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FRP Composite Strengthening of Concrete Slabs

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Summary

Fiber reinforced polymer matrix composite materials show significant potential for use in the rehabilitation of aging and/or deteriorating concrete civil infrastructure components. This paper describes results of a focussed test program on the use of prefabricated carbon/epoxy strips used for the external strengthening of concrete slabs. Tests are conducted at full scale level and emphasise aspects of strengthening and repair. The tailoring of strip capacity (modulus) is also addressed and it is shown that optimisation of materials form and performance can result in cost-effective structural functionality.

Keywords: Strengthening; Slabs; Fiber-reinforced-composites; Carbon; Debonding; Concrete.

1. Introduction

In the past steel plates have been used for the external strengthening of damaged/deteriorated slabs, or in cases where an increase in load capacity for an existing structures is required. Although clearly feasible the method has its disadvantages in that the steel plates are heavy, require substantial equipment to place and connect (adhesive bonding with end bolting or anchoring), have problems related to length restrictions and field joining, are difficult to erect in cases where clearance is limited, and are susceptible to corrosion. In comparison, fiber reinforced polymer matrix composite plates provide ease of installation, high stiffness-to-weight and strength-to-weight ratios, light weight, and do not corrode. Although these materials have been extensively used in the field through demonstration projects, research on structural response and the development of design guidelines has been almost restricted to their use for the flexural strengthening of beams. However, a review of a large number of field demonstrations shows that a significant number of these have been related to the use of composite material for the rehabilitation of slabs wherein the response and geometrical configuration is substantially different from that of a beam.

Previous studies on the use of externally bonded composite strips for the strengthening of scaled slabs [1,2] have indicated that failure was almost always through debonding at about 50% of the actual material capacity. Debonding was generally initiated in the midspan region as a tension failure of the concrete cover between the steel reinforcing bars and the adhesive with the final failure path being through the composite itself. Materials related reasons for this response were given in [1], and a number of issues were raised related to effects of materials and geometrical conditions on failure initiation and resulting performance of the strengthened slabs. This paper focuses on investigation of some of these issues through a series of full-scale tests in which reinforcement detailing, composite strip geometry and properties, and condition of the slab prior to application of the composite serve as variables.

2. Materials and Test Methods

All tests were conducted on reinforced concrete slabs of dimension 4500 mm x 960 mm x 203 mm, tested in flexural loading with clear spans of 4170 mm. Load was introduced at midspan through two line loads 450 mm apart with the line loads being applied over the central 760 mm of width. A schematic of the test set-up is shown in Figure 1. Load was applied in displacement control at a rate of 0.85 mm/s. A set of 17 slabs was tested with details of configuration as listed in Table 1. It should be noted that these 17 slabs were divided into four groups of which the first set was unstrengthened and served as the control for the investigation. The second set was strengthened externally with Sika Carbodur strips as detailed in Table 1. In the third set which were also strengthened with Sika Carbodur strips the longitudinal steel reinforcement was modified such that four of the seven rebar were cut at midspan prior to pouring of concrete to simulate damage. The fourth set used tailored strips fabricated using the wet layup process. The pultruded strips had nominal tensile modulus and failure strains of 175 GPa and 0.65% respectively, whereas the strips fabricated using the wet layup process had a modulus of 85 GPa. Design of the strip configuration was made following strain limitations.

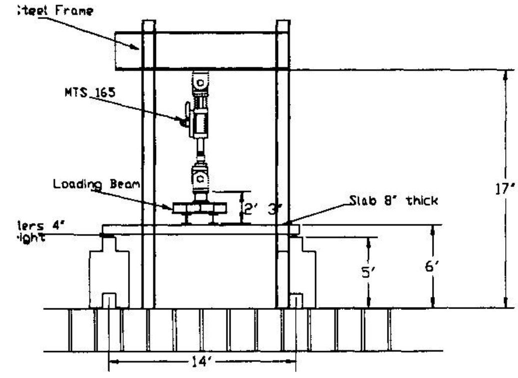

Figure 1: Test Set-Up

Type of Strengthening	Details of Longitudinal Steel Reinforcement	Details of CFRP Strengthening	Expected Moment Capacity for $\varepsilon_{L,u} = 0.65\%$
As-Built			
SF 01	3 # 6 bar (861mm^2)		62,0 kNm
SF 03	7 # 4 (896mm^2)		65,5 kNm
SF 07	7 # 4, 4 of them cut at midspan		28,7 kNm
Group A (Sika Strips)			
SF 1	3 # 6 (861mm^2)	2 * S1012 (240mm^2), L = 3250mm	113 kNm
SF 2	2 # 7 (782mm^2)	2 * S1012 (240mm^2), L = 3250mm	108 kNm
SF 15	7 # 4 (896mm^2)	2 * S1012 (240mm^2), L= 3250mm	116 kNm
SF 4	3 # 6 (861mm^2)	4 * S 512 (240mm^2), L = 3250mm	113 kNm
SF 5	3 # 6 (861mm^2)	2 * S1012 (240mm^2), L = 3610mm	113 kNm
SF 6	2 # 7 (782mm^2)	2 * S1012 (240mm^2), L = 3610mm	108 kNm
Group B (Repair)			
SF 7	7 # 4	2 * S1012 (240mm^2), L = 3250mm	80,4 kNm
SF 8	4 of them cut at	2 * S 512 (120mm^2), L = 1680mm	54,7 kNm
SF 9	midspan	4 * S 512 (240mm^2), L = 1680mm	80,4 kNm
SF 10	($A_{s,eff}$ = 384mm^2)	2 * S 512 (120mm^2), L = 1680mm + 2 * S 512 (120mm^2), L = 3250mm	80,4 kNm
Group C (VB Strips)			
SF 11	3 # 6 (861mm^2)	3 * 3 ply (397mm^2), L = 2900mm	103 kNm
SF 12	3 # 6 (861mm^2)	3 * 6 ply (650mm^2), L = 3250mm	129 kNm
SF 13	3 # 6 (861mm^2)	2 * 6 ply (431mm^2), L = 3250mm	107 kNm
SF 14	3 # 6 (861mm^2)	3 * 3 ply (395mm^2), L = 3250mm	103 kNm

Table 1: Overview of Test Specimens