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Seismic behavior study on RC-beam to CFST-column non-welding joints in field construction

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ABSTRACT

A newly developed reinforced concrete (RC) beam to concrete-filled steel tube (CFST) column joint without welding in the construction field is introduced in this paper. The seismic experiment is conducted on the joint, and the hysteretic curve of the specimen under cyclic loading on the top of the column is obtained. By analyzing the mechanical characteristics and the failure mode of the joint, a three-stage skeleton curve model is presented. In the elastic stage, the initial stiffness is evaluated by solving the stiffness matrix. In the perfect plastic stage and strength degradation stage, the ultimate strength and the degradation stiffness of the joint can be obtained with the limit equilibrium method. Moreover, the test is also simulated with FEM, and the results agree well with the skeleton curves obtained from the test. So this joint shows good ductility and the ability to dissipate energy, and it can be used to replace the joints welded with reinforcement on the outer annular plate. And the finite element analysis results are compared with the theoretical results, which verifies the theoretical model presented above. It is suggested that the three-stage skeleton curve model can be used to depict the mechanical behavior and bearing capacity of this new type of joint. In addition, Parametric analysis is conducted on this joint, with the consideration of different designs of beams, columns and steel brackets, and failure mode is discussed.

1. Preface

The concrete-filled steel tube column is considered as a composite structure style, which has many excellent mechanical behaviors and bearing capacity. For RC beam to CFST column joint, the response to disaster loads has a very important impact on such a structure. Generally, due to the form of beam members, CFST beam to column joints can be divided into steel beam-CFST column joint and RC beam-CFST column joint. Among them, the current reinforced concrete beam-CFST column joint types usually include rigid joints with interior and exterior reinforced loop, anchor and cross-core, etc. Based on the needs of this project, the related research and the improvement of the joints are more focused in China. Where, Xu et al. [1] analyzed the working mechanism and seismic behavior of beam-column joints of CFST frames systematically, based on some results from experimental research and engineering application. The formation suited in the frame structure system, calculation methods and several design suggestions are presented and discussed. Nie et al. [2–3] carried out fourteen connection specimens composed of concrete-filled square steel tubular columns (CFSSTCs) and steel-concrete composite beams with interior diaphragms, exterior diaphragms, or anchored studs in order to investigate the seismic behavior were tested, and the strength, deformation, and energy dissipation capacity of these composite connections were analyzed; 3-D nonlinear finite element models were established to analyze the mechanical properties of these three types of connection using ANSYS. Finite element analyses were conducted under both monotonic loading and cyclic loading. Han et al. [4] conducted an experiment on eight thin-walled steel tube confined concrete (TWSTCC) columns to reinforced concrete (RC) beam joints subjected to cyclic loading, where the level of axial load in the column and the type of column cross-section were selected as test parameters. In addition, two concrete-filled thin-walled steel tubular columns to RC beam joints were also tested for comparison. Qu et al. [5] tested eight reinforced concrete (RC) beams to concrete-filled steel tubular (CFST) column joints enclosed by rebar under reversal horizontal displacement with constant axial load in order to study their seismic behavior. The test parameters are the axial load level and the section type of CFST column. In this study, the failure model, hysteretic characteristic, ductility and energy dissipation were investigated. Wang et al. [6] studied the semi-rigid joint of steel-concrete composite beam to CFST column with stiffening rings. Two specimens were tested by incremental loading and cyclic loading. The finite element package ABAQUS was used to study the nonlinear behavior of such specimens. Li et al. [7–8] researched the seismic behavior of the joint of gangue concrete-filled steel tubular column-beam with ring stiffeners and steel corbels, and the quasi-static tests on the interior joint of gangue concrete-filled steel tubular column-ring beam joints in the low cycle reverse load by which the failure patterns, hysteretic characteristics, ductility and energy dissipation were studied. Liu et al. [9] carried out finite element analysis on the aseismatic

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behavior of the joints of the new type of concrete-filled steel tubes, which is based on fuzzy mathematics. The results of the example analysis have showed that the finite element calculation model based on fuzzy mathematics is suited for the mechanical properties of the analysis of the joints. Wang and Liu [10] presented the test results of six connections under cyclic loading. Each test specimen was properly designed to model the interior joint of a moment resisting frame, and was identically comprised of three parts that include the circular concrete-filled steel tube columns, the reinforced concrete beams, and the short fabricated connection stubs. Chen et al. [11] studied the bearing capacity, crack patterns, deformation, and strain of the reinforcements of the specimens through the compressive tests on this concrete-filled steel tubular (CFST) column-beam joint with the column tube discontinuous in the joint zone after cyclic reversed loading. J et al. [12] conducted an experimental investigation into the behavior of composite column-to-beam connections using ten large-scale connections, four under monotonic loadings and six under cyclic loadings. All connections consisted of a concrete-filled steel tube (CFST) column (circular), a compact universal beam section and a shop fabricated connection stub. Monotonic testing was first carried out and the results were used to conduct the cyclic tests. Wang et al. [13] investigated the seismic performance of the composite joint consisting of square concrete-filled thin-walled steel tubular (CFTST) column and steel beam with end plate and blind bolts. Four exterior joint specimens were tested under axially compressive load on the top of the columns and cyclic loads on the beam tip. The experimental parameters in the study were the thickness of the steel tube and the type of end plate. Zhang et al. [14] presented experimental and analytical studies on the seismic behavior of steel I-beam to circular CFST column assemblies with external diaphragms. In the experimental study, four specimens, i.e. two exterior joints and two interior joints in a frame structure, are tested under constant axial loads on columns and cyclic vertical loads on beam ends. The specimens are designed to be strong column-weak beam for exterior joints and strong beam-weak panel zone for interior joints.

The above joint types in the project have a range of applications to some extent, nevertheless, there are imperfections in some types, such as the need for a large number of welding work at the site, the influence of anchoring parts in column to internal concrete pouring, or as a result of the openings, the impact of the strength of joint region and continuity of steel tube, etc.

Based on the above problems, this paper conducted experimental study to seismic behavior, theoretical derivation and finite element calculation study on new typical RC beam to CFST column joints (shown in Fig. 1) without welding in the construction field, in which the joint steel components are required to be completed by factory processing.

2. Experiment research

2.1. Experiment design

During a real earthquake, joints tend to be larger in operating cyclic loading due to the ever-changing seismic wave to structure foundation. In order to ensure the safety of structures in the earthquake, the general design requirement is required to meet “strong column, weak beam, and stronger joints”. Ductility is an important seismic performance index, which marks energy consumption of the joints as well as deformation properties after yielding. Based on this, in the cyclic loading experiment, beam-column joint is conducted by constantly changing the positive and negative bending moment. Thus, it is obtained to analyze ductility coefficient, viscous damping coefficient and energy dissipation ratio, and others, which can be used to determine energy consumption and seismic performance of joints, and also give the reference for the engineering design.

In order to simulate real hysteretic behavior of joints, a typical part of the beam-column joints derived from the plane frame subjected to seismic loading have been tested with simulating beam-end and column-end actual boundary condition, as shown in Fig. 2. In which H is the distance between inflection point of the upper and lower frame column, L is the distance between inflection point of the left and right frame beam, N is axial force, V is the shear at the position of inflection point on beam, P, $\Delta/2$ are the horizontal shear and lateral displacement at the position of inflection point on column, respectively, and the second-order effect can be considered. Based on the above model, the proposed simplified test model is shown in Fig. 3.

On account of some constraints such as test environment and load capacity, the reduced scale test model is put forward, as shown in Fig. 1. Firstly in the factory manufactured phase, the steel column joint region is processed into exterior reinforced loop plate form, and connected with steel bracket. In addition, the steel bracket upper and lower flange position are welded with reinforced connection pieces with holes, and as the reinforced limit agencies, all holes of design corresponds to reinforced distribution location. In the installation phase, the processed reinforcement is planed pass through the holes on the reinforced connection pieces after column installation is completed, and connected with the reinforcement sleeve. This installation of the joints in the construction field is shown in Fig. 1. The joint is installed in the construction site without additional large number of welding work, saving funds for welding and inspection and greatly shortening the construction period. Through the above analysis, it shows that the new joint has good mechanical properties and ductility, and it can be served as a CFST beam-column joints in the project to promote the use.

a) Whole beam-to-column joints

b) Connection of reinforcement

Fig. 1. Joint with no welding in the construction field.