-Internal-2-Continuity Plate	Fig.4
5	CFTI2BM	Concrete Filled Tube-Internal-2-Bar Mat	Fig.5
6	CFTI4BM	Concrete Filled Tube-Internal-4-Bar Mat	Fig.6
7	HSSE1SP	Hollow Steel Section-External-1-Surrounding Plate	Fig.7
8	CFTE1SP	Concrete Filled Tube-External-1-Surrounding Plate	Fig.8
9	HSS1EVP	Hollow Steel Section-External-1-Vase Plate	Fig.9
10	CFTE1VP	Concrete Filled Tube-External-1-Vase Plate	Fig.10