Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Analytical Study on the Flexural Behavior of Reinforced Concrete Beams Strengthened with Prestressed Carbon Fiber-Reinforced Polymer Plates

S. K. Woo,a Y. C. Song,a H.P. Lee,a K. J. Byun,b
a Structural Safety Group, Korea Electric Power Research Institute, Daejeon, Korea, wskyun@kepri.re.kr
b School of Civil and Environmental Engineering, Yonsei University, Seoul, Korea, byun@yonsei.ac.kr

1. Introduction

This study aims to predict the behavior of concrete structures strengthened with prestressed CFRP plates with more reliability, and then develop a nonlinear structural analysis model that can be applied more effectively in reinforcement designs, after examining the behavior characteristics of CFRP plates and epoxy, and the behavior of the boundary layer between CFRP plates and concrete.

2. Behavior characteristics of carbon fiber reinforcement polymer(CFRP)

2.1 Behavior of characteristics of epoxy

In this study, the behavioral characteristics of epoxy are analyzed based on uni-axial tensile test results and other existing research. In addition, an epoxy behavior model, as in Fig. 1, is suggested.

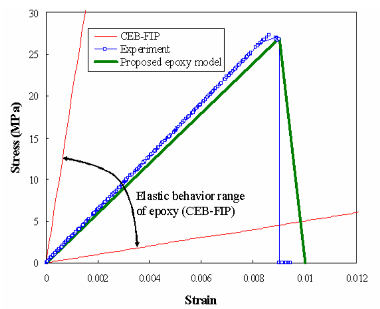

Fig. 1 Epoxy behavior model

2.2 Behavior of characteristics of CFRP

Presently, there has been a great amount of progress in studies regarding the behavior of CFRP. Previous research utilized theories that generally defined the fracture standard of CFRP as a uni-axial tensile strength. Most of these studies used tensile strength and linear elasticity to predict the behavior of CFRP before it reached fracture strength. However, existing research that categorizes CFRP as a linear elastic material tends to ultimately underestimate CFRP capacity by not considering the behavior of CFRP in the stages before it reaches the uni-axial tensile strength. These studies also underestimate CFRP performance by applying an average elastic modulus that only considers maximum tensile strength. Therefore, this research analyzes behavioral characteristics by sorting the tensile behavior of CFRP into four steps based on the uni-axial tensile test results of CFRP and suggests a CFRP behavior model as in Fig. 2.

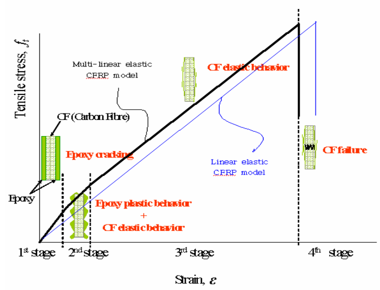

Fig. 2 Multiple linear CFRP behavior model

3. Experimental Program

This study performed a flexural test by manufacturing test specimens as in Fig. 3 to analyze the flexural capacity improvement effects for a reinforced concrete beam that has been strengthened with prestressed CFRP plate. The width and the height of the test specimen section is 300mm and the length is 2,980mm. And the strengthening method and the prestressing level of a CFRP plate were considered as test variables. The strengthening method was divided into un-strengthened, surface bonding, end fixing, and prestressing. The prestressing level was set at 4% and 6% respectively.

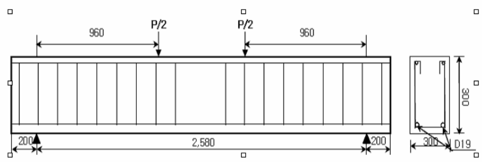

Fig. 3 Details of specimen (Unit: mm)

4. Experimental results

The results of the flexural experiment for each test specimen according to the strengthening method are shown in Table 1. According to the experimental results, the CFRP plate surface bonding increased load resistance as much as 14.3% compared to the control specimen, but the test specimens strengthened by fixed ends and prestressing increased by 43.8 ~ 52.6%, which confirmed that the strengthening effect improved greatly in comparison to surface bonding. The results also confirmed that for a prestressed specimen, the load for initial crack generation greatly increased, so the restraining effect for the initial crack was very high. However, displacement was relatively small compared to that of the control specimen because the prestressed specimen showed a brittle fracture mode through the fracture of the CFRP plate.

Table 1. Comparison of finite element analysis with experimental results of test specimens strengthened with CFRP plate

Specimens	Crack load (kN)		Yield load (kN)		Ultimate load (kN)	
	Experiment	Analysis	Experiment	Analysis	Experiment	Analysis
RU	26.4	24.5	121.3	107.8	146.7	142.2
RS	31.6	29.4	140.0	132.3	167.9	215.6
R0A	36.0	34.3	143.4	137.3	211.0	215.7
R4A	56.6	44.1	181.6	137.3	218.5	220.6
R6A	62.6	44.1	188.5	137.3	223.8	225.5
Reliability (%)	85.9		85.5		98.3	

5. Nonlinear analysis of a flexural member strengthened with prestressed CFRP plates

In this study, a nonlinear finite element analysis was carried out using an analysis technique that was developed based on a material property experiment. This experiment verified the reliability of the analysis model developed through comparison.

Concrete in the test specimens strengthened with prestressed CFRP plate used a three dimensional 8-node solid element (HX24L) with a Drucker-Prager fracture standard, and reinforcing bars were modeled by using the Bar element (BAR). Moreover, CFRP and the fixing device were modeled with the same solid elements as concrete. Meanwhile, as epoxy generally carries out the boundary function of concrete and CFRP, it is possible to carry out modeling by using boundary elements such as the three-dimensional interface element (Q24IF).

However, as epoxy used in the structural member for the analysis not only has a required thickness of 2mm, which is thicker than CFRP, but also requires the same level of strength as concrete, epoxy was modeled by using a solid element in this analysis. The finite element modeling configuration of the test specimen strengthened with prestressed CFRP plate that considered concrete, reinforcing bars, CFRP, fixing devices, and epoxy is shown in Fig. 4.

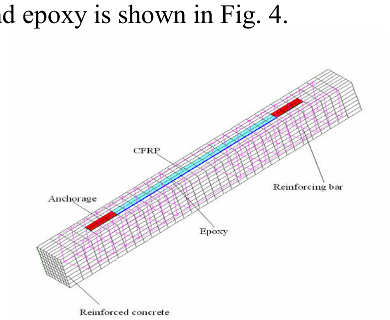

Fig. 4 Finite element modeling of specimen

The flexural fracture behavior analysis of test specimens strengthened with prestressed CFRP plates was carried out, and the load-displacement response for the center part of the test specimens is shown in Fig. 5.

As seen in Fig. 5, the analysis model that was developed fairly accurately estimates the fracture behavior of test specimens strengthened with prestressed CFRP plates. A finite element analysis on each test specimen was carried out by applying the developed model, and when the results are compared to the experimental results, they are as in Table 1. As shown in Table 1, about 90% reliability was secured as a result of calculating the experimental results and the results of the analysis.

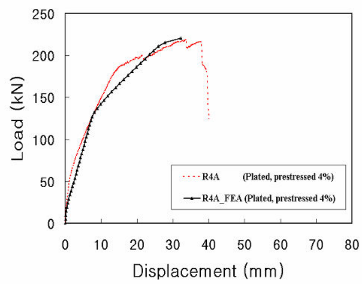

Fig. 5 Comparison of load-displacement responses of test specimens strengthened with prestressed CFRP plate

6. Conclusions

A structural analysis model that can predict the structural behavior of concrete structures strengthened with prestressed CFRP plate was developed by applying the suggested material model. By applying the analysis model developed in this study, the flexural fracture behavior of test specimens that are un-strengthened, surface bonded, and strengthened by prestressing were analyzed. In addition, the reliability of the analysis technique developed in this study was verified by a comparative analysis of the experimental results and the analysis results. The results show that this analysis technique can be applied effectively on the strengthening designs that use CFRP plate. However, this study also showed that reliability for surface bonding was rather low compared to that of other strengthening methods, and further supplemental research is needed.

REFERENCES

[1] Quantrill, R. J., Hollaway, L. C. and Thorne, A. M. Predictions of the Maximum Plate End Stresses of FRP Strengthened Beams : PartⅡ, Magazine of Concrete Research, 1996, Vol. 48, No. 177, pp. 343~351.

[2] Arduini, M. and Nanni, A. Parametric Study of Beams with Externally Bonded FRP Reinforcement. ACI Structural Journal, 1997, Vol. 94, No. 5, pp. 493~501.

[3] Quantrill, R. J., and Hollaway, L. C. The Flexural Rehabilitation of Reinforced Concrete Beams by the Use of Prestressed Advanced Composite Plates. Composites Science and Technology, 1998, Vol. 58, pp. 1259~1275.