Acta Technica *62* (2017), No. 6A, 157–166

Experimental research on seismic performance of CFRP-strength concrete frame structure

XIE YONGPING[1] JIA LEI[1,*] YU CHUNYI[2] LI YUAN[1]
BAI WENTING[1]

Abstract. In order to investigate the seismic performance of concrete frame structure with CFRP-strength, 2 specimens are designed, one is not strengthened and one is strengthened by CFRP, these specimens are test under low cyclic reversed loading. The seismic performance, including failure mode, hysteresis characteristics and energy dissipation capacity were studied. The results show that the specimen with CFRP form the failure mechanism of strong column weak beam, however, the specimen without CFRP is the failure mechanism of strong beam weak column. The bearing capacity and deformation capacity and energy dissipation capacity of the specimen with CFRP are improved, CFRP-strength column increase the stiffness of specimen and improve the shrinkage phenomenon. The shear bearing capacity is increased by 28.1%. The energy dissipation ability of specimen increases 24.9% when the displacement is 70 mm.

Key words. CFRP-strength, concrete frame structure, seismic performance, failure mechanism, bearing capacity.

1. Introduction

According to the investigation and research of seismic hazard, the failure mechanism of reinforced concrete structure under the strong earthquake is very complicated. It is generally believed that the failure mechanism of reinforced concrete frame structure can be divided into the beam hinge failure mechanism, the column hinge failure mechanism and the mixing failure mechanism composed of two kinds

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Supported by the National Natural Science Foundation of China (Fund No: 51408378) and the Natural Science Foundation of Hebei Province, China (Fund No: E2016403060 , E2015403018).

[1] College of Exploration Technology and Engineering, HeBei GEO University,Shijiazhuang 050031, China.

[2] College of Architecture and Civil Engineering., Beijing University of Technology, Beijing 100124, China.

[*] Corresponding author: E-mail: jialei198@126.com

Fig. 1. The column hinge failure of frame structure in Wenchuan earthquake

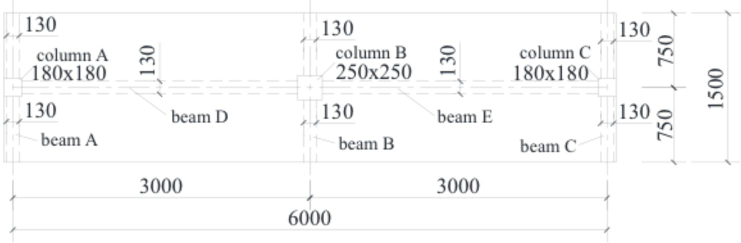
of failure mechanisms. Under the earthquake, the beam hinge failure mechanism is better than the column hinge failure mechanism, because, under the condition that carrying capacity is basically stable, the beam hinge failure mechanism can keep deformation without collapse and maximize dissipate earthquake energy.

However, existing investigation and research indicated that, because of the synergistic effect of floor slab and beam, the column was often destroyed, even if the joints meet the "strong column weak beam" required by Code for seismic design of buildings (GB50011-2010)(in Chinese) [1]. For example, in the Wenchuan earthquake, a large number of reinforced concrete structure occured column hinge failure to cause structural damage, as shown in Figure 1. In order to avoid this phenomenon, strengthening existing buildings is considered to be the main method to resolve such problems. At present, there are many methods of reinforcement, including increasing section method, fastened steel sheet strength method, strengthening with steel angle and carbon fiber reinforced polymer (CFRP)-strength method. CFRP is widely used in engineering with the advantages of light weight, high strength and simple construction. However, the strengthening effect of CFRP is studied by the scholars at home and abroad based on the simple specimens such as beams, columns and joints [2,3,4,5,6,7], but the strengthening effect of CFRP as a whole structure remains unclear. In this research, experiment was carried out through 2 frame specimens subjected to low cyclic reversed loading, the frames were designed that one was not strengthened and one was strengthened by CFRP. The seismic performance, including damage mode, hysteresis characteristics and energy dissipation capacity were studied.

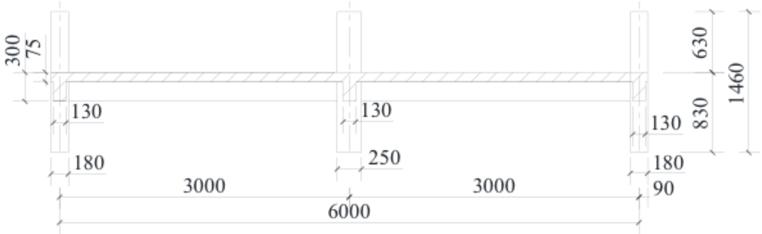
2. Experimental design

2.1. Specimens design

According to the requirement of "strong column weak beam", two specimens are designed, the first specimen KJ-1is not strengthened, the second specimen KJ-2 is



(a) The plan view of specimen



(b) The elevation view of specimen

Fig. 2. The model of specimen

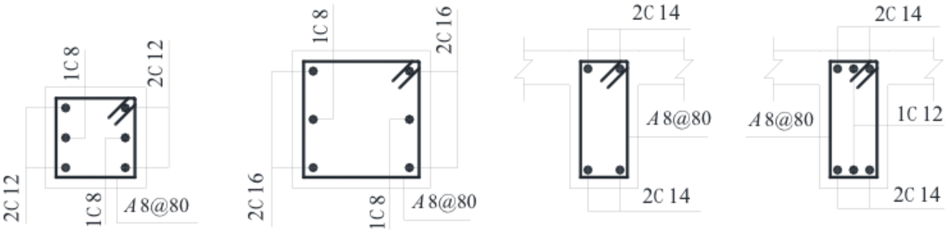
strengthened by CFRP, and the model of specimen is shown in figure 1. The size of cross-section of column A and C was designed with 180mm×180mm, and column B was designed with 250mm×250mm, and the height of column was 1460mm, the spans of beam was 3000mm, the thickness of floor was 75mm. The size of cross-section of all beams was designed with 130mm×225mm. The thickness of the concrete protection layer of beams and columns was 20mm, and the thickness of concrete protection layer of floor slab was 10mm. The grade of concrete was C30, its compressive strength was 21.3 MPa. The grade of longitudinal steel bar of beams and column was HRB335. The grade of floor distribution steel bar and stirrup was HPB300. The grade of the main reinforcement of the floor was HRB400. The detailed design of experiments is given in Figure 3 - Figure 4.

Figure 5 shows the reinforcement method of CFRP. The column above the floor was reinforced three sections with CFRP, the CFRP width of the column root was 200mm, the other width was 100mm, the distance between the two CFRP was 80mm. The column under the floor was reinforced two sections with CFRP, the CFRP width of the column root was 200mm, the width of the other CFRP was 100mm, and the distance between the two CFRP was 80mm.

2.2. Experimental Method

2.2.1. Instrumentation and setup of experiment

Figure 6 exhibits the setup of experiment. The contraflexure point at the upper end of column is seen as the hinge that produces horizontal displacement, the contraflexure point at the lower end of column is regarded as a fixed-pin pedestal, and



(a) Column A and C (b) Column B (c) Beam A and C (d) Beam B

Fig. 3. Reinforcement of the column and beam

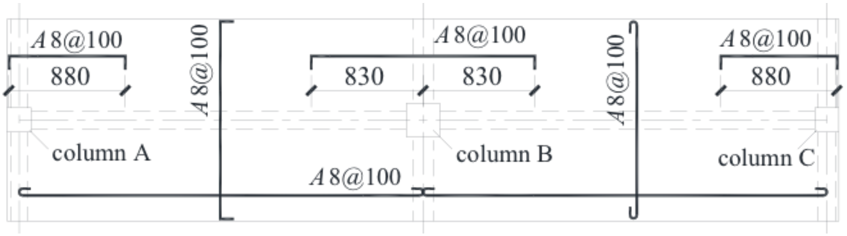


Fig. 4. Reinforcement of floor

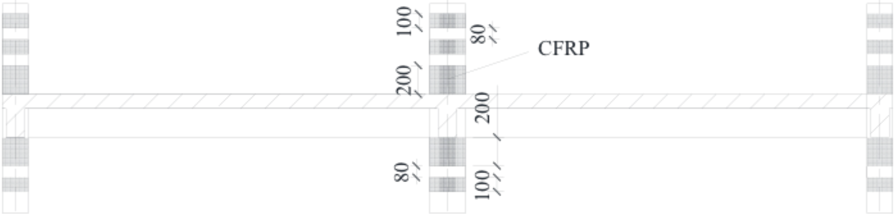


Fig. 5. The position of CFRP

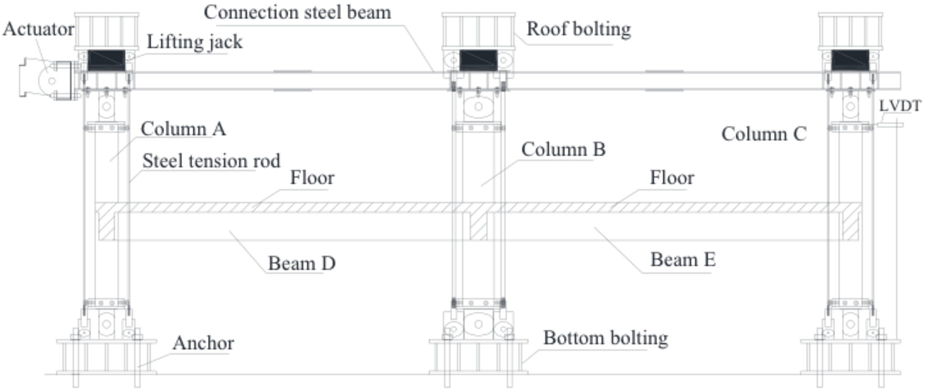


Fig. 6. Setup of experiment

the three columns at the top of specimen are connected by steel beams. The top of specimens was instrumented with linear variable differential transformer (LVDT) to measure horizontal displacement, the scale range of LVDT was 70 mm. In order to avoid the lateral displacement during loading, the lateral support is installed, as shown in Figure 7.

2.2.2. Load method

The test loading method is carried out according to the requirements of Specification for Seismic Test of Buildings (JGJ/t101-2015) (Ministry,2015). First, the axial loading is applied the top of specimen by lifting jack, and then the axial force is applied to the column by the steel tension rod. The ratio of axial compression stress to strength of column A and C is 0.3, and the axial force is 207kN. The ratio of axial compression stress to strength of column B is 0.6, and the axial force is 799kN. Second, the horizontal load is applied by actuator, and the displacement control method is adopted, which is 3mm, 6mm, 12mm, 18mm, 30mm, 40mm, 55mm and 70mm, respectively.

3. The process and modes of failure

3.1. Failure mode of specimen KJ-1

Figure 8 illustrates the failure mode of specimen KJ-1. When the displacement is less than 10mm, there are no obvious cracks. When the displacement is applied to 12mm, there are cracks in the roots of column A and column B. When the displacement is applied to 18mm, a vertical crack is found on the column A, and beam E near the column B appear some inclined cracks, and some micro cracks appear in the joint of the column B and beam A. When the horizontal displacement is applied to 30mm, there are more and more cracks in the beams and columns. Subsequently, the cracks of the column are widening and the concrete of column A

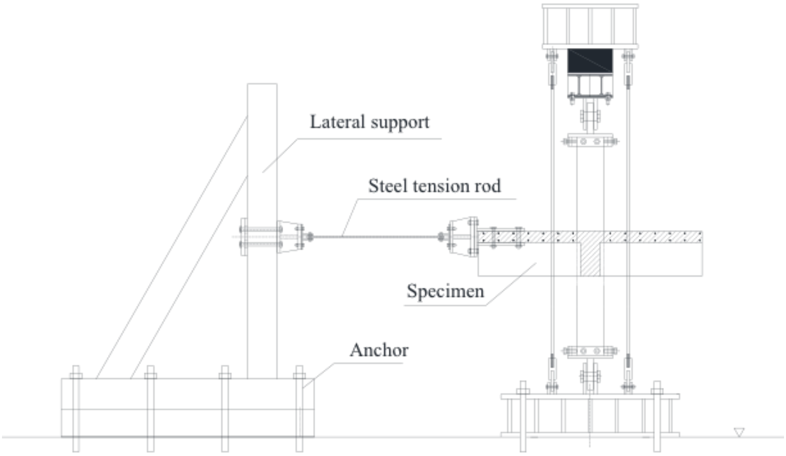


Fig. 7. Setup of experiment

Fig. 8. Failure mode of specimen KJ-1

falls off. When applied to 70mm displacement, the column below the floor is badly damaged, the destruction of the column upper the floor is relatively weak, and the cracks of the beams are widened. Finally, the failure mechanism of the strong beam weak column is formed by the failure of the column.

3.2. Failure mode of specimen KJ-2

Figure 9 illustrates the failure mode of specimen KJ-2. When the displacement is less than 10mm, the same as that of KJ-1, no crack is found in the specimen. When the displacement is applied to 12mm, a crack appears in beam E near column B. When the displacement is applied to 18mm, some cracks are found on the beam A, beam B and beam D. When the displacement is applied to 40 mm, the existing cracks are widened. When the displacement is applied to 55mm, the bottom concrete of beam D falls off. Finally, the failure mechanism of the strong column weak beam is formed by the failure of the beam.

It is can be seen from the damage phenomena and failure modes, columns of specimen KJ-1 are first found cracks and develop rapidly, and then the beams appear

Fig. 9. Failure mode of specimen KJ-1

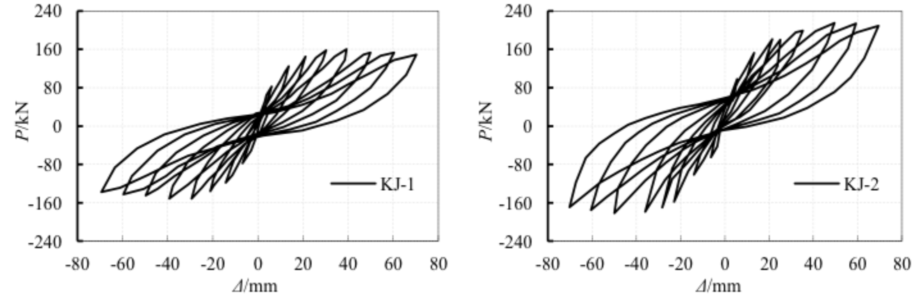


Fig. 10. Hysteresis curves

cracks, but the cracks of beams develop slowly, this indicates that the beams of specimen without CFRP are stronger than the column. However, the beams of specimen KJ-2 with CFRP are first found cracks, finally, the failure mechanism of the strong column weak beam is formed by the failure of the beam, so it is indicates that the CFRP-strength method can get better results.

4. Analysis of text data

4.1. Hysteresis curve

The relationship between horizontal load and displacement is illustrated in Figure 10. It is shown that the displacement and load are basically linear and the area enclosed by the hysteresis loop is approximately zero when displacement is small, the specimen is in an elastic phase. With the increasing of horizontal displacement, the hysteresis curve deviates slowly away from the vertical axis, and the area of the hysteresis loop gradually increases, which indicate that the specimen is in the elastic-plastic stage. Compared with the specimen KJ-1, the shrinkage effect of specimen KJ-2 is relatively small and the curve is more full, which shows that that the energy dissipation capacity of the specimen is enhanced, and the seismic performance of the specimen is improved.

4.2. Skeleton curve

Figure 11 illustrates the skeleton curves of specimens. It is shown that the skeleton curve of two specimens is approximately equal before the yield load. The shear bearing capacity of specimen KJ-1 is 155.6kN, which is the average value of positive and negative, and specimen KJ-2 is 199.4kN, so the shear capacity is increased by 28.1%. Unfortunately, due to the range of LVDT is small, limit deformation is not measured, but it can be seen form the deformation trend that the deformation ability of specimen KJ-2 is much better than specimen KJ-1. In addition, when the horizontal displacement is equal, the stiffness of the strengthened specimen is greater than that of unreinforced specimen, which indicates that the stiffness of specimen is increased by CFRP.

4.3. Energy dissipation

The relationship between the Equivalent viscous damping coefficient he and the horizontal displacement at the top of the column is shown in Figure 12. It is shown that the equivalent viscous damping coefficients of the two specimens are relatively small before yield. However, after yield, the equivalent viscous damping coefficients of specimen KJ-2 is larger than the specimen KJ-1. When the displacement is 6 mm, the equivalent viscous damping coefficients of specimen KJ-1 and KJ-2 is 0.0409 and 0.0419, respectively. When the displacement is 70 mm, the equivalent viscous damping coefficients of specimen KJ-1 and KJ-2 is 0.1117 and 0.1395, respectively, so the ability of energy dissipation increase 24.9%, which indicate that the energy dissipation capacity of the reinforced specimen is stronger than unreinforced specimen.

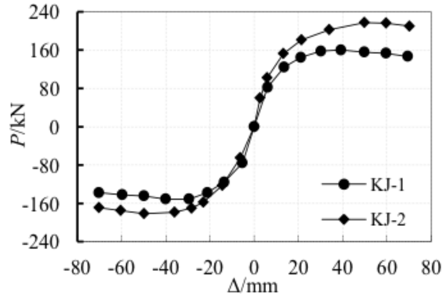


Fig. 11. Skeleton curve

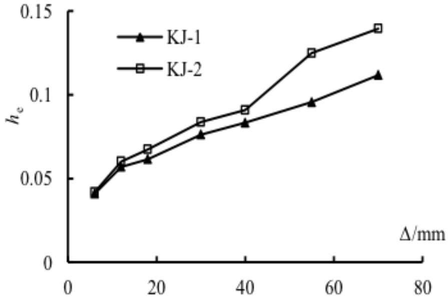


Fig. 12. Equivalent viscous damping coefficient

5. Conclusions

(1) The column of unreinforced specimen occurs failure column, which forms the failure mechanism of strong beam weak column. When specimen is strengthened by CFRP, the failure mechanism of the strong column weak beam is formed by the

failure of the beam.

(2) CFRP-strengthened column increase the stiffness of specimen and improve the shrinkage phenomenon, the curve is more full, and the shear bearing capacity is increased by 28.1%.

(3) CFRP-strengthened column improve the energy dissipation capacity of specimen. When the displacement is 6 mm, the equivalent viscous damping coefficients of specimen KJ-1 and KJ-2 is 0.0409 and 0.0419, respectively. When the displacement is 70 mm, the equivalent viscous damping coefficients of specimen KJ-1 and KJ-2 is 0.1117 and 0.1395, respectively, so the ability of energy dissipation increase 24.9%.

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Received November 16, 2017