Reinforcing Effects and Flexural Load Carrying Capacity of Stress-Hysteresis RC Beams with Carbon Fiber Sheet

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1. Introduction: The Carbon Fiber Sheet (CFS), which is light and has a long service life, can be used to repair and reinforce RC members of bridge [1-2]. The reinforcing effects of CFS were tested using two types of reinforced RC beams: ① RC beams reinforced without CFS, and ② stress-hysteresis RC beams reinforced with CFS.

2. Preparation of Test Specimens

2.1 Materials used for test specimens: The test specimens were produced using ordinary Portland cement, coarse aggregates with a maximum size of 20mm (Compressive strength are 38.5N/mm^2 and 41.5N/mm^2 for Type Ⅰ and Type Ⅱ), and D16 reinforcement of the SD 295A class (Yield and Tensile strength are 368N/mm^2 and 568N/mm^2). High-strength continuous CFS with a unit weight of 202g/m^2, a tensile strength of 4,420N/mm^2, a thickness of 0.111mm, and a width of 30cm were used as the reinforcing material to be placed on the bottom of each specimen. Epoxy resin (bond strength with concrete: 2.6N/mm^2) was used to bond CFS to the specimen.

2.2 Specimen size and reinforcement arrangement: Fig. 1 shows the detail of two groups of RC specimens with two different depths that were produced for the experiment.

3. Reinforce and Repair Stress-Hysteresis RC Beam

3.1 Method of creating stress hysteresis: The Running vibration load was created using wheels that traveled from support A to support B. The vibration load had a frequency of 2.0Hz and amplitude of ±20% and ±30%. The wheels were then returned to support A from support B at a speed of 22cm/sec to complete the 18-second cycle. Starting from 0kN, the load was increased by 5kN every cycle. A previous study [2] showed that RC beams subjected to static loads would fail when the deflection exceeded 20mm. Therefore, in this test, loading was stopped before the deflection reached 20mm.

3.2 Results of test on stress-hysteresis RC beam specimen

(1) Load carrying capacity of specimen: The loading capacity was 75.7kN for Ⅰ-V20, 75.2kN for Ⅰ-V30, 94.1kN for Ⅱ-V20, and 92.5kN for Ⅱ-V30. Fig. 1(2) shows the cracks conditions.

(2) Relationship between load and reinforcement strain: The relationship between reinforcement strains and residual strains under loads at the center of the span is shown in Fig. 2. For Ⅰ-V20, the maximum strain and the residual strain were

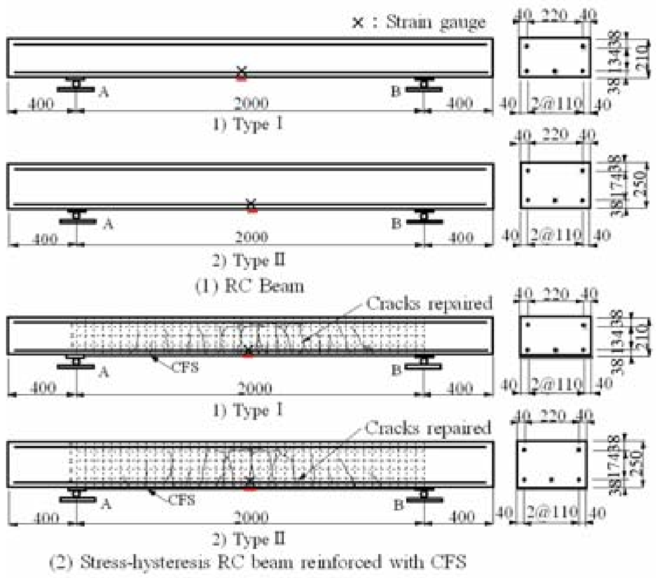

Fig. 1 Specimen size and reinforcement arrangement

6,300×10^{-6} and 967×10^{-6} when the load carrying capacity was 64.4kN. For Ⅰ-V30, the maximum strain and the residual strain were 7,600×10^{-6} and 1,189×10^{-6} when the load carrying capacity was 57.9kN. For Ⅱ-V20, the maximum strain and the residual strain were 8,700×10^{-6} and 2,100×10^{-6} when the load carrying capacity was 78.4kN. For Ⅱ-V30, the maximum strain and the residual strain were 5,200×10^{-6} and 1,500×10^{-6} when the load carrying capacity was 71.1kN.

(3) Relationship between load and deflection: The relationship between load and deflection is shown in Fig. 4. For Ⅰ-V20, the maximum deflection and the residual deflection were 12.3mm and 4.5mm when the load carrying capacity was 64.4kN. For Ⅰ-V30, the maximum deflection and the residual deflection were 12.8mm and 3.2mm when the load carrying capacity was 57.9kN. For Ⅱ-V20, the maximum deflection and the residual deflection were 12.7mm and 4.8mm when the load carrying capacity was 78.4kN. For Ⅱ-V30, the maximum deflection and the residual deflection were 11.5mm and 4.3mm when the load carrying capacity was 71.1kN.

3.3 Repairing Cracks in Stress-hysteresis RC Beams: The bottom of the RC beam was first ground smooth, then a crack sealing material was applied and allowed to cure for about 24 hours. Injection pipes were then inserted into the cracks. Finally, epoxy resin and a hardening solution (mixed at 2:1) were injected into the cracks through the pipes and allowed to cure for 7 days.

Key word: RC beam, Carbon Fiber Sheet (CFS), Stress-hysteresis, Reinforcing Effects
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Table 1 Maximum load carrying capacity and failure modes

Test Specimen	Flexural load (kN)	Average load (kN)	Ratio	Failure Modes
I-M-1	80.9	83.0	————	Flexural failure
I-M-2	85.1			Flexural failure
I-D20-C.M	109.4	107.6	D-C.M/M=1.30	Peeled off failure
I-D30-C.M	105.7			Peeled off failure
Ⅱ-M-1	105.6	102.9	————	Flexural failure
Ⅱ-M-2	100.1			Flexural failure
Ⅱ-D20-C.M	130.0	127.5	D-C.M/M=1.24	Peeled off failure
Ⅱ-D30-C.M	125.0			Peeled off failure

※Ⅰ,Ⅱ-:TypeⅠ,TypeⅡ; M-:Flexutal test under static load; C-:CFS
D-:Stress damage(20:amplitude±20%,30:±30%); 1,2-:Test specimen No.

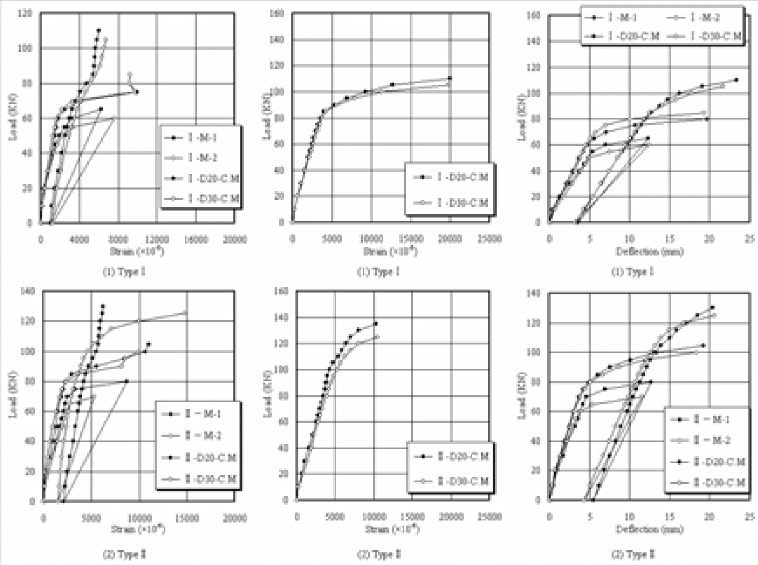

Fig. 2 Load and strain (rebar) Fig. 3 Load and strain (CFS) Fig. 4 Load and deflection

4. Failure Modes and Maximum Load Carrying Capacity

(1) RC beams without CFS: The average load carrying capacities under static loading were 83.0kN for TypeⅠ and 102.9kN for Type Ⅱ. The failure mode was flexural failure.

(2) Stress-hysteresis RC beams with CFS: Under static loading, the average load carrying capacity was 107.6kN for TypeⅠ and 127.5kN for TypeⅡ. The ratio (D-C.M/M) between stress-hysteresis RC beams with CFS and RC beams without CFS was 1.30 for TypeⅠ and 1.24 for TypeⅡ. The results show that the CFS effectively improved the strength of stress-hysteresis RC beams with CFS. The failure mode for CFS was peeled off failure.

5. Relationship Between Load and Strain

(1) Strain in tensile reinforcement: The relationship between the load and the strain for the tensile reinforcement at the center of the span is shown in Fig. 2. For RC beams without CFS, the yield strength of the tensile reinforcement was 65kN for TypeⅠ and 75kN for TypeⅡ. The strain sharply increased after yielding. For Stress-hysteresis RC beams with CFS, the residual strain (969×10^{-6}) obtained from the previous study is reflected in the results shown in Fig. 2. Therefore, the total strain of the beam is the sum of the residual strain and the strain after applying CFS. The yield strength was 40kN forⅠ-D20-C.M, and the strain increased gradually after yielding. The strain in the reinforcement showed little increase after the load exceeded 85kN. This indicates that CFS effectively reinforced the beam. The results for Ⅰ-D30-C.M were similar to those forⅠ-D20-C.M. The specimens had a yield strength of 95kN forⅡ-D20-C.M, and the reinforcement strain was similar to that for the TypeⅠ specimens. The yield strength of Ⅱ-D30-C.M was 80kN, and the reinforcement strain of this specimen sharply increased after the load exceeded 105kN.

(2) Strain in CFS: Figure 3 shows the relationship between the load and the CFS strain at the center of the span. In TypesⅠ and Ⅱ, the CFS strain increased linearly after the tensile reinforcement yielded and reached a maximum value of $20{,}000\times10^{-6}$ at the ultimate state. The CFS peeled off at the strain larger than the nominal peeling strain of $6{,}000\times10^{-6}$, and the increase in the CFS strain after peeling was small. After the load was 80kN for TypeⅠ and 100kN for TypeⅡ, the CFS strain was increased remarkably. Therefore, the increase in the reinforcement strain was small as the load increased for specimens, indicating that the rate of the tensile force transferred to the CFS had increased.

6. Relationship Between Loading and Deflection: Figure 4 shows the relationship between the load and the deflection at the center of the span. The results obtained from the previous study [2] and the residual deformations for stress-hysteresis RC beams with CFS are also shown in Fig. 4. With respect to stress-hysteresis RC beams, the increase in the deflection as the load increased was small.

7. Conclusion

(1) The load carrying capacity of stress-hysteresis RC beams with CFS was 1.30 and 1.24 times larger than the TypeⅠ and TypeⅡ of RC beams reinforced without CFS, respectively.

(2) The flexural strength of RC beams can be greatly increased by applying CFS. The strength of stress-hysteresis RC beams can also be increased by also repairing cracks. Therefore, it can be concluded that the CFS reinforcing method is very effective in improving the strength of RC bridge slabs.

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