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PREDICTION OF PERFORMANCE FOR HIGH STRENGTH CONCRETE (HSC) BEAMS STRENGTHENED WITH GFRP LAMINATES

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Abstract: *This paper proposed the regression model to evaluate the efficiency of Glass Fibre Reinforced Polymer (GFRP) laminates in a high strength concrete beams. In order to assess the efficiency of GFRP laminates a total of ten beams were cast, strengthened and tested. Out of ten beams four beams were strengthened in flexure with Chopped Strand Mat Glass Fibre Reinforced Polymer (CSMGFRP) and four beams were strengthened with Uni-Directional Cloth Glass Fibre Reinforced Polymer (UDCGFRP) of 3mm and 5mm thicknesses and remaining two beams served as control beams. All the test specimens were tested under two-point loading. The study parameters are the percentage of steel reinforcement ratio, GFRP laminate material and their thicknesses. The results show that the prediction of the proposed regression model agreed well with the experimental test database.*

Keywords: *GFRP laminates, high strength concrete, regression*

INTRODUCTION

An increasing number of reinforced concrete structures have reached the end of their service life, either due to deterioration of concrete and reinforcements caused by environmental factors and the widespread application of deicing salts, or due to increase in applied loads. These deteriorated structures may be structurally deficient or functionally obsolete, and most are now in serious need of extensive rehabilitation or replacement. Fibre Reinforced Polymers (FRP) laminates or wraps are well suited to this application because of their high strength-to weight ratio, good fatigue properties, and excellent resistance to corrosion.

Many experimental studies have been performed to verify the efficiency of the GFRP on flexural strengthening of reinforced concrete beams (Khaled and Sherwood 2001, Rahimi and Hutchinson 2001). Toutanji et al conducted a study on reinforced concrete beams retrofitted with CFRP laminates. The study showed an increased maximum load up to 170 % as compared to control beams. Experimental and analytical studies concerning the flexural strengthening of HSC beams by external bonding of FRP sheets. 6 concrete beam specimens with dimensions of 150 x 250 x 3000mm were cast and tested less than 2 point loading. The principal variables included in their study were different layouts of CFRP sheets and tensile steel reinforcement ratio. They concluded that as the amount of tensile steel reinforcement was increased, the additional strength provided by the carbon FRP external reinforcement got reduced. Also their finite element model results showed good agreement with the experimental results (Reza Mahjoub and Syed Hamid Hashemi, 2010). Esfahani et al., 2007, investigated the flexural behaviour of reinforced concrete beams strengthened by CFRP sheets. 12 concrete beam specimens with dimensions of 150 x 250 x 2000 mm length were cast and tested. Beam sections with three different reinforcing ratios (ρ) were used. Nine specimens were strengthened in flexure by CFRP sheets. The other three specimens were considered as control specimens. The length, width and number of layers of CFRP sheets varied in different specimens. The flexural strength and stiffness of the strengthened beams increased compared to the control specimens. Based on the results, it was concluded that the design guidelines of ACI 440.2R-02 and ISIS Canada overestimate the effect of CFRP sheets in increasing the flexural strength of beams with small ρ values compared to the maximum value, $\rho_{max,}$ specified in these two guidelines. With increase in the ρ value in beams, the ratios of test load to the load calculated using ACI 440 and ISIS Canada increased. Therefore, the equations proposed by the two design guidelines are more appropriate for beams with large ρ values.

High strength concrete (HSC) are used extensively in the construction projects for its stiffness and durability characteristics. The lack of ductility in high strength concrete results in sudden failure without warning in structural members. In seismic prone zone, ductility is an vital factor to be considered in design of HSC members under flexure. In spite of many studies, the effectiveness of glass fibre reinforced polymer in high strength concrete beams has not been explored. The present study focussed on predicting the performance of glass fibre reinforced polymer (GFRP) laminated high strength concrete beams using regression model. The main variables in this study are the reinforcement steel ratio, type of GFRP laminate and thickness of laminate.

MATERIALS AND METHODS

Details of Test Specimens

The test program including ten beams was carried out. All beam specimens had a target concrete compressive strength of 60MPa The main test variables considered in the study include steel reinforcement ratio, types of GFRP laminate and thickness of GFRP laminate. The beams were 150 x 250 mm in cross-section and 3000 mm in length. The beams of 'A' series were reinforced with two numbers of 10 mm diameter steel bars as tension reinforcement giving a ratio of 0.416%. The beams of 'B' series were reinforced with two 12 mm diameter steel bars were used as bottom tension bars giving a reinforcement ratio of 0.628%. Stirrups of 8 mm diameter, at a spacing of 150 mm were used for the beams. Out of ten beams, two were served as control beams and the remaining beams were strengthened with GFRP laminate. The details of test specimen are presented in Table 1.

Table 1. Details of Test Specimens

Beam series	Beam Designation	% Steel Reinforcement	GFRP Laminate	
			Type	Thickness
A	RA	0.416	-	-
	RAC3	0.416	CSMGFRP	3
	RAC5	0.416	CSMGFRP	5
	RAU3	0.416	UDCGFRP	3
	RAU5	0.416	UDCGFRP	5
B	RB	0.628	-	-
	RBC3	0.628	CSMGFRP	3
	RBC5	0.628	CSMGFRP	5
	RBU3	0.628	UDCGFRP	3
	RBU5	0.628	UDCGFRP	5

Regression

Regression analysis is a time tested method for relating given input parameters and resulting parameters by assuming a suitable form of relationship, like polynomial, logarithmic, exponential etc.. The type of relationship assumed reflects the perceived form of relationship between the inputs and results. The essence of regression is to evaluate the unknown coefficients in the regression equation, mostly using the procedure called Legendre's principle of least squared errors, the technique which chooses such values for the coefficients that the prediction errors may be low.

Usually, regression equations relate one independent parameter and one dependent parameter. But, the real world applications of regression might have more than one independent variable, for which the solution is not so direct and the problem is called multi-variate regression or simply multiple regression. But, proper formulation of the basic relationships would help to develop equations and solution procedures for multiple regression problems.

Multivariate linear regression

Multivariate linear regression helps to construct first order equations involving more than one independent variable. The basic formulation for multivariate linear regression is,

$$\begin{Bmatrix} \frac{\partial}{\partial a_0} \\ \frac{\partial}{\partial a_1} \\ \frac{\partial}{\partial a_2} \\ \frac{\partial}{\partial a_3} \\ \vdots \\ \frac{\partial}{\partial a_n} \end{Bmatrix} \sum_{i=1}^{K} \left(P_i - (a_0 + a_1 x_{1i} + a_2 x_{2i} a_3 x_{3i} + \cdots + a_n x_{ni})\right) = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ 0 \end{Bmatrix} \quad \text{Eq.1}$$

where, $a_0 \ldots a_n$ are the coefficients to be determined, $x_{1 \ldots} x_n$ are the independent variables, P is the dependent variable or the actual result value for the set of i^{th} input data and K is the number data sets available for regression. On executing the partial derivative operators, Equation 1 reduces to

$$\sum_{i=1}^{K} \begin{bmatrix} 1 & x_{1i} & x_{2i} & x_{3i} & \cdots & x_{ni} \\ x_{1i} & x_{1i}^2 & x_{1i}x_{2i} & x_{1i}x_{3i} & \cdots & x_{1i}x_{ni} \\ x_{2i} & x_{2i}x_{1i} & x_{2i}^2 & x_{2i}x_{3i} & \cdots & x_{2i}x_{ni} \\ x_{3i} & x_{3i}x_{1i} & x_{3i}x_{2i} & x_{3i}^2 & \cdots & x_{3i}x_{ni} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{ni} & x_{ni}x_{1i} & x_{ni}x_{2i} & x_{ni}x_{3i} & \cdots & x_{ni}x_{ni} \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_n \end{Bmatrix} = \sum_{i=1}^{K} \begin{Bmatrix} P_i \\ P_1 P_i \\ P_2 P_i \\ P_3 P_i \\ \vdots \\ P_n P_i \end{Bmatrix} \quad \text{Eq.2}$$

The above equation can be solved by summing up the values of independent and dependent variables after carrying out the required operations and executed using Minitab software. The data used for the regression analysis is presented in Table 2 and the proposed regression equations are presented in Table 3.

Table 2. Data Used for the Regression Analysis

Designation	**Yield Load (kN)**	**Yield deflection (mm)**	**Ultimate Load (kN)**	**Ultimate deflection (mm)**	**Deflection Ductility**	**Energy Ductility**	**Maximum Crack width**
RA	29.42	7.91	41.68	21.05	2.66	4.16	1.08
RACSM3	36.77	9.02	51.48	33.46	3.71	6.82	1.00
RACSM5	46.58	10.1	66.19	46.81	4.63	7.81	0.70
RAUDC3	51.48	11.42	71.09	53.26	4.66	7.98	0.84
RAUDC5	53.7	10.74	78.45	57.21	5.33	9.27	0.66
RB	39.22	8.11	53.93	31.28	3.86	6.97	1.00
RB CSM3	51.48	11.35	61.29	36.23	3.19	7.58	0.66
RB CSM5	53.24	12.41	63.74	56.91	4.59	7.65	0.54
RB UDC3	58.8	12.85	88.25	61.04	4.75	7.78	0.65
RB UDC5	63	12.69	100.51	65.59	5.17	8.80	0.59

Table 3 Proposed Regression Equations

Sl. No.	Prediction Parameter	Equation	Fitness	RMS Error
1	Yield Load (kN)	13.62+34.34Sr+0.0489ffu+1.17tf	0.860	3.39
2	Yield Deflection (mm)	3.489+8.054Sr+0.00581ffu+0.417tf	0.917	0.40
3	Ultimate Load (kN)	10.35+56.53Sr+0.07124ffu+2.85tf	0.879	7.32
4	Ultimate Deflection (mm)	11.69+26.12Sr+0.0439ffu+2.913tf	0.914	0.48
5	Deflection Ductility	3.59-0.4325Sr+0.00178ffu+0.140tf	0.466	0.071
6	Energy Ductility	4.79+1.695Sr+0.00264ffu+0.342tf	0.703	11.9
7	Maximum Crack Width (mm)	1.37-0.6216Sr-9.94e-5ffu-0.07266tf	0.822	0.88

Table 3 inferred an observation of the measures of fitness of regression shows that the multivariate linear regression can estimate the prediction values with reasonable levels of accuracy for yield load, yield deflection, ultimate load, ultimate deflection, deflection ductility, energy ductility and maximum crack width. The fitness of the proposed regression model varied from 0.466 to 0.917 and the root mean square value varied from 0.40 to 11.90 was observed. Linear regressions are inherently limited in their ability to model very complex sets of data, since first order regression parameters try to fit a monotonically varying linear relationship curvature for the prediction parameter. Predictions from the regression equations agreed well with those against experimental values

CONCLUSIONS

The regression equations proposed in the present study closely predict the study parameters yield load, yield load deflection, ultimate load, deflection at ultimate load, deflection ductility, energy ductility and maximum crack width of GFRP strengthened high strength concrete beams. The fitness of the proposed regression model varied from 0.466 to 0.917 was observed. The regression equations proposed in the study provide an easy means of computing the performance characteristics of high strength concrete beams strengthened with GFRP laminates with reasonable accuracy, in situations where high computational power is not available.

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