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Finite Element Analysis of Increasing Column Section and CFRP Reinforcement Method under Different Axial Compression Ratio

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Abstract. Eight less stirrups in the core area frame joints are simulated by ABAQUS finite element numerical software. The composite reinforcement method is strengthened with carbon fiber and increasing column section, the axial compression ratio of reinforced specimens is 0.3, 0.45 and 0.6 respectively. The results of the load-displacement curve, ductility and stiffness are analyzed, and it is found that the different axial compression ratio has great influence on the bearing capacity of increasing column section strengthening method, and has little influence on carbon fiber reinforcement method. The different strengthening schemes improve the ultimate bearing capacity and ductility of frame joints in a certain extent, composite reinforcement joints strengthening method to improve the most significant, followed by increasing column section, reinforcement method of carbon fiber reinforced joints to increase the minimum.

1. Introduction

Increased column section reinforcement and carbon fiber reinforced plastics (CFRP) method are common structural reinforcement technology in recent years [1]. Both of these methods have advantages and disadvantages, and it's very important to reinforce the beam-column joints by the method of increasing the column section and carbon fiber composite reinforcing.

Many researchers have attempted to ensure the axial compression ratio has a great influence on the seismic performance of the joint [2-4]. In this paper, the cross-section frame structure with fewer stirrups in the core area is taken as the object of this study. The finite element software ABAQUS is used to simulate the various reinforcement schemes under the different axial compression ratio. The ultimate bearing capacity, ductility, stiffness and other effects are considered.

2. Establishment of finite element model

2.1. Fundamental assumption

(1) The concrete is an isotropic elastic material, and the plastic deformation is accompanied by plasticity damage after cracking.

(2) The volume of reinforcement is neglected as linear during the simulation.

(3) It is assumed that there is no relative bond slip between the reinforcement and concrete.

(4) It is reasonable to suppose the carbon fiber fabric is an anisotropic brittle material. The elastic modulus and tensile strength in the direction of the carbon fiber bundle is much larger than the tangent direction and the thickness direction [5].

(5) The CFRP is assumed to be a membrane structure of the concrete without a relative slip.

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2.2. Constitutive model

The uniaxial stress-strain curve of concrete and the monotonic tensile stress-strain curve of reinforce are shown in figures 1 and 2. The yield strength f_y and ultimate strength $k_4 f_y$ of ordinary steel in figure 2 are taken as the mean value according to the reference [1], and the curved segment is simplified into a straight line segment. Carbon fiber sheets are anisotropic brittle materials with no yield strength, and the ultimate strength is σ_{cf}, $\sigma_{cf} = E_{cf} \varepsilon_{cf} (\varepsilon < \varepsilon_{cf})$.

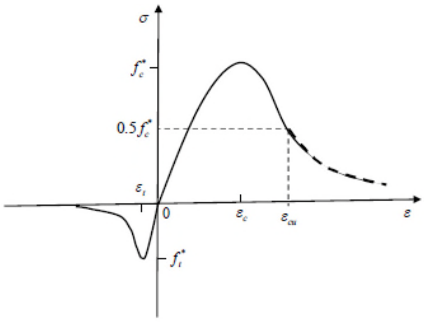


Figure 1. Uniaxial stress-strain curve of concrete.

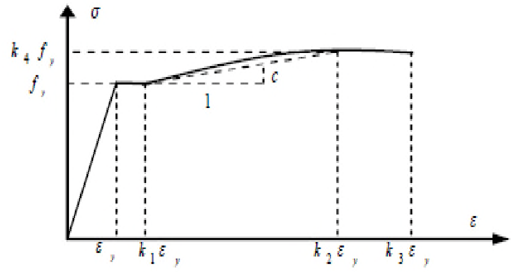


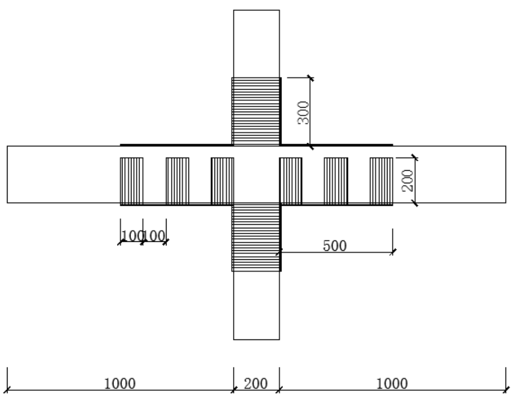
Figure 2. Monotonic stress-strain curve of steel bar.

2.3. Finite element model

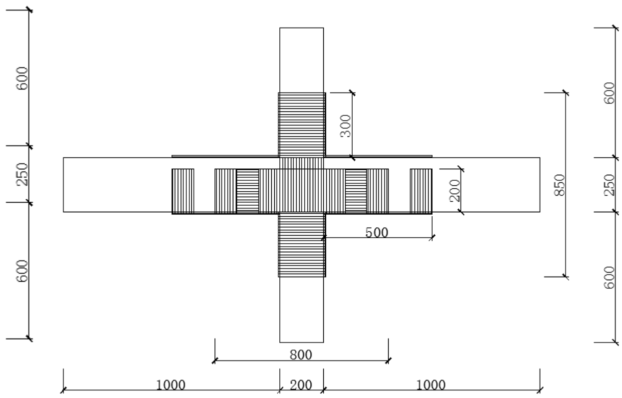
Table 1 lists the designing scheme of concrete specimens. The size of beam and column of reference specimen are 150×250×1000mm and 200×200×600mm respectively. The strength of the concrete is C25. The stirrup and longitudinal reinforcements adopt HPB300 and HRB335 respectively.

Table 1. Specimen design.

Series	Increasing column section reinforcement	The layers of CFRP	remarks
KJG-1	reinforced	0	Core area does not match stirrups [6]
KJG-2	reinforced	0	Core area with stirrups
KJG-3	unreinforced	1	Core area does not past carbon fiber sheet
KJG-4	unreinforced	1	Core area paste carbon fiber sheet
KJFG-5	reinforced	1	Core area does not match stirrups, does not past carbon fiber sheet
KJFG-6	reinforced	1	Core area with stirrups, does not past carbon fiber sheet
KJFG-7	reinforced	1	Core area does not match stirrups, paste carbon fiber sheet
KJFG-8	reinforced	1	Core area with stirrups, paste carbon fiber sheet



(a) Core area does not past carbon fiber sheet



(b) Core area paste carbon fiber sheet

Figure 3. Carbon fiber reinforced plastics (CFRP).

Increasing the column section reinforcement method is to add 60mm thick concrete along the long direction around the column, the thickness of concrete protection layer is 30mm, and the strengthening concrete is C30. Carbon fibre reinforcement is a method of pasting carbon fibre sheets in the 300mm length range between the top and bottom of the cross-shaped core area. Two forms of pasting CFRP as depicted in figure 3.

2.4. Loading method

Monotonic static loading is adopted. The end of the column is hinged seat and the force of 200kN, 300kN and 400kN is applied at the end of the column respectively. The axial compression ratio is 0.3, 0.45 and 0.6. At the same time, the displacement loading mode is applied to the concentrated vertical load at both ends of the beam. In the course of loading, a rigid block is added at the ends of the beam to minimize the effect of stress concentration and make the component in the same plane as a whole loading system.

3. Results and discussion

3.1. Load-displacement curve

The ultimate bearing capacity of the reference specimens are expressed by the load peak of the load-displacement curve. Figures 4-11 indicate the load-displacement curves under different axial compression ratios.

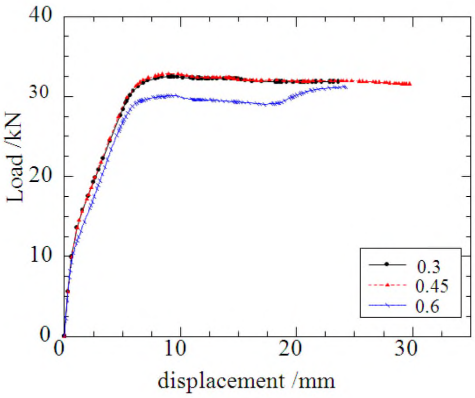


Figure 4. The load-displacement curve of KJG-1.

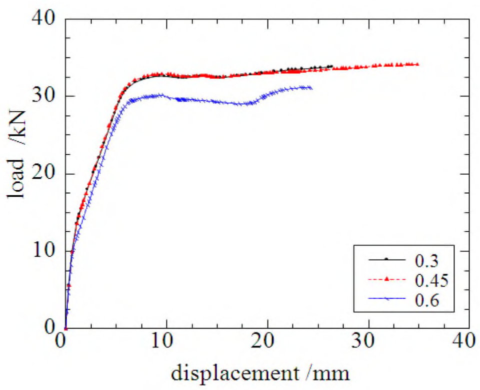


Figure 5. The load-displacement curve of KJG-2.

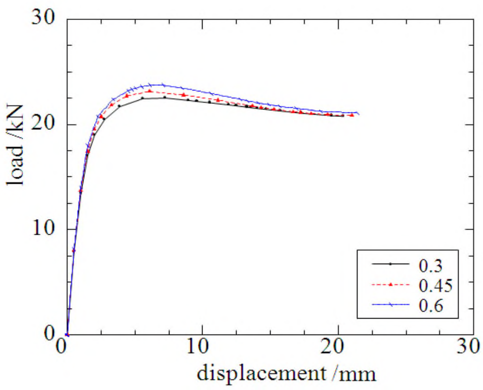


Figure 6. The load-displacement curve of KJG-3.

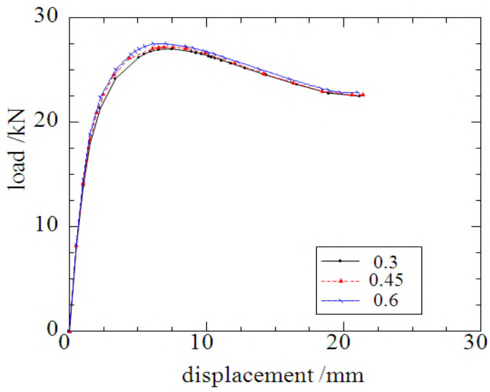


Figure 7. The load-displacement curve of KJG-4.

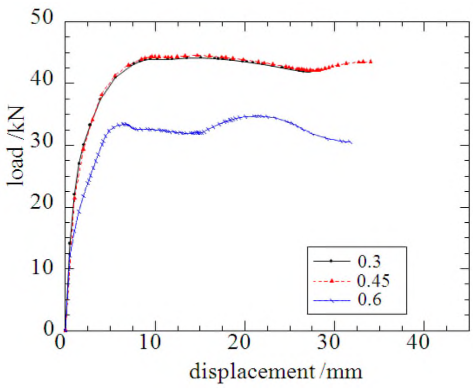


Figure 8. The load-displacement curve of KJFG-5.

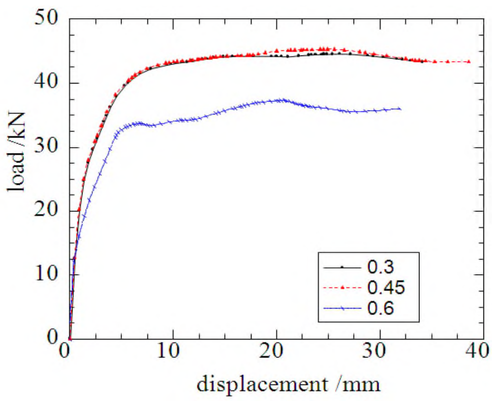


Figure 9. The load-displacement curve of KJFG-6.

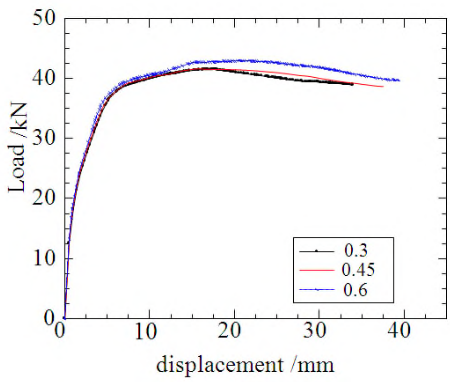


Figure 10. The load-displacement curve of KJFG-7.

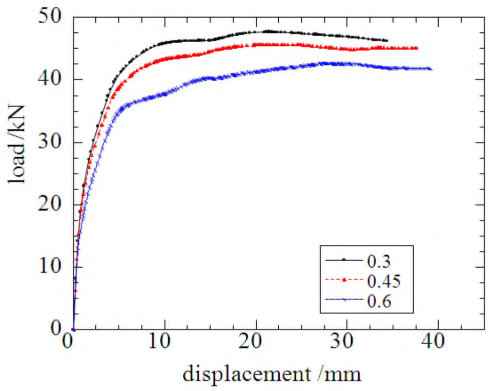


Figure 11. The load-displacement curve of KJFG-8.

Increasing the column section reinforcement method has less influence on the axial compression ratio, as showed in figures 4 and 5. The load-displacement curves of component KJG-1 and KJG-2 almost coincide when the axial compression ratio is 0.3 and 0.45, and the ultimate bearing capacity is less affected and the ultimate displacement is improved. When the axial compression ratio is 0.6, the yield load and ultimate displacement decreased significantly. Meanwhile the ultimate load decreased less.

The load-displacement curves of the component KJG-3 and KJG-4 under the axial compression ratio of 0.3, 0.45 and 0.6 are illustrated in figures 6 and 7. The ultimate bearing capacity of specimens is increased with the increase of axial pressure ratio. The amplitude is small and the limit displacement is almost constant. The CFRP obviously improved the load-carrying capacity when the axial pressure is larger.

The load-displacement curves of the component reinforced by the increasing column section and CFRP are given in figures 8-11. The load-bearing capacity of the reinforced bar in the core of the column section is decreased relatively. The limit displacements of paste carbon fiber sheet (KJFG-7 and KJFG-8) are increased with the increase of axial compression ratio.

3.2. Ductility

The displacement ductility coefficient β_Δ is defined as the ratio of the ultimate displacement of the yield displacement in the case of retaining the basic bearing capacity, as shown in formula (1). Where the Δu is the corresponding displacement when the load-displacement curve has a significant descending section reaching the load peak after 85%, and Δy is yield displacement.

$$\beta_\Delta = \Delta u / \Delta y \tag{1}$$

It can be seen from table 2 that the ductility of the joints strengthened by increasing the column section is much higher, the carbon fiber reinforcement is less, and the composite reinforcement is the greatest. Increasing the column section method, the ductility coefficient increases with the increase of axial compression ratio. The ductility coefficient of the carbon fiber reinforced joints decrease with the increase of the axial compression ratio and the adhesion of the carbon fiber sheet in the core area has an important effect on the ductility.

Table 2. Ductility coefficient.

Series	Δu/mm			Δy/mm			β_Δ		
	0.3	0.45	0.6	0.3	0.45	0.6	0.3	0.45	0.6
KJG-1	23.6	29.7	24.3	4.2	4.3	3.5	5.62	6.91	6.94
KJG-2	26.4	34.8	29.2	4.3	4.5	3.8	6.14	7.73	7.68
KJG-3	20.4	21.0	21.4	3.0	3.1	3.3	6.80	6.77	6.48
KJG-4	21.4	21.2	21.1	3.2	3.2	3.8	6.69	6.63	5.55
KJFG-5	27.3	34.0	31.7	3.9	4.1	3.8	7.00	8.29	8.34
KJFG-6	34.1	37.6	31.9	4.0	4.3	3.9	8.53	8.74	8.18
KJFG-7	33.9	37.5	39.4	4.2	4.3	4.0	8.07	8.72	9.85
KJFG-8	34.4	37.6	39.1	4.0	4.4	4.3	8.60	8.55	9.09

3.3 Rigidity

The ratio of force and deformation at the load displacement curve $0.75P_u$ is used to indicate the resistance to deformation of the member. The rigidity of the specimen is calculated in accordance with formula (2).

$$K_j = 0.75P_u / \Delta w \tag{2}$$

where, P_u is the ultimate load, Δw is the displacement corresponding to $0.75P_u$ in the load-displacement curve. The rigidity of all reference specimens are listed in table 3. No matter what kind of reinforcement method is expected to be adopted, when the axial pressure ratio is 0.6, the rigidity of the specimens decreases, and the stiffness of the composite reinforcement method is the biggest. It is not obvious that the rigidity improved by increasing the column section reinforcement, although the rigidity of the column is improved. The stiffness of the structural member is mainly affected by the beam. The rigidity of the carbon fiber reinforced joint is obviously increased because of the restraint between the beam end and the column end.

Table 3. Rigidity.

Series	$0.75P_u$/ kN			Δw/mm			Rigidity /$kN\cdot m^{-1}$		
	0.3	0.45	0.6	0.3	0.45	0.6	0.3	0.45	0.6
KJG-1	24.36	24.62	22.59	3.9	3.7	3.8	6.25	6.65	5.94
KJG-2	25.35	25.58	24.3	4.1	3.9	4.3	6.18	6.56	5.65
KJG-3	16.91	17.4	17.79	1.7	1.7	1.9	9.95	10.21	9.36
KJG-4	20.24	20.39	20.63	2	2.1	2.2	10.12	9.71	9.38
KJFG-5	33.1	33.4	26.0	3.0	2.8	2.8	11.04	11.92	9.29
KJFG-6	33.4	34.0	28.0	3.2	3.1	3.1	10.45	10.96	9.02
KJFG-7	31.1	31.2	32.1	3.1	2.9	3.2	10.04	10.74	10.03
KJFG-8	35.7	34.2	32.0	3.4	3.2	3.6	10.51	10.69	8.88

4. Conclusion

(1) The influence of different axial compression ratios on the bearing capacity of the strengthened method of column section is larger, and the bearing capacity of CFRP is less.

(2) The reinforcement scheme can improve the ultimate bearing capacity and ductility of the frame joints in different degree, and the reinforcement method of the composite reinforcement joint is the most notable. The reinforcement of the column section is larger, and the strengthening method of CFRP is the smaller.

(3) The rigidity of the reference specimen with the composite reinforcement scheme increases the maximum and the degradation is stable. Increasing the column section reinforcement method has little effect on the rigidity of the component. The rigidity of the CFRP specimen is improved remarkably, but the stiffness decreases quickly after the peak load.

5. References

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