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RC beams strengthened by prestressed CFRP plate subjected to sustained loading

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Abstract
Prestressed carbon fiber reinforced polymer (CFRP) is effective in strengthening of deficient reinforced concrete (RC) structures. However, the long-term performances of the strengthened RC beams under sustained loading are not fully understood yet. In this paper, the prestress-loss and flexural behaviour of the RC beams strengthened by prestressed CFRP plate subjected to sustained loading was experimentally studied. The prestressed levels were 20 and 40% of ultimate strength of CFRP plate. Two levels of sustained load were considered as well. The experimental results showed that the end plate anchorage system has good performance under two levels of sustained load. The beams with prestress level at 40% showed better performance against crack generation and development, time-dependent deflection than prestress level at 20%. Moreover, the deflection increases during the sustained loading due to the creep of concrete but it become almost constant after 180 days and the CFRP strain increase only occurred at the first 15 days, which show good performance of the anchorage device for one-year prestress loss control. For one-year exposure, furthermore, the sustained loading has insignificant influence on the yield load, ultimate load and ultimate deflection of the strengthened RC structures.

Keywords: prestressed CFRP plate; RC beams; sustained loading; flexural behaviour; prestress loss

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Introduction

Reinforced concrete (RC) structures could be deteriorated after long-term service due to mechanical loading. To guarantee the safety of the RC structures, maintenance measures could be taken by external bonding carbon fiber reinforced polymer (CFRP) and prestressing CFRP [1-2]. For the strengthened RC structures, damage could occur due to the mechanical loading such as sustained loading. Although RC beams strengthened with externally bonded (EB) CFRP under sustained loading has been widely concerned [3-4]. The combined effect of prestressing and sustained loading were rarely considered.

In this study, time-dependent behaviours including cracking propagation, variation of deflection and CFRP strain were investigated for RC beams subjected to the combined effect of prestressing and sustained loading. Subsequently, the four-point bending tests were conducted for the strengthened RC beams to study the mechanical performance influenced by the time-dependent cracking. The influence of different prestress levels and sustained loading levels are compared and studied.

Experimental program

To understand the mechanical behaviour of RC beams strengthened by prestressed CFRP plate subjected to sustained loading, a series of tests were carried out. Prior to flexural test, the devices for prestressing of CFRP plates and applying sustained loading were proposed. 4 strengthened specimens were prepared for testing, as shown in Table 1. The effects of two prestress levels (20% and 40% of the ultimate tensile strength of the CFRP plate), two sustained loading levels and durations (170 days and 360 days) were considered.

Table 1 Test specimens details and test results

Specimen No.	CFRP prestress level	Sustained load (kN)	Sustained loading durations（Days）	Yield load (kN)	Ultimate load (kN)	Ultimate deflection (mm)
P20%-S1	20% fu	94	170	208.10	244.60	24.39
P40%-S1	40% fu	94	170	232.38	280.94	28.12
P20%-S2	20% fu	120	360	204.48	245.95	26.51
P40%-S2	40% fu	120	360	253.34	280.19	28.28

The length of the beam is 2800 mm with a cross section 160×300 mm, as shown in Figure 1, concrete with compressive strength of 40 MPa was used in this test.Two reinforcing steel bars with a diameter of 20 mm were used in the tension zone and compression zone for main reinforcement. Double-legged steel stirrups of 10 mm diameter uniformly spaced at a 100 mm. CFRP plates have a thickness of 3 mm, a width of 50 mm, the tensile strength and Young's modulus of which were 2450 MPa and 171 GPa. Adhesive with the tensile strength of 51.3 MPa were used. After 28 days of curing, the CFRP plate was prestressed and externally bonded on RC beams. As shown in Figure 1, hydraulic jack was installed at one end of tensile face while the other end was fixed. Two strain gauges were attached on the CFRP plate to measure the prestress. The nuts were fastened after the strain value reach the designed value.

Strengthened specimens were subjected to sustained loading after the adhesive was cured. A reaction frame can accommodate two beams subjected to the same sustained loading. The sustained loading values are defined in accordance with Chinese standard (JTG D60-2015) [5]. Among them, 94 kN is the calculated value of long-term effect combination, while 120 kN is the value of short-term effect combination. In particular, under the sustained loading, the concrete under tension could be cracking and the tension reinforcement was not yielded. It can simulate the cracking condition of prestress CFRP plate strengthened RC bridge in site. Load on the reaction frame was applied by hydraulic jack and was monitor by the load cell at mid-span, the strain variation of CFRP was monitored by fibre Bragg Grating (FBG) and the mid-span deflection was measured through LVDT. After a certain period of sustained loading, the four-point bending tests were conducted. The test was displacement controlled with a loading speed 0.5mm/min. When the crushing on the compression zone or rupture of CFRP plate was observed, the specimen was considered as failure and the loading will be stop.

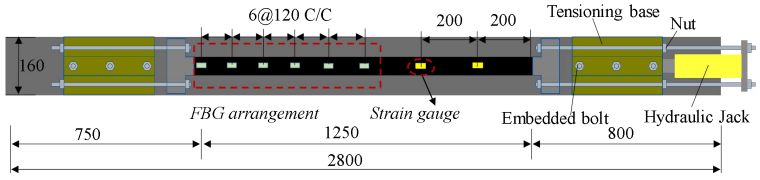

Figure 1: Prestressing set up and sustained loading system

Results and discussions

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Cracks initiation and propagation were monitored by the crack observation instrument. The number of cracks for P20%-S1, P20%-S2, P40%-S1 and P40%-S2 were 8, 2, 12 and 5 mm, respectively. The maximum crack width of specimens on 170 days can be seen in Figure 2a. The crack widths of 40% specimens were less than 0.2 mm, regardless of the loading level. While the maximum crack width for P20%-S1 and P20%-S2 were 0.24 and 0.42 mm, respectively. It is clear that beams with prestress level at 40% showed better performance against crack generation and development than 20%.

Mid-span time-dependent deflection was monitored by LVDT. As shown in Figure 2b, the deflection increased rapidly in the first month and then increased gradually until 180 days. After that, the deflection was almost constant. Under the same sustained load level, the beams with prestress level at 40% can reduce the initial deflection significantly. The prestress level increase can somehow beneficial to the restraint of deflection increase.

The CFRP strain variation was monitored during the whole sustained loading test and presented in Figure 2c. The CFRP strain increased greatly at the first half a month and then kept almost constant, which means that the Lica anchorage system is very reliable in controlling the stress on CFRP plate in one-year monitoring.

After sustained loading, the static flexural tests were conducted to understand the effects of sustained loading on flexural behaviour of strengthened RC beams. As observed, the failure mode of all the strengthened specimens were crushing on the concrete compression zone. According to our previous test, the yield load of P20% and P40% specimens (without sustained loading) were 210.82 and 239.32 kN, the ultimate load of P20% and P40% specimens were 248.22 and 264.35 kN. For 20% specimens under sustained loading, refer to specimen P20%, the average yield load, ultimate load and ultimate deflection variations were -2.1%, -1.2% and -6.3%, respectively. Compared with specimen P40%, the average yield load, ultimate load and ultimate deflection variations of 40% specimens under sustained loading were 1.5%, 6.1% and 6.6%, respectively. The results indicate the

sustained loading has insignificant influence on the yield load, ultimate load and ultimate deflection of the strengthened RC structures.

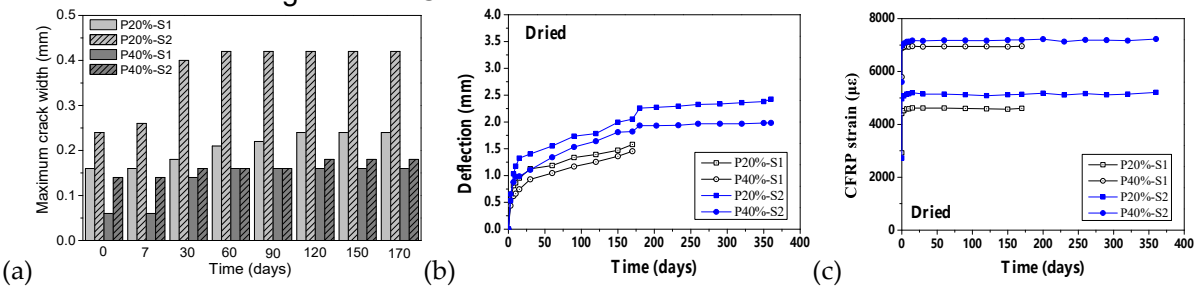

Figure 2: Maximum crack width (a), time-dependent deflection (b) and CFRP strain (c) of specimens

Conclusion

(1) Under sustained loading, specimens with prestress level at 40% have fewer number of cracks and smaller crack width than 20%. Additionally, the specimens with prestress level at 40% can better reduce the time-dependent deflection. Hence, specimens with prestress level at 40% showed better performance against crack generation and development and time-dependent deflection than 20%.

(2) Under sustained loading, the deflection increases at the first 150 days and kept almost constant until 360 days. The anchorage device is effective in restricting the deflection and strain development. It shows good long-term performance.

(3) By comparing to the reference specimens, the sustained loading applied on the prestressing specimens has insignificant influence on the yield load, ultimate load and ultimate deflection.

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