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EXPERIMENTAL STUDY ON BEHAVIOROF STEEL BEAM TO CONCRETE COLUMN CONNECTION IN RETROFITTING

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SUMMARY

A new combined connection for steel beam to existing RC column in retrofitting is brought forward with the idea that most components which fabricated in factory are assembled with high strength bolts on site. Two full-scale specimens with such new connection are tested under cyclic loading in order to investigate the strength, deformations and failure mode. Experimental results showed the connection is not only capable to achieve anticipated strength and stiffness, but also to possess good seismic performance. Nonlinear full range analysis of this composite connection is carried out with proposed model and good agreement is found between experimental results and numerical analysis.

BACKGROUND

With the urban development, more and more factories have to be moved to suburb. And the left industrial buildings in downtown have to be reconstructed to fit new purpose, such as used for office, exhibition hall, supermarket, and so on. Most of these industrial buildings are single-story or multistory buildings with reinforced concrete structure. Figure 1a shows a typical multi-story industrial building. The structures of these buildings, built before 1990's, generally consisted of parallel plane frame in transverse direction designed to support vertical loads. Due to no consideration of seismic design, these plane frames are linked with slender beams in longitudinal direction. Sometimes it could be worse that no beam set in longitudinal direction[1]. In other way, there are only transversal frames in such building. So, it is unable to resist the earthquake action in longitudinal direction. According to Code for Seismic Design of Buildings[2] , these buildings should be strengthened at first, then to be retrofitted.

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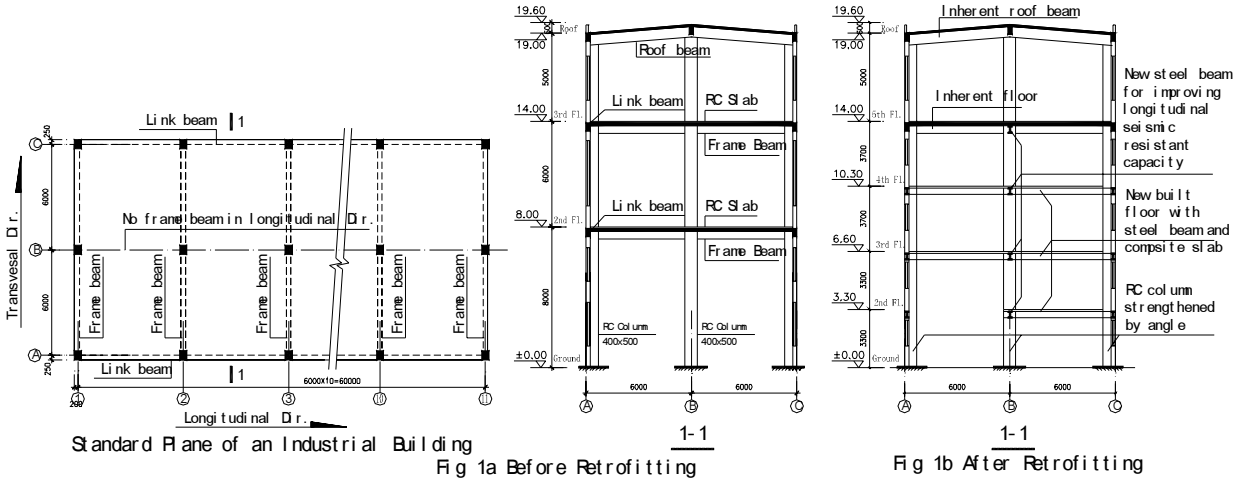


Fig. 1 Standard plane and vertical section of one typical existing industrial building

Owing to the height between two floors almost more than 6 meters in existing workshop, new floors used to be built up to expand the service area. The structure of new built floor with wide flange steel beams and steel-concrete slabs are gradually utilized with their advantages in low weight, high strength and construction speed in such case. Fig 1b shows the section of the existing industrial building after retrofitting. In this case, the inherent second floor will be taken down and three new floors will be built up with the steel beams and composite slab. And new steel beams will be connected to the existing RC columns.

The usual connection type of new steel beams to existing RC columns is shown in Figure 2. Four brackets are attached to column by through bolts in two directions. And new beams are set on the brackets for simple connection type or link it by welding or bolting for moment connection type. Due to drilling holes in concrete core zone, this connection may further reduce the strength of the old existing RC column.

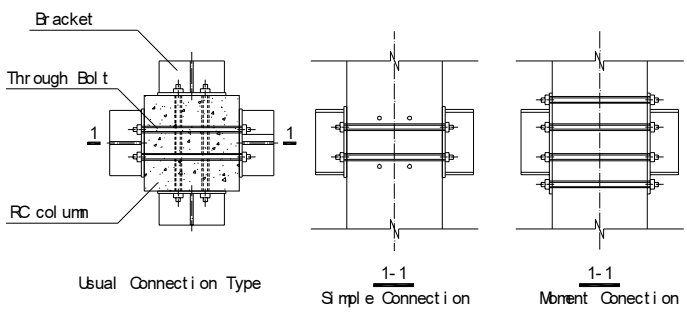


Fig 2. brackets attached to RC column by through bolts

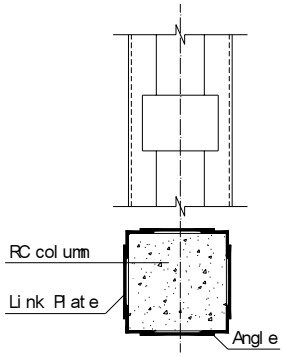


Fig.3 RC column strengthened by Angle

In order to improve the seismic resistance of the structure of existing building, three items work should be done as follows[3]: 1) new steel wide flange beams will be built up to form a new longitudinal frame with the existing column, or long steel sheets will be stuck to the bottom of slender beams to enhance the

inherent longitudinal frame. 2) Transversal beam should be checked and strengthened if needed. 3) old RC column need to be wrapped with four angles, shown in Figure 3.

In this paper, a new combined connection (NCC), which connects new steel beam to existing RC column, is put foreword with the idea of cooperating the strengthening with retrofitting together.

INTRODUCTION OF NCC

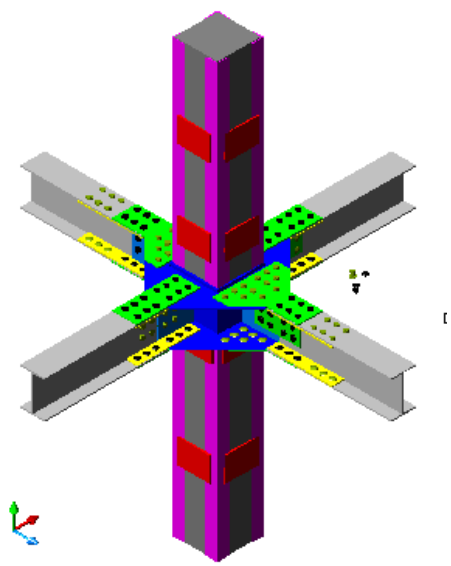


Fig.4 3D model of the NCC

The new combined connection (NCC) is made of two parts, which combined by high strength bolts on site. Each part is fabricated in factory with two out diaphragms, rectangular tube, and vertical stiffening rib welded together. The out diaphragm is designed to transfer the tension force produced by bending moment acting on the steel beams. The tube is designed to strengthen the joint of column and resist the shear force produced by webs. The vertical stiffening rib, welded to tube and diaphragms, not only enhances the connection, but also links the beam web to the panel zone. Figure 4 shows the 3D model of the NCC.

Compare with the other connections, NCC does strengthen the joint of existing RC column. Moreover, it is easily assembled on site with high strength bolts. In order to investigate the performance of NCC, two full-scale specimens are tested in The State Key Laboratory Division for Disaster Prevention in Tongji University.

OUTLINE OF EXPERIMENT

Specimen and Material Property

In order to investigate the seismic behavior of a frame with NCC, a subassemblage from a typical frame is adopted to form a specimen. Due to the connection has two parts to be combined, and different combinative direction may bring on different results, two full-scale specimens with longitudinal and transversal combination, SA and SB, were tested under reverse cyclic loading. The details of SA and SB are list in Table 1and described in Figure 5 .

Table 1 The Illumination of Specimens

Specimen	Comment
SA	Connection in longitudinal direction
SB	Connection in transversal direction

The ultimate compressive strength of concrete at 67 days by cube test is 30.2MPa with the modulus of elasticity, 2.35×10^4MPa. The material properties of angle, steel plate and high strength bolt are presented in Table 2.

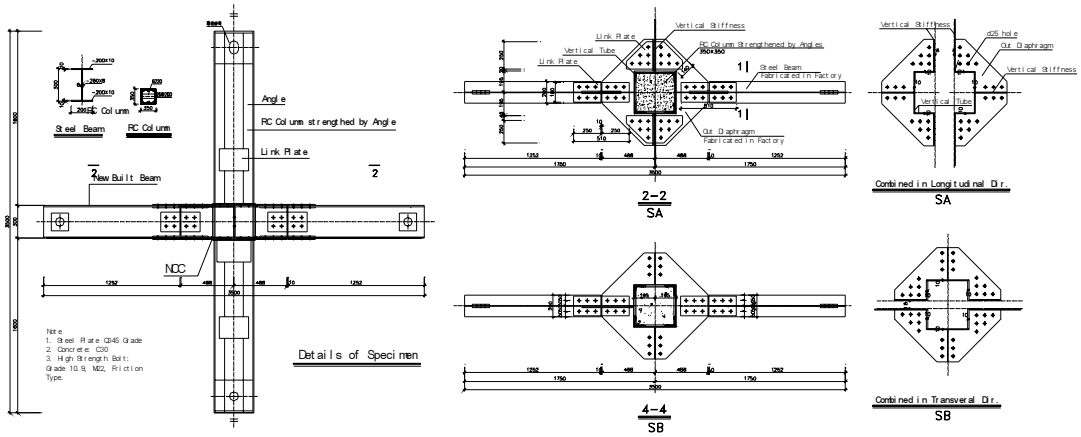


Figure 5 Details of Specimens of SA and SB

Table 2 Material Properties

Component	Element	Grade	fy	fu
Existing Column	Rebar	HRB335	380	500
	Hoop	HPB235	260	375
Strengthen Components	Angle	A3	260	375
	Link Plate	Q345	380	500
Beam	Wide Flange Type	Q345	380	500
NCC	Diaphragm	Q345	380	500
	Vertical stiffening rib	Q345	380	500
	Tube	Q345	380	500
Bolt	M22, Friction Type	10.9	1072	1123

f_y: The yield tensile strength, f_u: The ultimate tensile strength,

Test Setup

In case to simulating the performance of structure frame under earthquake action, A Test Apparatus (TA) with stiff beams and stiff columns which hinged at every joint was set up. A specimen is arranged to it by simple connected to the TA. When a lateral load acts on the top beam of TA, it can be transfigured from rectangular to parallelogram. Simultaneity, it can produce a pair of lateral force at the tips of column and a pair of vertical force at the ends of beam of the specimen. Test setup is shown in Fig 6.

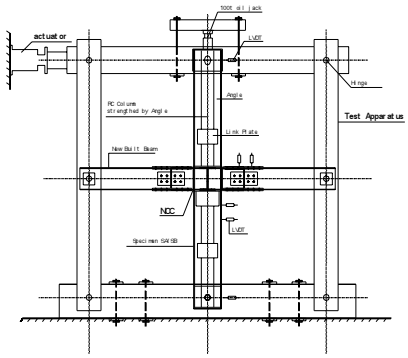


Fig 6. Test Setup

Loading System and Instrumentation

Reverse cyclic loads were applied at the top end of the TA by an actuator controlled by computer system. And simultaneously a constant axial load, 400kN, was applied at the column tip by 100 ton oil jack. The cyclic loading was controlled by force before yielding

calculated by numerical analysis, then by drift. Two cycles were applied to each step.

Instrumentation for displacement and rotation measurements of the specimen was planned considering the characteristics of the connection deformation. 50mm and 200mm LVDTs were attached to the panel zone and the ends of the column and beams respectively. Wire strain gauges were attached to rebar and hoops in the RC column, the surfaces of angles and the NCC. Photo 1 shows the SA before tested.

Photo 1 SA before tested

Experimental Results

Failure Mode

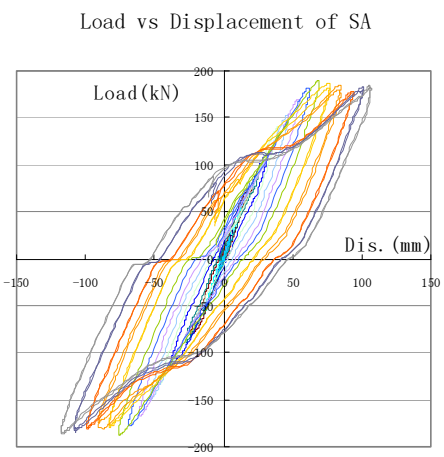
The failure modes of two test specimens were similar. First, the angle was pulled away slightly from RC column when the side was in tension. Then the horizontal cracks of concrete near the top and bottom of panel zone appeared. After that the connecting plates with steel beam flange and diaphragm were yielding, the diaphragms near the corner of tube were yielding too, shown as photo 2. On the first yielding, the lateral force is about 75kN with displacement about 15mm for SA and the lateral force is about 70kN with displacement about 18mm for SB respectively. Then, the displacement at the tip of column became larger when the lateral loads near to ultimate loads, due to the yielding of plates and a little slid of bolts. At last, the rupture was happened in corner welding seams. For SA, the first rupture happened at top of tube corner on one side, then developed on another side. For SB, the first fracture happened at the corner of angle and diaphragm then developed to the tube in vertical welding line and to the hole in horizontal direction, shown as photo 3.

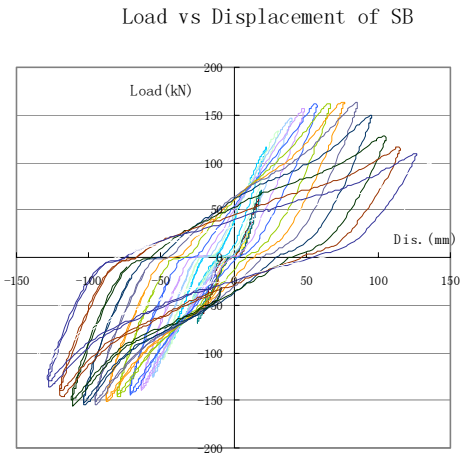
Photo 2 Yielding line at diaphragm

Photo 3 Rupture at tube corner

Hysteretic Loops

The hysteretic loops of lateral load vs. displacement at tip of column, which depicted in figure 7a and 7b for SA and SB respectively, show that the specimens (SA, SB) with NCC have good seismic performance. SA accumulated absorption Energy is a little large more than SB and gets larger ultimate loads.





OUTLINE OF NUMERICAL ANALYSIS

Finite element analysis (FEA) is demonstrated to be a powerful auxiliary approach in studying structure behavior under different loading condition. In this paper, a full range nonlinear numerical analysis of a subassemblage is performed by means of ANSYS (version 6.1). And most components are modeled by suitable element provided by ANSYS respectively.

The element type of SOLID65 is used to model concrete column. Rebar in column is modeled by LINK8. 4-Node shell element, called SHELL43, is applied to simulate diaphragm, angle and vertical stiffening ribs. Panel zone tube is modeled by the element SOLID45 in case to eliminate the geometrical difference between prototype and model. Considering the primary purpose of analysis is to investigate work performance of this subassemblage and to minimization the calculation, weld seams, bolts and holes are not modeled specially, with the assumption that they work together.

In this model, the contact interactions between column and angle are taken into consideration by defining CONTA174 and TARGE170 on their interface, whenever they come in contact with each other.

Being symmetry in geometry and asymmetry in loading for the subassemblage, a quarter of model has been built and analyzed. Boundary conditions of model are based on experimental setup. Meshed model is depicted in Figure 8.

Mechanism of Concrete, Steel, Reinforcement

The stress-strain relationships of concrete, reinforcement and steel are all simulated by multi-linear model in this analysis. For concrete, a seven-linear model is set up according to imitating a parabolic curve determined based on Saenz formula and experimental data. For rebar, angle and steel plate, a three-linear model is set up, which yielding stress and ultimate strength is listed in the table 2.

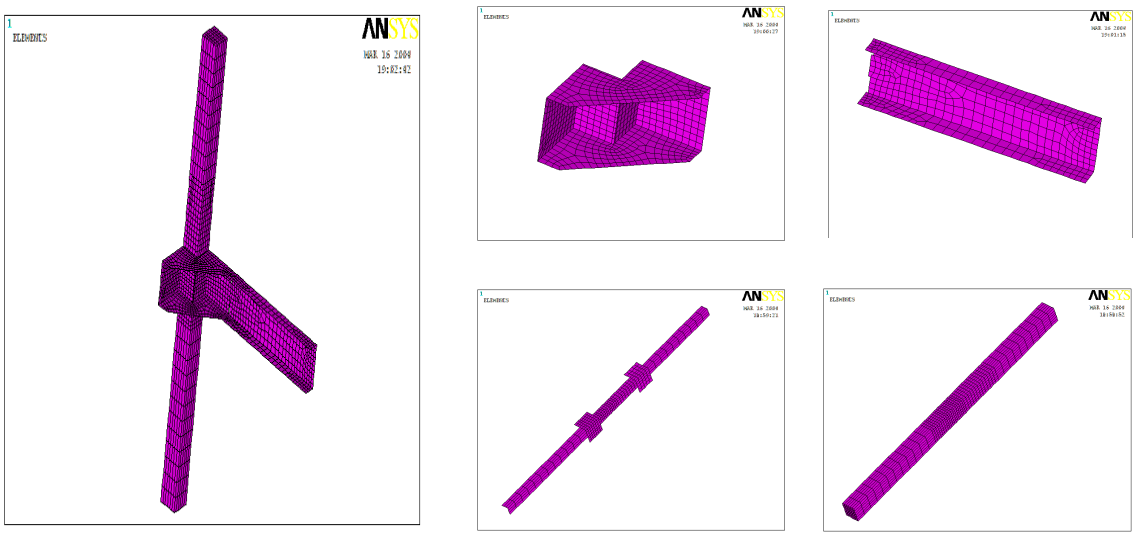


Fig. 8 Meshed model for SA

Failure Criterion of Concrete

Cracking and crushing of concrete are determined by a failure surface. Tensile failure consists of a maximum tensile stress criterion. When the failure surface is reached, stresses in that direction can be modified with adaptive descent and gradually drop to zero to reduce convergence difficulties. The residual shear transfer capacity along the crack plane represents the aggregate interlock and friction of rough crack is taken into account. The failure surface for compressive stresses is based on Willam-Warnker failure criterion, which depends on five material parameters. There is no stress softening in compression, when crushing occurred.

Solution Method

In order to perform full-range nonlinear analysis, Newton-Raphson(N-R) and arc-length method are adopted. N-R is an available iterative process of solving the nonlinear equations and able to receive results of every sub-step. But, while structure load-displacement curve reach extreme point it may become unstable. Therefore, arc-length method is applied to continue the analysis. Automatic load increment scheme is preferred because ANSYS selects increment size based on computational efficiency.

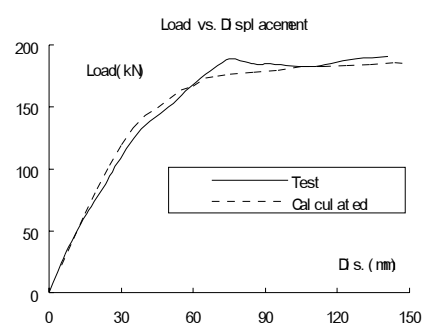


Fig. 9 Loads vs. dis. curve of SA

Analytical Results and Discussions

The load vs. column tip displacement relationship corresponding to the test and analysis are shown in Figure 9, which showed good agreement with each other in the full range, especially in linear elastic range.

The test and analysis results indicated that the NCC is a semi-rigid connection, because the drift of NCC under yielding load exceeds the criterion for moment connection according to Seismic Code. The reason is that the tube of NCC didn't work harmony with the column and distorted

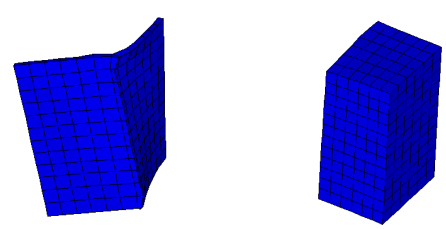


Fig. 10 Distortion of tube and column

separately under yielding loads, shown in Figure 10. The MISES stress distribution of tube, the principal compressive stress of concrete, The MISES stress distribution of top diaphragm and bottom diaphragm are depicted in Figure 11respectively.

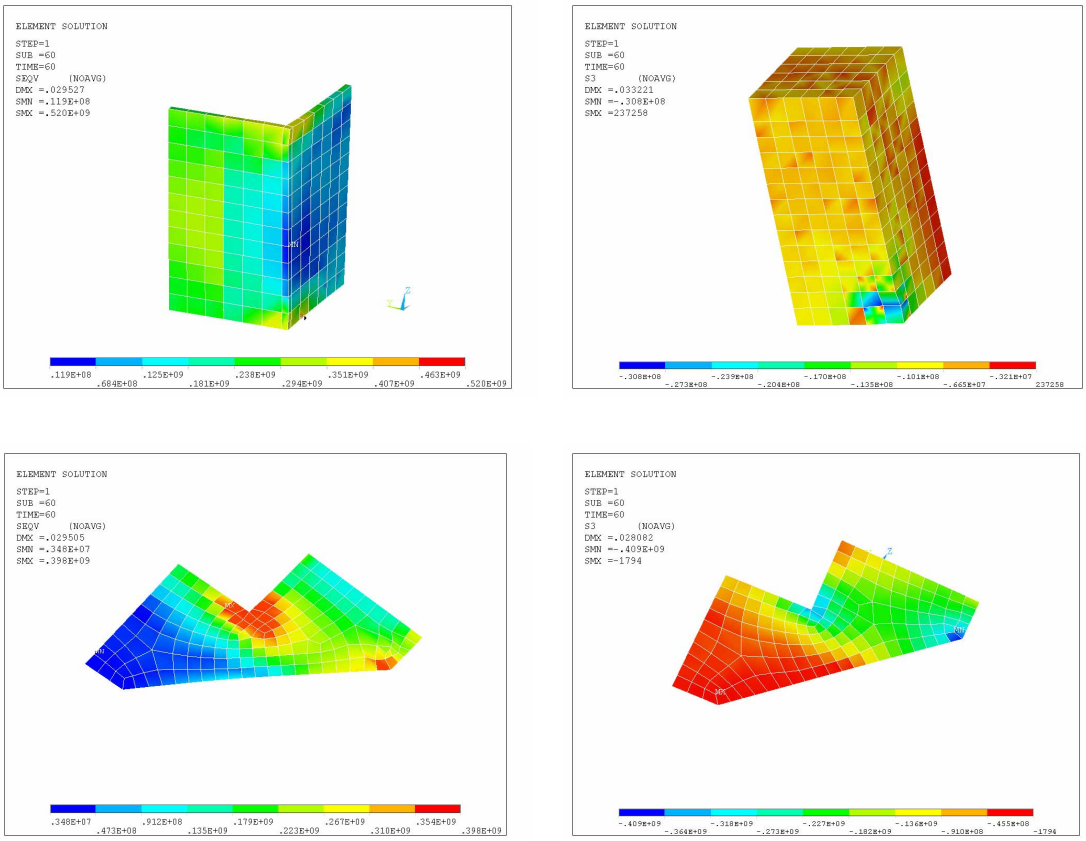


Fig. 11 The Distribution of tube, column and diaphragm

Suggestion

To improve aforementioned NCC to be more rigid, two suggestions are put forward. One is to cast flowing Epoxy with cement to the aperture between tube and column, based on the idea of making them work together. The other is to strengthen the vertical tube stiffness by thickening the vertical tube plate or stiffening rib to resist the shear force reduced by lateral loads. The ameliorated NCC is modeled and calculated. Figure 12 depicts the comparison between calculated results of ameliorated NCC and test result of SA.

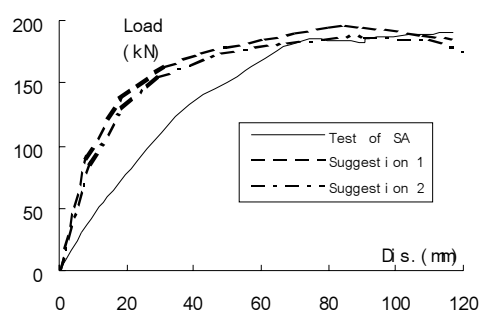


Fig. 12 comparison between

CONCLUSIONS

A new combined connection (NCC) for steel beam to existing RC column in reconstruction is brought forward. Two full-scale specimens with such new connection are tested under cyclic loading. Experimental results and nonlinear full range analysis showed that this connection is not only capable to achieve anticipated strength and stiffness, but also to possess good seismic performance. Due to the drift of NCC under yielding load exceeds the criterion for moment connection according to Seismic Code, this connection belongs to semi-rigid connection. To improve the NCC to be rigid connection, two suggestions are put forward. One is to cast flowing Epoxy with cement to the aperture between tube and column, the other is strengthen the vertical tube stiffness by thickening the plate of vertical plate of tube or vertical stiffening ribs. Numerical analysis indicates this ameliorated NCC achieved the performance of anticipated moment connection.

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