INVESTIGATION OF CEMENT BASED ADHESIVES TO REPLACE EPOXY BOND IN CFRP/CONCRETE COMPOSITE

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Degree of Master of Engineering in Structural Engineering Design

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Dissertation submitted in partial fulfillment of the requirements for the Degree Master of Engineering in Structural Engineering Design

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DECLARATION

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Dr.(Mrs). J.C.P.H.Gamage

Supervisor

ABSTRACT

Fibre Reinforced Polymer (FRP) application is a very effective way to repair and strengthen structures that has become structurally weak over their life span. The strengthening and rehabilitation of existing structures are major issues worldwide. In most situations, strengthening is required when there is an increase in the applied load, human error in the initial construction, a legal requirement to comply with updated versions of existing codes, or as a result of the loss of strength due to deterioration over time. Fibre-Reinforced Polymer (FRP) strengthening systems are enjoying a great deal of popularity as a result of the unique properties of FRPs - namely, their light weight, fatigue resistance non-corrosive characteristics and ease of application. The repair and strengthening technique with epoxy-bonded advanced composites has been applied to a large number of bridges around the world. At elevated temperatures, normally beyond the glass transition temperatures of epoxy adhesive, the mechanical properties of the polymer matrix deteriorate rapidly. It will be very beneficial if they can be replaced by cement grout bonding agents such as modified concrete, in order to produce fire-resistant strengthening systems.

This report includes the investigation of the flexural behavior of FRP-strengthened reinforced concrete beams using epoxy adhesive and cement grout adhesive. A total of ten RC beams were cast. All of them were having the same cross section of 100 mm X 150 mm and the span of 500 mm. Two beams were tested as control beams and another two beams were strengthened with CFRP using epoxy adhesive. Remaining six beams were strengthened with CFRP using cement grout with different bonding arrangements.

Finally, experimental results were compared with theoretical results and previous research data. The results showed that a considerable strength gain can be achieved when beams were strengthened using cement grout as a bonding agent. It was revealed that primer has the ability to increase the ultimate load carrying capacity as well. Furthermore, use of anchoring system to strengthen beams is an effective technique.

KEYWORDS: Carbon Fiber Reinforced Polymers (CFRP), Reinforced Concrete Beams, Failure Load, Anchoring system, Epoxy, Cement grout

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LIST OF ABBREVIATIONS

AFRP	:	Aramid Fibre Reinforced Polymer
ACI	:	American Concrete Institute
A_s	:	Provided area of main tension reinforcement.
A_{sv}	:	Provided area of shear reinforcement
b	:	Width of the section
CFRP	:	Carbon Fibre Reinforced Polymer
d	:	Depth of the section
E	:	Young's Modulus
F_c	:	Force in concrete compression zone.
f_{cu}	:	Characteristic strength of concrete.
FRP	:	Fibre Reinforced Polymer
F_t	:	Force in main tension Reinforcement.
f_y	:	Characteristic tensile strength of main Reinforcement
f_{yv}	:	Characteristic tensile strength of shear Reinforcement
GFRP	:	Glass Fibre Reinforced Polymer
GS	:	Galvanized Steel
IC bonding	:	Intermediate crack bonding
IESL	:	Institution of Engineers of Sri Lanka
l	:	Length of specimen
M	:	Expected maximum moment.
NSM	:	Near Surface Mounted.
RC	:	Reinforced concrete
RF	:	Reinforcement
s	:	Spacing of shear links along the members
UOM	:	University of Moratuwa
w	:	Uniformly distributed self –weight of concrete element.
W	:	Applied point load.
x	:	Depth to the neutral axis
Z	:	lever arm

LIST OF SYMBOLS

A_f	:	$nt_f w_f$, area of FRP external reinforcement (mm^2)
A_g	:	gross area of section (mm^2)
A_s	:	area of nonprestressed steel reinforcement (mm^2)
A_{st}	:	total area of longitudinal reinforcement (mm^2)
b	:	width of rectangular cross section (mm)
c	:	distance from extreme compression fiber to the neutral axis (mm)
CE	:	environmental-reduction factor
D	:	distance from extreme compression fiber to the neutral axis (mm)
d_f	:	depth of FRP shear reinforcement (mm)
E_c	:	modulus of elasticity of concrete (MPa)
E_f	:	tensile modulus of elasticity of FRP (MPa)
E_s	:	modulus of elasticity of steel (MPa)
f_c	:	compressive stress in concrete (MPa)
f'_c	:	specified compressive strength of concrete (MPa)
f_f	:	stress level in the FRP reinforcement(MPa)
$f_{f,s}$	:	stress level in the FRP caused by a moment within the elastic range of the member (MPa)
f_{fe}	:	effective stress in the FRP; stress level attained at section failure (MPa)
f^*_{fu}	:	ultimate tensile strength of the FRP material as reported by the manufacturer (MPa)
f_{fu}	:	design ultimate tensile strength of FRP (MPa)
F_y	:	specified yield strength of nonprestressed steel reinforcement (MPa)
h	:	overall thickness of a member (mm)
M_n	:	nominal moment strength (N-mm)

p^*_{fu} : ultimate tensile strength per unit width of the FRP Reinforcement (N/mm)

T_g : glass-transition temperature, °F (°C)

b1 : ratio of the depth of the equivalent rectangular stress block to the depth of the neutral axis

$€_b$: strain level in the concrete substrate developed by a given bending moment (tension in positive)

$€_{bi}$: strain level in the concrete substrate at the time of the FRP installation (tension is positive)

$€_c$: stain level in the concrete

$€_{cu}$: maximum usable compressive strain of concrete

$€_f$: strain level in the FRP reinforcement

$€_{fe}$: effective strain level in FRP reinforcement; strain level attained at section failure

$€_{fu}$: design rupture strain of FRP reinforcement

$€^*_{fu}$: ultimate rupture strain of the FRP reinforcement

$€_s$ strain level in the nonprestessed steel reinforcement

$€_{sy}$ strain corresponding to the yield strength of nonprestressed steel reinforcement

φ : strength reduction factor

k_a : efficiency factor for FRP reinforcement (based on the section geometry)

k_m : bond-dependent coefficient for flexure

y_f : additional FRP strength-reduction factor

LIST OF APPENDICES