Reinforcement of Damaged Frame Joint with Carbon Fiber by Finite Element Analysis

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Abstract

Building carbon fiber reinforcement using soft ANSYS of damaged frame joints under cyclic loading of finite element model shows that the main effect of carbon fiber reinforcement of damaged specimen are to change failure types of joints from core area of shear failure into a mix of beam bending failure and core shear failure damage and to improve strength deterioration, stiffness degradation and seismic behavior of energy dissipation, though carrying capacity, rigidity and ductility of joint have little impact after reinforcement. The research provides some theoretical basis and certain practical value in carbon fiber reinforcement with great commercial future.

Keywords: carbon fiber; reinforcement; damaged; frame joints; finite element analysis

1. Introduction

Analysis and calculation of reinforced concrete structure is the traditional method for structural testing. There are a lot of defects by experimental research methods for some complex structures that it is difficult to study and use data which can’t be tested. In many cases, we conducted structural tests which were only for a certain parameter without fully consideration of the effects of various parameters, and the test result is not accurate. In addition to testing, more and more researches are accomplished by using numerical simulation study on analysis method of reinforced concrete structures. ANSYS software models are used in this article, providing reference for the actual strengthening damaged joint. [1-5]

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2. ANSYS Modeling

2.1. Material unit

Concrete takes SOLID65 unit, cube compressive strength standard values $f_{cu} = 35\text{N/mm}^2$; Compressive strength $f_c = 16.7\text{N/mm}^2$; tensile strength $f_t = 1.57\text{N/mm}^2$; Poisson’s ratio $\nu_c = 0.2$; Elastic modulus $E_c = 1.5865 \times 10^5 \text{N/mm}^2$; Stress-strain relationship of concrete mainly take the KINH model, the stress-strain relationship of concrete is as shown in Figure 1.

![Concrete stress-strain diagram](image1)

Steel bar unit takes LINK8 units, material parameters are shown in Table 1

| Reinforced model | Bar area /mm² | Yield strength / N/mm² | Tensile strength / N/mm² | Elastic modulus N/mm² | Poisson’s ratio |
|------------------|---------------|-------------------------|--------------------------|-----------------------|-----------------|
| 6                | 28.3          | 210                     | 475                      | 21000                 | 0.3             |
| 12               | 113.1         | 300                     | 550                      | 20000                 | 0.3             |
| 18               | 254.5         | 300                     | 540                      | 20000                 | 0.3             |
| 20               | 314.2         | 300                     | 555                      | 20000                 | 0.3             |

Stress-strain relationship of reinforced material takes linear elastic model and double linear elastic (BKin) model. Stress-strain relation of steel bar is shown in Figure 2.

![Reinforcement stress-strain relationships](image2)

Carbon fiber takes SHELL181 unit. The material parameters are as follows: thickness 0.12mm, elastic modulus $E_c = 2.2 \times 10^5 \text{N/mm}^2$, tensile strength $f = 2.7 \times 10^5 \text{N/mm}^2$

2.2. Finite element model
2.2.1. The building of model
A combined model is conducted without considering slip between steel bar and concrete. SJ-1 is not impaired frame joint; SJ-2 is the damaged frame joints strengthened with CFRP sheets. Finite element model of structure is as shown in Figure 3.

Fig.3. (a). Finite element model of concrete; (b). Finite element model of steel; (c). Finite element model of Carbon fiber; (d). Boundary conditions;

2.2.2. Loading method
In finite element calculation, it takes displacement of monotonic loading in end of column by \( \Delta, 2\Delta, 3\Delta \). (\( \Delta \) is estimated yield displacement)

3. Calculation of results

3.1. Cracks and calculation of results

Fig. 4. (a). SJ-1 crack; (b). SJ-2 crack

Table 2 lists the results of finite element calculation of SJ-1~SJ-2 of six indexes. Comparison of SJ-1~SJ-2 in Table 2, ultimate load and ultimate displacement have been greatly improved after the reinforcement of CFRP, the material is better used with better ductility due to constraints on the nodes with carbon fiber sheets.

Table 2 finite element calculation of results

| Specimen number | Cracking loads /kN | Yield load /kN | Yield displacement /mm | Ultimate load /kN | Ultimate displacement /mm | Ductility factor |
|-----------------|--------------------|----------------|------------------------|-------------------|---------------------------|-----------------|
| SJ-1            | 12.15              | 45.24          | 9.68                   | 54.01             | 13.9                      | 1.44            |
| SJ-2            | --                 | 56.7           | 14.6                   | 89.82             | 42.61                     | 2.92            |
3.2. stress and strain analysis

3.2.1. Stress analysis of concrete

From finite element calculations, SJ-1 beam longitudinal reinforcement yield when damaged, SJ-2 did not even reach the yield strength of reinforcement, shear capacity of reinforcement specimen is primarily determined by the core of the concrete, judged by the third principal stress of concrete. Specimen of the third principal stress is as shown in Figure 6.

Fig.5. (a). SJ-1 third principal stress; (b). SJ-2 third principal stress

From third principal stress, the core area of concrete in compression zone conduct distinct diagonal strut, which mainly bear shear coming from the beam and column end at this time, the core area of concrete stress, and the size of diagonal strut bear the capacity of the node. Comparison with specimen before the reinforcement, the difference of strut is not obvious, though the bearing of diagonal strut after the reinforcement is more strengthened than before, which explain the strengthening of diagonal strut, it also can be verified from the final damaged load. Under similar loads, shear stress is increased much after reinforcement which illustrates the effect of strengthening Stiffness.

3.2.2. Stress analysis of reinforced

Comparison before and after strengthening of steel stress values are shown in Figure 6 and Figure 7, reinforcement with carbon fiber has a very good binding on crack of concrete, which makes the core area of beam longitudinal reinforcement and stirrup are fully utilized to yield strength.

Fig. 6. (a). SJ-1 longitudinal reinforcement stress; (b). SJ-2 longitudinal reinforcement stress

Fig. 7. (a). SJ-1 hoop stress; (b). SJ-2 hoop stress
3.2.3. stress and strain of carbon fiber sheet

Fig. 8. SJ-2 carbon fiber stress-strain

As in Figure 8, carbon fiber hasn’t reach the yield strength at the time of destruction of specimens, the material properties have not been fully utilized; Corner stress of the transfer of carbon fiber cloth in beam-column joints is large, and we must strengthen the corner of bond to avoid debonding of carbon fiber in practice.

4. Conclusion

It is based on the finite element results that crack after reinforcement in beam are more significant than before, it shows that reinforcement with carbon fiber improves the destruction state of specimens, from its core area of shear failure into a mix of beam bending failure and core shear failure damage. After reinforcement, beam longitudinal reinforcement and stirrup of core area have reached yield status. Strength deterioration, stiffness degradation and seismic behavior of energy dissipation are improved meanwhile carrying capacity; rigidity and ductility of joint aren't improved obviously. The research provides some theoretical basis and great practical value in carbon fiber reinforcement with great commercial future.

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