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Preface

This Geotechnical Special Publication (GSP) consists of 22 papers covering various topics, including innovative construction materials, numerical and experimental work, analysis methodology, assessment and evaluation of case studies. These papers were presented at the Geohubei International Conference, held in Hubei, China, July 20 to 22, 2014. This GSP includes contemporary subjects and research findings from numerous countries. A number of papers feature innovation and emerging technologies in materials, while others address key issues in the accuracy and efficiency of analysis. Several papers present case studies, particularly taking Three Gorges Reservoir for example, with valuable discussions about esthetics, safety and environmental impacts. It expands ranges of knowledge, and tools that are available to scientists, researchers and engineering practitioners.

The following individuals have assisted on preparing the GSP and reviewing the papers:
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Reinforced Concrete Structures with Hybrid Technology of Pre-stressed CFRP Sheets and Pre-screwed Bolts

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ABSTRACT: The carbon fiber reinforced composite polymer（CFRP）reinforcement is currently one of the most popular and effective methods for retrofitting and strengthening concrete structures. However, the non-prestressed CFRP reinforcement cannot make full use of the tensile strength of CFRP , the crack development of the stiffening beam cracks cannot restrained actively either. The failure of a strengthened or retrofitted structure with the non-prestressed CFRP was usually caused by the breakdown of the bond at the CFRP-epoxy interface or at the concrete-epoxy interface where is weaker than other place. Much effort had been made in researching community to improve the bond strength and restrain the crack development of the strengthening beam cracks actively. The full CFRP strength can usually be achieved in the strengthened or retrofitted structure with the prestressed CFRP. The Pre-screwed bolts fastening is another new mechanical fastening technique that is used to bond one material to another to improve the bond interface strength. Therefore, this paper introduces a new hybrid bonding prestressed technique that combines the prestressed CFRP reinforcement and the pre-screwed bolts fastening. A new tensioning equipment was developed in order to prestress CFRP. The strengthened reinforced concrete (RC) beam experiments have been finished to check the strengthening effect. The experimental tests demonstrated the new hybrid technology of pre-stressed CFRP sheets and pre-screwed bolts can make full use of the tensile strength of CFRP and restrain the crack development of the strengthening beam cracks actively.

KEYWORDS: Carbon fiber reinforced polymer, Pre-screwed bolt, Hybrid method, Strengthening technology, Prestress, Concrete structures

INTRODUCTION

The external bonding of carbon fiber-reinforced polymer(CFRP)reinforcements has emerged as one of the most popular methods for structural rehabilitation in recent years. So far, two type methods for bonding CFRP reinforcements onto concrete structures have been developed. The first and most common method involves the bonding of the CFRP on the external surface of the reinforced concrete (RC) members, another method is known as non-prestressed CFRP reinforcement (Yue 2000, Wang 2005, Li et al 2005). But the engineering practice shows that the non-prestressed CFRP reinforcement cannot make full use of the tensile strength of CFRP or cannot restrain the crack development of the strengthening beam cracks actively (Li et al 2004, Yun et al 2008). The second type method is the prestressed CFRP technique, as we all know, the prestressed CFRP reinforcement can make full use of the tensile strength of CFRP and the crack development of the strengthening beam cracks can be restrained actively (Garden and Hollaway 1998b). However, the technology of prestressed CFRP reinforcement is very complicated. The current study and application of prestressed CFRP reinforcement mainly focus on the prestressed CFRP plates. Because of the stretching and fastening of prestressed CFRP sheets are difficult in practical reinforcement application, there are very few study and application about the technology of prestressed CFRP sheets reinforcement. Further efforts to find the alternative means of stretching and fastening FRP is needed.

A NEW HYBRID BONDING PRESTRESSED TECHNIQUE

The technique of hybrid bonding CFRP reinforcement is an non-prestressed CFRP reinforcement with steel sheet capping plates and mechanical fasteners of pre-screwed bolts, namely hybrid bonding CFRP reinforcement (HB-CFRP). The experimental study shows that HB-CFRP is a highly effective technique in increasing the bond strength(Guan et al 2012). But it cannot restrain the crack development of the strengthening beam cracks effectively. The study shows that the beams strengthened with prestressed CFRP can not only to restrain the crack development of cracks effectively, but also to make full use of the tensile strength of CFRP. So the new hybrid bonding prestressed technique that combines the prestressed CFRP reinforcement and the hybrid bonding CFRP reinforcement, and that's why named the hybrid bonding prestressed CFRP system (HB-PRECFRP). A new tensioning equipment has been developed to prestress CFRP in concrete structures reinforcement, which is showed in Fig.1. This new HB-PRECFRP system demonstrated highly effective in increasing the bond strength and restraining the concrete beam crack by experimental testing. The details of the experimental tests are reported in the following sections.

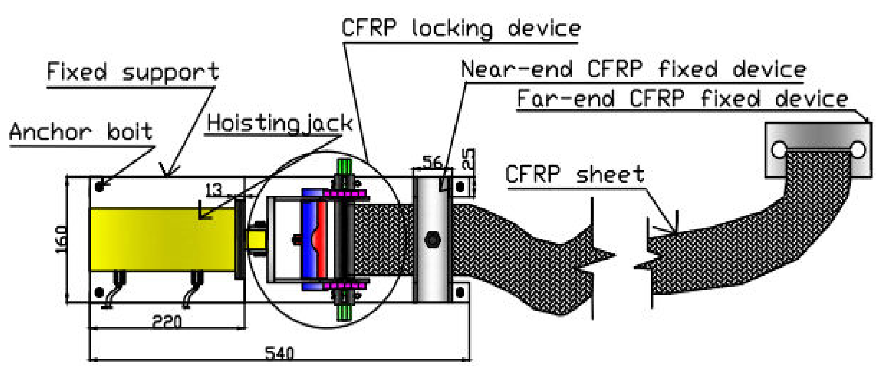

Fig.1. Tensioning equipment schematic diagram

TEST SPECIMENS

Six flexural members were tested in experimental program, including one reference specimen which was not strengthened with any technique, and another one specimen was strengthened with the HB-CFRP technique, and three specimens were strengthened with the prestress CFRP technique(PRE-CFRP), last one specimen was strengthened with the HB-PRECFRP technique. Details of the RC specimen is shown in Fig. 2.

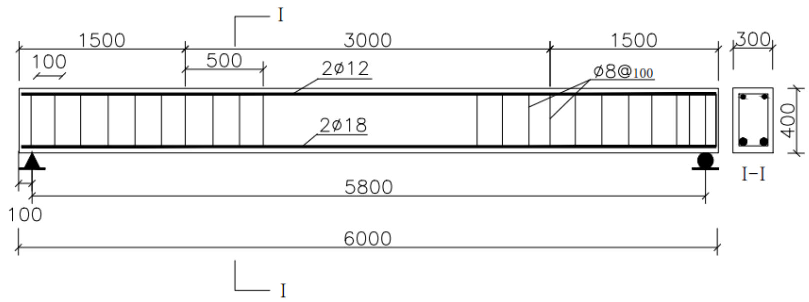

Fig. 2. Details of the RC specimen（unit:mm)

The details of the strengthening specimens are shown in Fig.3, and the material properties of the specimens is given in Table1.

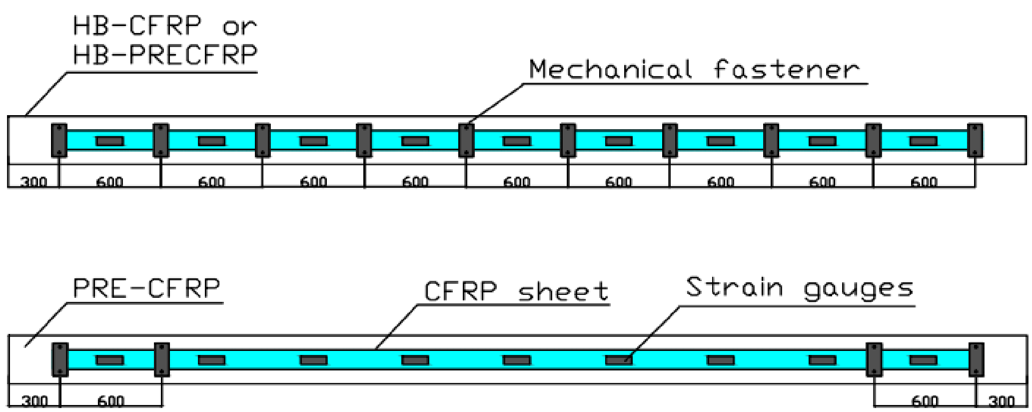

Fig.3. Details of the strengthening specimens

Table 1. Material Properties

			Steel bars		CFRP strip			
Specimen	Strengthening method	Concrete cube strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate strain (%)	Prestress (MPa)
BM1	—	39.5	345	207	4192	240	1.75	—
BM2	HB-CFRP	42	343	207				—
BM3	PRE-CFRP	41.5	349	206				479
BM4	PRE-CFRP	42.5	338	207				719
BM5	PRE-CFRP	40	340	208				958
BM6	HB-PRECFRP	42	339	208				958

Five specimens were strengthened with two plies of CFRP. The width of CFRP strip was 100mm. Specimen BM2 was strengthened with the HB-FRP system. Specimens BM3, BM4, BM5 were strengthened with the PRE-FRP system in different prestress respectively. Specimen BM6 were strengthened with the HB-PREFRP system.

The CFRP for strengthening beams was Toray Carbon Fiber UT70-30. The nominal thickness of the CFRP was 0.167mm for each ply. The mechanical fastener that was used in the experiment consisted of one steel capping plate and two bolts. The capping plate was cut from 3mm thick mild steel plate. The high-strength bolts which generally available in the market were used as the anchors. The prestress was applied to the high-strength bolts by the screw nuts and the pressure was forced on the CFRP strip by the capping plates. The epoxy resins were adopted to anchor bolts and bond the capping plates. The strength of epoxy resin was 54MPa which provided by the manufacturer.

Before bonding the CFRP strip, the bottom face of the specimen was roughened and cleaned. The holes were drilled with 12mm drill bit to penetrate into the concrete in the depth of 50mm for the installationing of the bolts. After the drilling, some epoxies were filled into the predrilled holes to anchor bolts. When the epoxy had hardened sufficiently, the CFRP strip was anchored on the one end of the beam, and then the bottom face of the specimen was covered with the resinous bond materials evenly. Next, the CFRP was prestressed with the new tensioning equipment on another end of the beam. When the prestress of CFRP reached to design standard, the CFRP was anchored on the end of beam and bonded to the concrete specimen according to the manufacturer's instructions. Finally, another coat of epoxy was applied on top of the FRP strip at the positions of the mechanical fasteners to ensure a good contact , and the capping plates were installed, the nuts were screwed up to reach the design pretightening force.

TEST SETUP AND INSTRUMENTATIONS

Schematic representation of test set-up for specimens is shown in Fig.4.

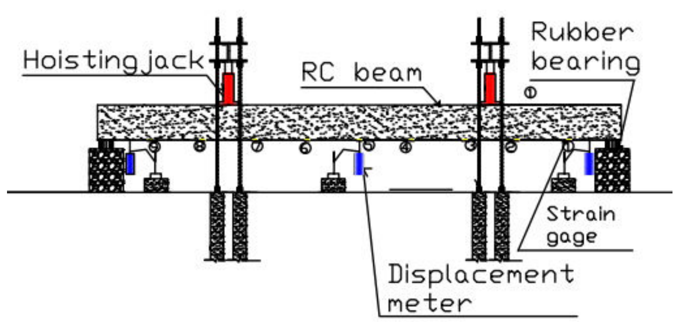

Fig.4. Schematic representation of test set-up

The loads were applied at the quarter-span. The measurement instruments included two load cells to measure the applied load on the beam, and three flexometers on the bottom of the beam to measure the displacement. Strain gauges were installed on the external surface of the CFRP to measure the strains. All six specimens were tested under a displacement control mode at a loading rate of 0.05mm/ s. The responses of the beam load, displacement, and strains were recorded by an automatic data logger.

OBSERVATIONS AND TEST RESULTS

Specimen BM1 failed and other normal beams are intact. The failure mode is shown in Fig.5. Concrete cracking and crushing can be seen in the figure. This failure mode indicates that specimen BM1 belongs to under-reinforced beam.

Fig.5. Failure of specimen BM1

Specimens BM2, BM5 and BM6 underwent similar failure processes that were caused by the rupture of the CFRP strip near the quarter-span. A weak sound from the cracking of the epoxy was heard before the CFRP broke. The failure mode is shown in Fig.6. Significant concrete cracking and local rupture of the CFRP strip can be seen in the figure, but this beams damage did not occur before the rupture of the FRP strip, except for a few fine flexural cracks that were similar to those found in normal RC members. The load decreased suddenly and the midspan displacement increased continually after the explosive breaking of the CFRP strip. No concrete damage on the tension and compression sides were observed, except for some local distress at the surface of beneath the concentrated point load. The failure mode of specimens BM2, BM5 and BM6 indicated that the bond strength of the three beams exceeded the material strength of the two-ply CFRP strip.

(a) BM2

(b) BM5

(c) BM6