Full Process Nonlinear Analysis the Fatigue Behavior of the Crane Beam Strengthened with CFRP *

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Abstract: Based on appropriate material stress-strain relations and failure criteria and application development of ANSYS, 3-D nonlinear finite element models were used to analyze the mechanical properties of the RC crane beam strengthened with CFRP. A method for fatigue damage full-range nonlinear analysis of the RC crane beam strengthened with CFRP that can account for the coupling action between concrete and reinforcements is proposed. The strain-life curves and deflection-life curves by finite element analyses show good agreement with those of the experiments. Parametric analyses were conducted to investigate the influences of CFRP layers and length.

Keywords: RC crane beam; fatigue; CFRP; finite element analysis; parametric analysis

1 Introduction

Carbon fiber reinforced polymer (CFRP) composite materials have been successfully used in new construction and for the repair and rehabilitation of existing structures. Some tests and theory analysis have been conducted investigating strengthening reinforced concrete members with CFRP [1 – 3], there are still many aspects of their use that remain to be investigated. Owing to the complicated condition, long test time, excessive charge and so on, only experiment is deficient. Finite element analysis is an indispensable, dependable and reasonable method. The experimental studied on the RC crane beams have been conducted [4], based on the study we will carry through the finite element analysis. Based on the plate floor of ANSYS, via application development, the fatigue behavior of the RC crane beams are investigated by finite element analysis method. Then the parameters which include the layers and length of CFRP are researched.

2 Finite element modeling

The finite element modeling which the geometrical and physical parameters are the same as experiment is established, and the full process fatigue behavior of the beams strengthened with CFRP is simulated. Based on the simulation, parametric analysis is conducted. The elements of materials choose SOLID65, LINK8 and SHELL41.

2.1 Fatigue behavior of materials

The concrete introduces the elastic-plastic model and Willam-Warnker failure rule [5]. The stress-strain curve of concrete under constant amplitude uniaxial fatigue loading shows in Fig. 1. OA is the modulus of

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elasticity tangent of concrete origin: OB is the stress-strain curve under the first fatigue cycle of concrete. Figure 1 shows: \( \varepsilon_{\text{tol}} = \varepsilon_1 + \Delta \varepsilon_{\text{fat}} \), where: \( \varepsilon_{\text{tol}} \) - whole strain; \( \varepsilon_1 \) - strain correspond with \( \sigma_{\text{max}} \) of first cycle; \( \Delta \varepsilon_{\text{fat}} = 129S_m^{1/3} + 17.8S_m\delta N^{1/3} \)[6], where: \( \Delta \varepsilon_{\text{fat}} \) - strain at the maximum fatigue load along with cycle increasing, \( \delta \) - dispersion of stress, \( S_m \) - average of stress, \( N \) - cycle, \( t \) - time.

The residual intension of concrete is calculated as \( f_{t,N} = f_t \cdot r_t = f_t (a \log N + b) \), where: \( a, b \)-constants. The symbol of concrete fatigue press damage is \( \Delta \varepsilon_{\text{fat}} = 0.4\varepsilon_0 \), where \( \varepsilon_0 \) - maximum strain under static loading.

The rebar adopts Multilinear-kinematic hardening model, modulus of elasticity is assumable constant. The residual intension of rebar is calculated as \( \sigma_r = C (1/N)^\alpha \), where: \( \sigma_r \) - scope of stress; \( N \)-cycle: \( C, \alpha \)-constant.

The stress-strain curve of CFRP adopts linear elastic theory [4],[7], and CFRP only endure pulling stress. When \( \varepsilon_{\text{cfs}} \leq \varepsilon_{\text{cfs,u}} \), \( \sigma_{\text{cfs}} = E_{\text{cfs}}\varepsilon_{\text{cfs}} \); When \( \varepsilon_{\text{cfs}} \geq \varepsilon_{\text{cfs,u}} \), CFRP rupture. The pulling stress is no allowable exceed \( \varepsilon_{\text{cfs,u}} \), Where \( \varepsilon_{\text{cfs,u}} \) equals the least value of \( 2 \varepsilon_{\text{cfs}}/3 \) or 0.01.

### 2.2 Finite element modeling

The analytic modeling and gridding which is plotted show in Figure 2.

![Figure 1: Stress-strain of concrete under constant amplitude loading](image1.png)

![Figure 2: Finite element modeling](image2.png)

### 2.3 Analytic method

The fatigue behavior of materials degenerates along with increasing cycles, the stress-strain changes, intensity degenerates, plastic deformation is more and more serious in the fatigue process. Under high fatigue cycle, every cycle is accurately calculated to reflect the behavior of specimens is difficult. Furthermore, engineers more concern the reflection of materials during the maximum fatigue loading. Thus, the fatigue process is divided into a monotonic load and the material behavior degeneration during the maximum fatigue loading concomitantly cycle increasing.

According to the feature of problem and the rationality of calculation, there are several keys to establish model as follows:

The flow diagram of fatigue analysis by finite element technique is show in Figure 3.

The broad time is defined as 1 at the first fatigue loading.

Load step can fractionize as sub-step, and one step contains 10000 cycles.

The calculation is end when the beam damage or the cycles equal 2000000.

At the balance iterative integral point, FORTRAN sub-program is used to calculate and the residual fatigue strain is given.

3 Comparison of calculation and experiments

Analysis results and experimental data which the strain-life curve of the material is measured on the maximum loading show in Figure 4~ Figure 6, and show good agreement. Some error comes from the stress-strain mode, which is needed to ameliorating. The deflection-life curves show in Figure 7, analysis results is lesser than experimental data, the error is agreement.

Figure 4: Strain – life curves of the concrete

(a) JGL1
(b) JGL2
(c) JGL3

Figure 5: Strain – life curves of the concrete

(a) JGL1
(b) JGL2
(c) JGL3

Figure 6: Strain – life curves of the concrete

Figure 7: Deflection – life curves.
4 Parametric analyses

In order to investigate the influence of the CFRP quantity, which the RC beam is strengthened with, the parameters are studied on JGL3. Based on JGL3, the mode of parametric analysis only changes the layers or length of the CFRP, then researching the fatigue behavior of the beams from the parameter changes.

\( n \) is the layers of the CFRP. From Fig. 7, we can see that the strain of the bar when layer equal 12 is reduced 15%~20% and 24%~28% compare with un-strengthened beam, the variety which the strain of the bar is not evidence when two layers compare with three. From Fig. 7, we can see that the deflection of the beams when layer equal 1, 2 is reduced 20%~25% and 30%~35% compare with un-strengthened beam, the variety which the deflection of the beams is not evidence when two layers compare with three. Apparently, the function of the layers is evidence for the life and stiffness of the beams, while the function of each layer more and more fewer along with layers increasing.

\( L \) is the length of CFRP (mm). From Fig.10 and Fig. 11, we can see that the effect which different lengths of the CFRP strengthen the beams behavior under flexural fatigue loading is not evidence, when the CFRP of beams are anchored.

5 Conclusions

(1) Full process nonlinear analysis is used to investigate the fatigue behavior of the RC crane beams strengthened with CFRP. Analysis results are compared with experimental data show good agreement and the mode
(2) Parametric analysis shows that the life and stiffness of the RC beams is evidently influenced by the CFRP layers, and increasing along with the layer increased. It is suggest that the layer is less two. When the longitudinal CFRP of beams is additionally anchored by U-shaped CFRP in the shear spans, the function of CFRP which strengthened on the both sides of the beams is not obvious.

(3) There is error between finite element analysis and experiment. The reasons are follows: the mode of stress-strain of the material is no exact; the finite element method can not simulate deflection from the cracking of concrete; the method of full process nonlinear analysis of the fatigue behavior is based on static analysis.

References


