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Experimental investigation on flexural behavior of concrete beams strengthened under constant load by CFRP sheets

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ABSTRACT: Today, strengthening of reinforced concrete structures and especially flexural strengthening by fiber reinforced polymers (FRP) is used worldwide as an efficient way. In this study, the existing of a constant load during FRP flexural strengthening versus load removal before strengthening were experimentally investigated and compared. A preload with two different predetermined amounts, one to make the beam cracked elastically and the other to make beam deflected to plastic region, was applied before the strengthening of beam samples. All Externally Bonded Reinforcement In Groove (EBRIG) installed FRP sheets were ruptured during test and no de-bonding was observed. Pre-cracking of beams in unloaded strengthened beams caused a minor decrease in ultimate load capacity of strengthened beams. Also ductility and ultimate deformation was decreased. Flexural strengthened beams under constant load showed better ultimate strength (up to 8%) and also better ductility and energy dissipation ability.It can be concluded that FRP flexural strengthening of beams under constant load is more appropriate than load removal of beams during strengthening. The appropriate amount of load during strengthening must be studied in detail but excessive loading to plastic extents is not appropriate.

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1. Introduction

Many reasons can be cited for the necessity of strengthening of concrete beams, including computational errors, poor performance, changing service condition, changing regulations, structural deterioration over time and etc. The use of FRP sheets is the most common method. The main features that makes this material suitable for retrofitting are simple use, anti-corrosion resistance and high strength to weight ratio.

Certain benefits of externally bonded reinforcement (EBR) technique for strengthening of RC beams and slabs, such as simple and rapid installation, may reduce the labor costs of strengthening projects. The technique, however, suffers from premature de-bonding of FRP composites from concrete substrate [1-4].

Mostofinejad and Hajrasouliha [5] studied on performance of grooving method to postpone de-bonding of FRP sheets in strengthened concrete beams. Mostofinejad and Shameli [6] presented an improved grooving method named as EBRIG (externally bonded reinforcement in grooves). In this method, the FRP sheets are adhered in direct contact with the internal surfaces of the grooves. Test results showed that the ultimate load capacity for the specimens strengthened by EBRIG method raised up to 86% compared to the conventional surface preparation.

Mostofinejad et al. [7] and Hosseini et al.[8], also studied on bond efficiency of EBR and EBROG methods in different flexural failure mechanisms of FRP strengthened RC beams and grooving patterns. Mostofinejad and khozaei studied on different longitudinal grooving patterns and proposed appropriate grooving patterns based on three criteria of ultimate load capacity, ductility and failure mechanism [9]. Morsey et al. studied on preloading effect on flexural strengthening of beams [10]. They concluded that the preloading levels have very minor effect on the enhancement capacity of RC strengthened beams. In this study both EBR and EBRIG method for installing of FRP sheets were examined. Also FRP strengthening under constant load was compared to strengthening after load removal. The amount of pre-load was also changed.

2. Experimental program

In order to carry out this experiment, 11 reinforced concrete beams with the dimensions of 200 × 200 × 1700 mm3 were made and tested as simple 1500 mm span beams. All beam samples have the same reinforcement: two No.12 deformed bar at each side as flexural reinforcement and No.8 deformed bar at 80 mm for shear. The compressive strength of concrete was 25 MPa and concrete cover was 25 mm in each side.

Reference beam tested without strengthening and pre-loading. Other beams tested with different level of pre-load (without, elastic and plastic), different type of FRP installation (EBR or EBRIG) and strengthening without or after pre-load removal. Pre-load means the load applied on beams before strengthening. In elastic pre-loading only minor cracks were observed and in plastic pre-loading cracks were somewhat opened. These pre-loads simulates the RC beam condition before strengthening. The major question in tests was: It is better to install FRP sheets after load removal or to install them under constant load?

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3- Results and Discussion

Summary of test results are presented in Table 1. With EBR method of FRP installation de-bonding was observed in all samples and the load capacity was less than the EBRIG method. Also the load removal before strengthening decreased the ultimate load capacity of the beams which was a surprising result. Pre-loading to elastic extent and saving the load during strengthening showed the best results (ultimate strength, ductility ratio and energy dissipation).

4. Conclusions

An experimental study on flexural strengthening of RC beams was performed in Yazd University Structural Lab. The main question was: what is the influence of existing beam load during installing of FRP sheets on flexural strengthening performance of RC beams? Based on the results, EBRIG method of installing FRP sheets prevented de-bonding and increased the effect of strengthening. Also the existence of constant load (not so high to creates open cracks in beams) during FRP strengthening increased the ultimate load capacity up to 10%. Energy dissipation capacity and ductility factor were also better in strengthening under constant load. It can be concluded that installing FRP sheets under constant service load (load that creates minor flexural cracks) leads to better results than installing after load removal.

Table 1: Test Results

Beam Group	Beam No.	Beam code	Ultimate load (kN)	Displacement, mm	Energy Dissipation kN-mm	FRP Behavior
1	1	Reference	60.4	25	1240	-
	2	EBR	81.5	12.6	810	FRP debonding
	3	EBRIG	96.1	25	1550	FRP rupture
2	4	EBR-Elastic	78	10.6	500	FRP debonding
	5	EBR-Elastic-Constant load	83.1	9.7	630	FRP debonding
	6	EBR-Plastic	70.8	15	757	FRP debonding
	7	EBR-Plastic-Constant load	76	11.9	786	FRP debonding
3	8	EBRIG-Elastic	93.5	19	1150	FRP rupture
	9	EBRIG-Elastic-Constant load	103	17.6	1395	FRP rupture
	10	EBRIG-Plastic	90.2	15	868	FRP rupture
	11	EBRIG-Plastic-Constant load	96.8	14.9	1180	FRP rupture

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