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Experimental investigation of shear behavior of one-way reinforced slabs with high-performance fiber-reinforced cementitious composite laminates

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ABSTRACT: It has been used to preserve structures and extend their useful life, retrofit damaged structures. Concrete slabs, as a key structural member, play an important role in the load distribution and structural behavior, and lack of resolving the damage to concrete slabs can lead to irreparable damage. In this experimental study, the one way reinforced concrete slabs were strengthened by using high-performance fiber-reinforced cementitious composite (HPFRCC) laminates in the slab's tensile side. Its lateral surfaces are then strengthened with carbon fiber reinforced polymer laminates to increase shear capacity. This study is summarized in three steps. In the first step, the mixing design and mechanical properties of fiber-reinforced cement composites were investigated. In the second step, the flexural capacity of fiber-reinforced cement composite laminates was determined separately before bonding to the slab. In the final step, shear and shear reinforced concrete slabs were tested for shear behavior investigation. The results showed that the strengthening of the lateral sides of the specimens was improved the flexural capacity, fracture pattern, stiffness, and energy absorption by examining the shear behavior of the specimens. Also, for one-way slabs strengthened with fiber-reinforced cement composite laminates, if the concentrated load is applied to the slab so that the shear Span-to-effective height ratio is less than 2.5, even If it is strengthened at the lateral surfaces to increase the shear capacity of the cross-section, the failure pattern will certainly be shear.

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1. INTRODUCTION

Many reasons may necessitate strengthening existing structures. Several techniques may be used to strengthened structures. All these techniques have advantages and disadvantages. RC jacket applications are feasible using large thickness layers of concrete [1]. Concrete has been proven to be a suitable material for structures because of its durability, formability, strength, and low retention costs. However, concrete is brittle under tensile stress and has low tensile strength. Therefore, using fiber-reinforced concrete has been gained according to its enhanced feature after cracking. HPFRCCs are specified by a stress-strain response in tension that shows multiple cracking behavior and strain-hardening and related quite large energy absorption capacity. HPFRCC material is classified according to its behavior under the tensile test [2]. In several articles, the effect of HPFRC and UHPFRCC material has been tasted as a layer to the flexural and shear behavior of RC slabs and beams. In this research, longitudinal reinforcement ratio and the effect of a/d ratio were studied also using other types of reinforcing such as CFRP, GFRP to the ultimate behavior were investigated [3, 4].

2. EXPERIMENTAL STUDY

In this paper, the first HPFRCC material was investigated to determine the mix proportion that can be exploited for the strengthening of weak one-way RC slabs when applied as a real-size laminate. Then, the laminate has been tested to define attributes 25 mm thickness actual dimensional HPFRCC laminates have been manufactured with longitudinal steel reinforcements (Fig. 1). In the final stage, strengthening slabs were subjected to a four-point loading test (Figures 2 and 3). This experimental study consists of three 1000×400×100 mm^3 weak one-way slabs (Table 1). One slab was a reference specimen "WS", and the other two were strengthened slabs with HPFRCC laminate, "WS-L1-Steel" and "WS-L1-

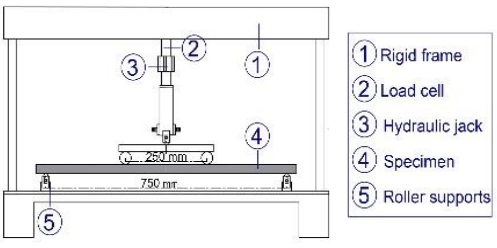

Fig. 1. Laminate setup test

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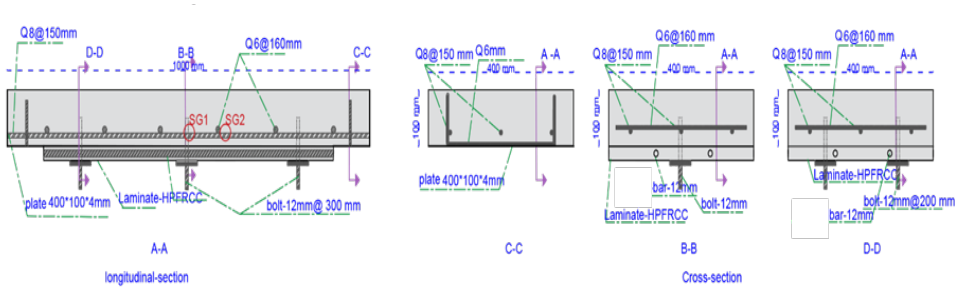

Fig. 2. Reinforcement details of the strengthened slabs

Table 1. Properties of specimens

Specimen	Bonding procedure			strengthening		HPFRCC laminate properties	
	Epoxy	Anchorage	CFRP-U-jacketing	HPFRCC laminate	CFRP sheet	Type of bars	Steel fiber (%)
WS	No	No	No	-	-	-	-
WS-L1-Steel	Yes	Yes	No	Yes	No	steel	1
WS-L1-Steel-Shear	Yes	Yes	Yes	Yes	Yes	steel	1

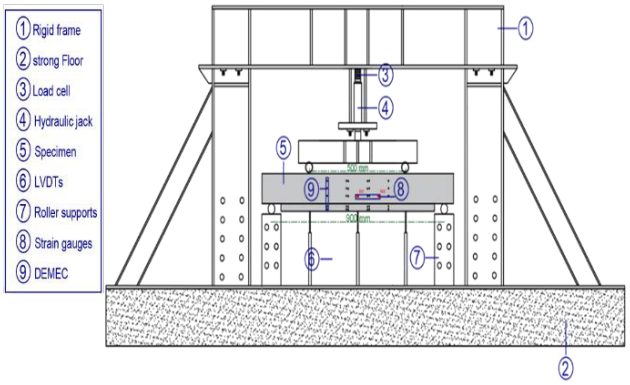

Fig. 3. Test setup and instrumentation

Fig. 4. Anchorage procedure

Steel-Shear". For the installation of the HPFRCC laminates on slabs, the mechanical anchorage was suggested to bond reinforced HPFRCC in addition to epoxy resin (Fig. 4).

WS-L1-Steel-Shear was repaired by applying carbon fiber reinforced polymer (CFRP) to each lateral face of the slab using the epoxy adhesive process, which was designed with the help of ACI 440.2R-08 [5] (Fig. 5). Additionally, two U-shaped layered unidirectional CFRP wraps were installed with a width of 50 mm at both free ends of all glued HPFRCC laminates, and they were spaced at 100 mm from each (Fig. 6).

3. RESULTS AND DISCUSSION

The load versus mid-span deflection curves at all stages of loading up to the failure of all tested slabs were presented in Fig. 7. In this study, a comparison between the strengthened slabs and the reference slab was made. The behavior of

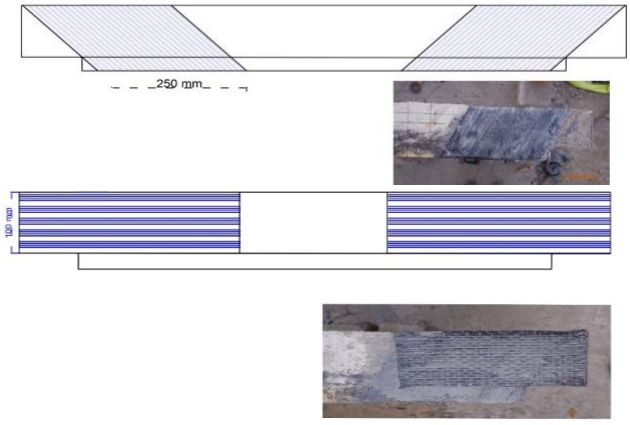

Fig. 5. Epoxy adhesive process for shear strengthening of slabs specimens

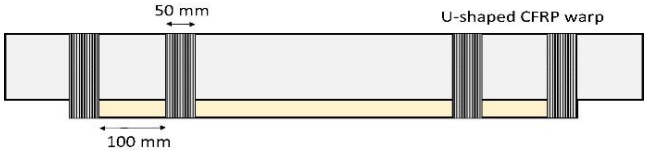

Fig. 6. U-shaped CFRP wraps locate

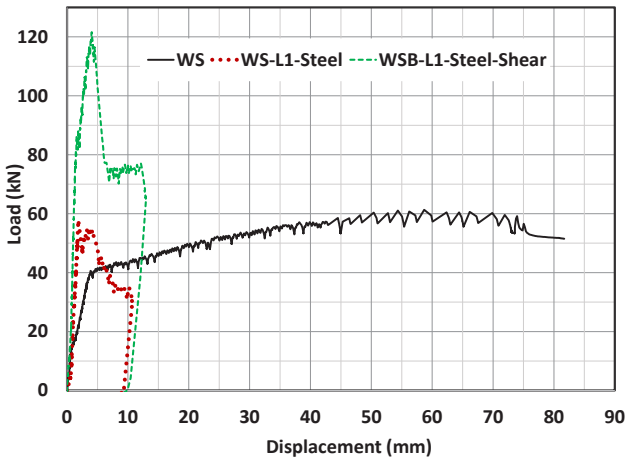

Fig. 7. Load-deflection curve

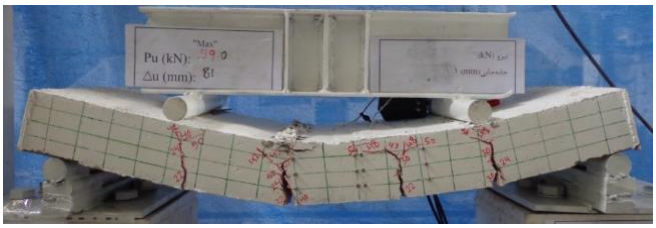

Fig. 8. The failure mode of the WS.

specimens during loading and its failure mode was evaluated. The load-deflection curve of the reference specimen, WS, illustrated the usual elastic and inelastic parts. However, for specimens strengthened with HPFRCC laminates, shear failure is observed with a sudden decrease in load level. Also, due to the increase in stiffness of the strengthened specimens with the HPFRCC laminates, the initial slope of the load-displacement curve has increased compared to the reference specimen. Figures 8-10 relate to the final failure of the reference slab, WS-L1-Steel and WS-L1-Steel-Shear, respectively. A comparison of the cracking pattern is important because it shows the performance of the structure's members at different loading stages. It also specifies how the cracks spread and the measure of repairing needed after the damage (Figures 11 and 12).

4. CONCLUSIONS

- Among slabs strengthened with HPFRCC laminate using bars, due to increasing the effective depth, the possibility of shear failure increases.

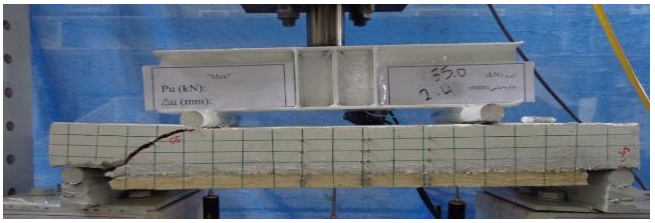

Fig. 9. The failure mode of the WS-L1-Steel

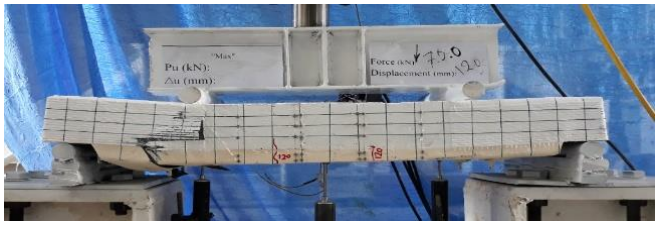

Fig. 10. The failure mode of the WS-L1-Steel-Shear

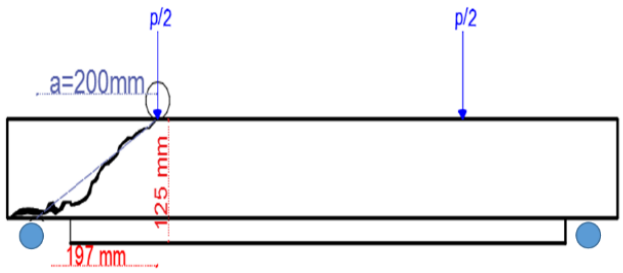

Fig. 11. The shear crack pattern of WS-L1-Steel

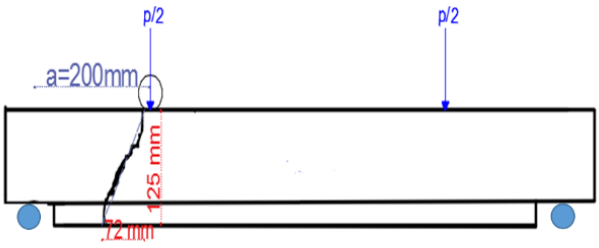

Fig. 12. The shear crack pattern of WS-L1-Steel-Shear

- The addition of HPFRCC laminate has increased the strength of strengthened specimens compared to the reference specimen. The addition of the CFRP sheet to the shear strengthening of slabs has resulted in greater strength and ultimate load.

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