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The Performance Of Pre-Stressed Concrete Beams Reinforced With Fiber-Reinforced Polymer Laminates

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Abstract: Strengthening of pre-stressed concrete structures using Fibre Reinforced Polymer (FRP) shows better promise for extending their service life. Knowledge about the actual performance of the strengthened members is an essential prerequisite for an effective application of the technology. The main objective of this research work is to evaluate the static response of pre-stressed concrete beams strengthened with externally bonded Fibre Reinforced Polymer (GFRP) laminates at the soffit of beam. A total of fourteen beams of 3 m length and 150 mm x 250 mm in cross-section were cast and tested in the laboratory. Two unbonded post-tensioned beams served as reference beams and the remaining twelve beams were strengthened with GFRP laminates on their soffit. 7 beams cast with M35 grade concrete were strengthened with three different GFRP laminates having two different thicknesses 3 mm and 5 mm and tested under monotonically increasing loading and manual readings were recorded. Remaining 7 beams cast with M60 grade concrete were strengthened with three different GFRP laminates having two different thicknesses 3 mm and 5 mm and tested under monotonically increasing loading and manual readings were also recorded directly. The variables considered included grade of concrete, type of GFRP laminate and thickness of GFRP laminate. The GFRP laminates also varied in their configuration, viz., Chopped Strand Mat (CSM), Woven Roving (WR) and Uni- Directional Cloth (UDC). Responses of all the beams were evaluated in terms of strength, stiffness, ductility, composite action between concrete and external reinforcement and the associated failure modes for beams tested under static loading. The study parameters considered for this research work included yield load, deflection at yield load, ultimate load, deflection at ultimate load, deflection ductility, deflection ductility ratio, energy ductility, energy ductility ratio, number of cracks and energy absorption.

Keyword: Fibre Reinforced Polymer (FRP), Post-tensioned beams, GFRP laminates, Chopped Strand Mat (CSM), Woven Roving (WR) and Uni- Directional Cloth (UDC)

1. INTRODUCTIONS

A structure plays an important role in the development of an individual or state or country. Without high rise strong and aesthetic structures development of human race is unimaginable.A structure comprises of three major elements namely beam, column and slab. All these elements have importance of their own. Beams are one the most important structural member for any structures; it may be bridge, Industrial building, roadways etc. Beams must be designed in such a way that it can withstand any type of loads without producing any deformation or cracking to the structures. But at times the beams may experience sudden static loads for which they are not designed. Due to these sudden loads the beams tends to crack. This is mainly due to the tension or compression in the beam. In the bridges, industrial buildings etc the most common type of beams used are pre-stressed beams. The pre-stressed beams are designed to withstand heavy loads. These beams have lesser beam depths, posses improved resistance

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to shearing. These beams are mostly used where the span is more. In order to protect the beam from the cracking produced due to the sudden application of the fatigue load additional strengthened should be done. By strengthening the beams it is observed that the crack produced in the beams are greatly reduced. The size and the width of the crack are considerably reduced. Pre-stressed concrete is a method for overcoming concrete natural weakness in tension. It canbe used to produce beams, floors or bridges with a longer span than is practical with ordinary reinforced concrete. Pre-stressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load which produces a compressive stress that balances the tensilestress that the concrete compression member would otherwise experience due to a bending load. Traditional concretes based on the use of steel reinforcement bars, rebar, inside poured concrete. Pre-stressing can be accomplished in three ways: pre-tensioned concrete, and bonded or un-bonded post-tensioned concrete. It is a structural material possessing great strength. The unique characteristics of pre-stressed concrete allow predetermined, engineering stresses to be placed in members to counteract stresses that occur when the unitis subjected to service loads.

To examine the effect of GFRP plating on the strength and deformation capacity ofpre-stressed concrete beams. To study the effect of GFRP plating on ductility of pre-stressed concrete beams. To examine the failure modes of test specimens. To compare the experimental results with analytical results. To propose a finite element-based model using ANSYS software and to compare theexperimental and analytical predictions. To propose a regression equation for estimating the characteristics of pre-stressedconcrete beams strengthened with and without GFRP laminates. To propose suitable recommendation and guidelines for pre-stressed concrete beams strengthened with GFRP laminates.

2. METHODOLOGY

A total of 14 RC beams were cast for the present research work. The beams were 150 mm x 250 mm in cross-section and 3000 mm long. The beams were tested in four- point bending over a simple span of 2800 mm. Longitudinal steel ratio adopted for the beam specimen was 0.603%. 2 numbers of 12mm diameter bars were used for tension reinforcement, 2 high tensile 7mm diameter pre-stressing wires with eccentricity 50mm and 2 numbers of 10 mm diameter bars were used as hanger bars. 2-legged 8 mm diameter stirrups were provided at 150 mm c/c, in order to avoid any shear failure and ensure flexural action of beams up to failure. The detailing of reinforcement is shown through

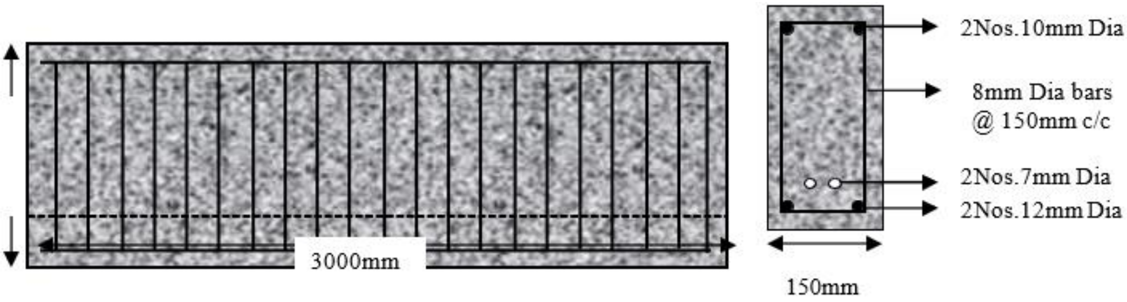

Figure 1: Reinforcement Details of Beam Specimen

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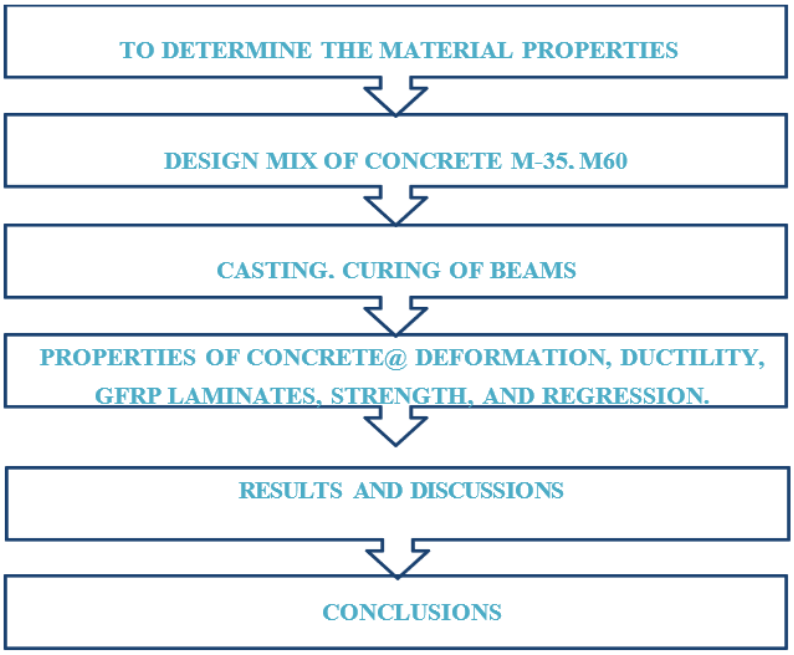

Figure 2: Methodology

Two unbonded post-tensioned beams served as reference beams and the remaining twelve beams were strengthened with GFRP laminates on their soffit. 7 beams cast with M35 grade concrete were strengthened with three different GFRP laminates having two different thicknesses 3 mm and 5 mm and tested under monotonically increasing loading and manual readings were recorded. Remaining 7 beams cast with M60 grade concrete were strengthened with three different GFRP laminates having two different thicknesses 3 mm and 5 mm and tested under monotonically increasing loading and manual readings were also recorded directly. The variables considered included grade of concrete, type of GFRP

laminate and thickness of GFRP laminate. The GFRP laminates also varied in their configuration, viz., Chopped Strand Mat (CSM), Woven Roving (WR) and Uni-Directional Cloth (UDC). Responses of all the beams were evaluated in terms of strength, stiffness, ductility, composite action between concrete and external reinforcement and the associated failure modes for beams tested under static loading. The specimens were tested under two- point loading system. Sufficient data was obtained on the strength, deformation and failure characteristics of pre-stressed beams with and without GFRP laminates for beams tested under static loading.

Table 1: Details of Test Specimens

Beam Designation	% Steel Reinforcement	Grade of Concrete	GFRP	
			Type	Thickness
T	0.603	35	-	0
TC1	0.603	35	CSM	3
TC2	0.603	35	CSM	5
TU1	0.603	35	UDC	3
TU2	0.603	35	UDC	5
TW1	0.603	35	WR	3
TW2	0.603	35	WR	5
S	0.603	60	-	0
SC1	0.603	60	CSM	3
SC2	0.603	60	CSM	5

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SU1	0.603	60	UDC	3
SU2	0.603	60	UDC	5
SW1	0.603	60	WR	3
TW2	0.603	60	WR	5

2.1 Mix Design

The concrete used for T-series beam specimens had a compressive strength of 42 MPa. The designed mix proportion was 1: 1.30: 2.35 : 0.42. The concrete consisted of 474 kg/m^3 of ordinary Portland cement, 616 kg/m^3 of fine aggregate, 1114 kg/m^3 of coarse aggregate and 199 kg/m^3 of water. The concrete used for S-series beam specimens had a compressive strength of 69MPa. The designed mix proportion was 1: 1.35 : 2.19 : 0.29. The concrete consisted of 498 kg/m^3 of ordinary Portland cement, 672 kg/m^3 of fine aggregate, 1091 kg/m^{3}of coarse aggregate and 144 kg/m^3 of water. For both T and S-series beam specimens HYSD bars of characteristic strength 436 MPa were used for the longitudinal reinforcement. Pre- stressing wires of 7mm diameter having ultimate stress 1532 MPa, breaking load 59.1KN and 4 percentage elongation were used. The specimens were provided with 8mm diameter (characteristic strength 287MPa) stirrups at 150 mm spacing. Three types of GFRP laminates were used for the study, namely, Chopped Strand Mat (CSM) Woven Roving (WR) and Unidirectional Cloth (UDC) of 3mm and 5mm thickness


Figure 3: Casted Specimen


3. RESULTS AND DISCUSSIONS

The static test results of experimental investigation carried out on fourteen beams which included two control beams and twelve GFRP strengthened beams are presented and discussed in this chapter The study parameters considered for this research work included yield load, deflection at yield load, ultimate load, deflection at ultimate load, deflection ductility, deflection ductility ratio, energy ductility, energy ductility ratio and number of cracks.

Table 2: Strength and Deformation Properties Pertaining to various Load Levels

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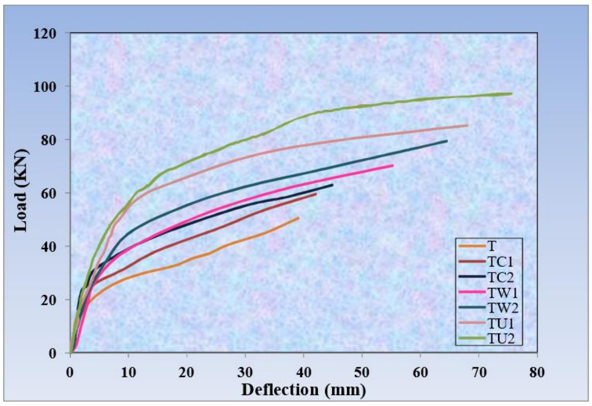
Beam Designation	Yield load (kN)	Deflection at Yield Load (mm)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
T	18.62	3.08	50.52	39.25
TC1	20.00	3.00	59.56	42.00
TC2	22.24	3.10	63.00	44.86
TW1	25.60	3.24	70.20	55.20
TW2	23.24	3.93	79.44	64.50
TU1	33.74	4.09	85.26	68.00
TU2	36.12	4.53	97.58	75.50
S	20.43	10.70	70.50	62.34
SC1	30.70	11.70	78.00	68.45
SC2	35.86	11.70	82.30	71.30
SW1	35.14	12.00	83.50	73.86
SW2	42.70	12.37	87.60	77.65
SU1	45.00	13.03	93.50	83.98
SU2	48.86	13.57	108.70	89.58



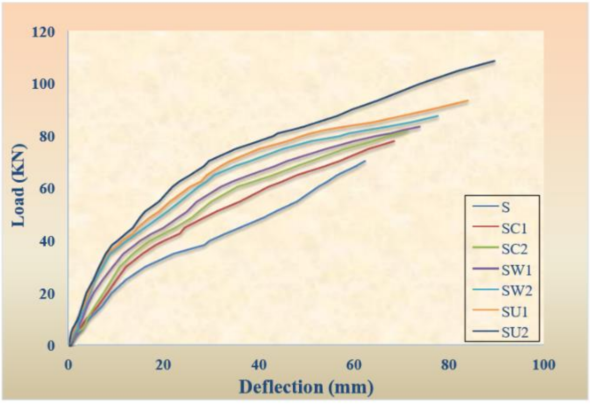


Figure 5: Load-Deflection Response of Control and GFRP StrengthenedS-T-series PSC Beams

The load-deflection response of all specimens shown in Figs. 5 exhibit three regions of behaviour. At low load levels, stiffness of beam is relatively high indicating that the concrete behaves in a linear elastic manner. As the load increases, the extreme fibre stresses in bending increase until the tensile strength of concrete is reached. This causes flexural cracking initially in the constant moment region. Flexural cracking causes a marked reduction in stiffness as shown by a sudden change of gradient in the response.

3.1 Effect of GFRP Plating on Strength

The loads carried by all the test beams at yield stage and ultimate stage were obtained experimentally. The yield loads were obtained (by inspection) corresponding to the stageof loading beyond which the load- deflection response was not linear. The ultimate loads were obtained corresponding to the stage of loading beyond which the beam would not sustain additional deformation at the same load intensity. Fig. 4.3 shows the effect of GFRP laminates on various load levels for T-series beams. The beams strengthened with 3mm thick CSMGFRP, WRGFRP and UDCGFRP exhibit an increase of 7.41%, 37.49% and 81.20% respectively in yield load when compared to control beam and those with 5mm thick CSMGFRP, WRGFRP and UDCGFRP laminates showed an increase up to 19.44%, 24.81% and 93.98% respectively in yield load when compared to control beam. The beams strengthened with 5mm thick CSMGFRP, WRGFRP and UDCGFRP exhibit an increase of 17.89%,

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38.95% and 68.76% respectively in ultimate load when compared to control beam and those with 5mm thick CSMGFRP, WRGFRP and UDCGFRP laminates showed an increase upto 24.70%, 57.24% and 93.15% respectively in ultimate load when compared to control beam. Fig. 6 shows the effect of GFRP laminates on various load levels for S-series beams. The beams strengthened with 3mm thick CSMGFRP, WRGFRP and UDCGFRP exhibit an increase of 50.27%, 72.00% and 120.26% respectively in yield load when compared to control beam and those with 5mm thick CSMGFRP, WRGFRP and UDCGFRP laminates showed an increase up to 75.53%, 109.01% and 139.16% respectively in yield load when compared to control beam. The beams strengthened with 5mm thick CSMGFRP, WRGFRP and UDCGFRP exhibit an increase of 10.64%, 18.44% and 32.62% respectively in ultimate load when compared to control beam and those with 5mm thick CSMGFRP, WRGFRP and UDCGFRP laminates showed an increase up to 16.74%, 24.26% and 54.18% respectively in ultimate load when compared to control beam.

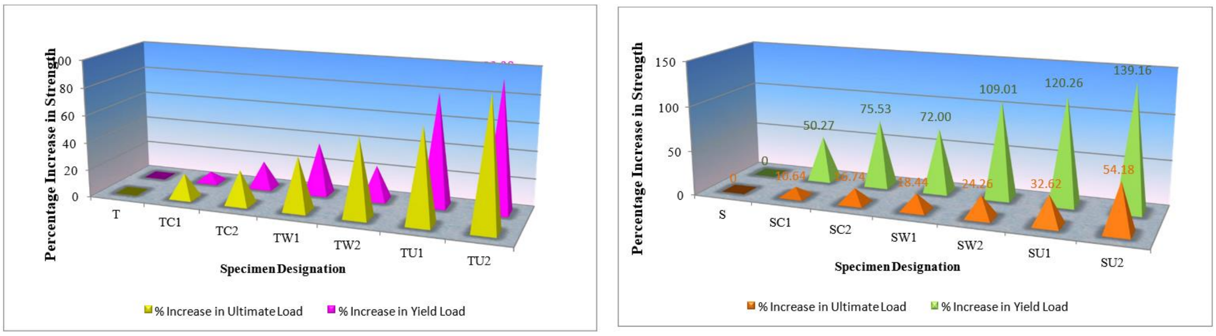

Figure 6: Effect of GFRP Plating on Strength for S-T-series Beams

3.2 Effect of GFRP Plating on Failure Modes and Crack Patterns

Flexural cracks are initiated in the constant moment region as the tensile strength of concrete is reached. The cracks propagate upwards as loading progresses but remain very narrow throughout the loading history and significantly smaller than those in the control beams. Thisdemonstrates the restraining effect caused by the plate on crack openings. Further flexural cracks initiate at locations along the shear spans of the beam as the load level increases. Inclined cracks propagate towards the loading points. These cracks widen as the applied loadincreases but remain narrow at the base of the beam, demonstrating the confining effect of theexternal strengthening. Average crack widths were measured in the middle-third region using a crack detection microscope of 0.02mm precision. It can be inferred from the test results recorded in that change in configuration and thickness of GFRP laminate has appreciableeffect on the crack widths.

Table 3: Crack Width and Mode of Failure at Ultimate Stage

Sl. No.	Specimen Designation	Number of Cracks	Crack Width at Ultimate Stage (mm)	Mode of Failure
1.	T	9	1.58	Flexure
2.	TC1	14	1.19	Flexure
3.	TC2	17	0.89	Flexure
4.	TW1	25	0.81	Flexure
5.	TW2	28	0.76	Flexure

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6.	TU1	31	0.72	Flexure
7.	TU2	34	0.7	Flexure
8.	S	11	1.71	Flexure
9.	SC1	16	1.48	Flexure
10.	SC2	20	1.26	Flexure
11.	SW1	27	1.08	Flexure
12.	SW2	30	0.97	Flexure
13.	SU1	31	0.82	Flexure
14.	SU2	36	0.76	Flexure

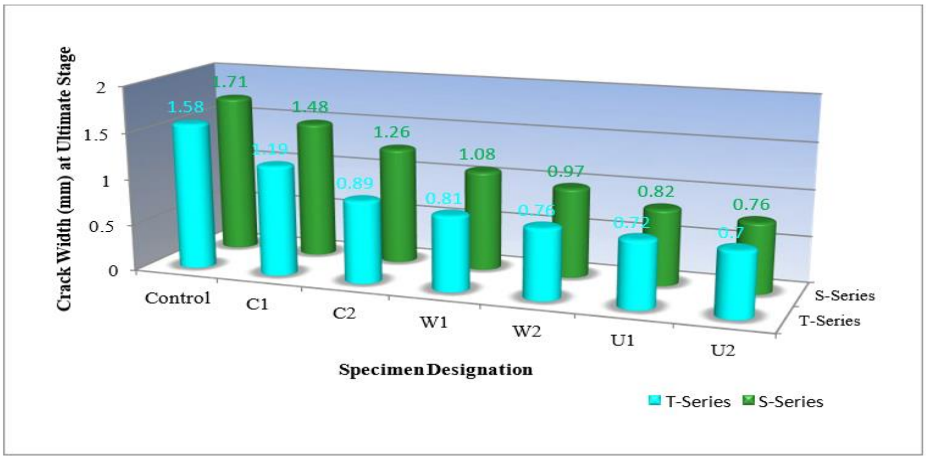

Figure 7: Crack Width at Ultimate Stage

It is evident from Table 3 and Fig7 that the FRP strengthened PSC beams exhibit more number of cracks with lesser crack widths at all load levels when compared with the control beams. In all the beams, flexural cracks were observed. Theses observed cracks were mostly in constant moment region. Average crack widths were measured in the middle third region using crack detection microscope. The reduction in crack width for T-series beams, at ultimate load level was found to be 24.68% with 3mmCSMGFRP, 48.73% with 3mm WRGFRP, 54.43% with 3mm UDCGFRP, 43.67% with 5mm CSMGFRP, 51.91% with 5mm WRGFRP and 55.70% with 5mm UDCGFRP when compared to the control beam. the reduction in crack width for S-series beams, at ultimate load level was found to be 13.45% with 3mmCSMGFRP, 36.84% with 3mm WRGFRP, 52.05% with 3mm UDCGFRP, 26.32% with 5mm CSMGFRP, 43.27% with 5mm WRGFRP and 55.56% with 5mm UDCGFRP when compared to the control beam.

3.3 Comparison with experimental results

The load-deflection responses of typical un-strengthened and strengthened PSC beams obtained experimentally and those obtained by non-linear finite element analysis are. It can be seen from the results that the experimental and numerical solutions are in reasonably good agreement for both the categories of beams signifying the validity of the numerical model adopted for the purpose. The method adopted for modeling the PSC beams (both un-strengthened and strengthened) using three-dimensional finite element technique has proved to be reasonably reliable as a predictive tool for the analysis of externally strengthened (with GFRP laminates) PSC beams.It is to

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be noted that, when carrying out a non-linear finite element analysis, it is very important to choose appropriate finite elements and correct mesh density to obtain a satisfactory solution to the problem.

4. CONCLUSIONS

The epoxy bonding of GFRP laminates offers an attractive means of strengthening RC beamsin flexure. Based on the results obtained from laboratory experiments, non-linear finite element analysis, modeling with artificial neural network and their discussions, the following conclusions are drawn.

GFRP laminates properly bonded to the tension face of PSC beams can enhance the flexural strength capacity substantially. The strengthened beams exhibit an increase in flexural strength upto 24.70% with CSMGFRP, 57.24% with WRGFRP and 93.15% with UDCGFRP laminate for T-series beams and an increase of 16.74% with CSMGFRP, 24.26% with WRGFRP and 54.18% with UDCGFRP laminate for S-series .
At any given load level, the deflections and the crack widths in the strengthened PSC beams are reduced significantly compared to the unstrengthened beams. At the ultimate load level of the reference specimens, strengthened beams exhibit a decrease of deflectionupto 38.85% with CSMGFRP, 69.43% with WRGFRP and 80.89% with UDCGFRP laminate for T-series beams and a decrease of 16.59% with CSMGFRP, 35.84% with WRGFRP and 51.88% with UDCGFRP laminate for S-series .
The reduction in crack width for T-series beams, at ultimate load level was found to be 24.68% with 3mmCSMGFRP, 48.73% with 3mm WRGFRP, 54.43% with 3mm UDCGFRP, 43.67% with 5mm CSMGFRP, 51.91% with 5mm WRGFRP and 55.70% with 5mm UDCGFRP when compared to the control beam.
The reduction in crack width for S-series beams, at ultimate load level was found to be 13.45% with 3mmCSMGFRP, 36.84% with 3mm WRGFRP, 52.05% with 3mmUDCGFRP, 26.32% with 5mm CSMGFRP, 43.27% with 5mm WRGFRP and 55.56% with 5mm UDCGFRP when compared to the control beam.All the PSC beams strengthened with GFRP laminates experience flexural failure. None of the beams exhibit premature failure of the laminate. An examination of the crack distribution indicates that the size and density of cracks are less in the strengthened beamsthan in the un-strengthened beam.
The PSC beams strengthened with externally bonded GFRP laminates provide adequate ductility to ensure a ductile mode of failure. The GFRP strengthened PSC beams exhibit an increase in deflection ductility of 30.84% and an increase in energy ductility of 59.64% with 5mm UDCGFRP with respect to the control beam.
The ultimate loads obtained from experiments agree well with the values predicted usinganalytical work.
The non-linear finite element modeling adopted proves to be an acceptable predictive tool for the analysis of PSC beams strengthened externally with GFRP laminates. The numerical predictions show a good correlation with the experimental results.
The regression equations proposed in the present study closely predict the study parameters of yield load, yield load deflection, ultimate load, ultimate load deflection, deflection ductility, energy ductility, deflection ductility ratio, energy ductility ratio, number of cracks, maximum crack width and total energy absorption of GFRP strengthened PSC beams.

REFERENCES

1. Almusallam, T. H., H. M. Elsanadedy, and Y. A. Al-Salloum. (2014), Effect of Longitudinal Steel Ratio on Behavior of RC Beams Strengthened with FRP Composites: Experimental and FE Study. *Journal of Composites for Construction* 19(1) 0401- 4028.
2. Chan, K.H. and Au, F.T., 2015. Behaviour of continuous pre-stressed concrete beams with external tendons. *Structural Engineering and Mechanics*, *55*(6), pp.1099-1120.
3. Chowdhury and Loo, 2001. A new formula for prediction of crack widths in reinforced and partially pre-stressed concrete beams. *Advances in Structural Engineering*, *4*(2), pp.101-110.
4. Du, J.S., Au, F.T., Chan, E.K. and Liu, L., 2016. Deflection of un-bonded Partially Pre-stressed Concrete Continuous Beams. *Engineering Structures*, *118*, pp.89-96.
5. Du, J.S., Au, F.T., Cheung, Y.K. and Kwan, A.K., 2008. Ductility analysis of pre- stressed concrete beams with unbonded tendons. *Engineering Structures*,*30*(1), pp.13-21.

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AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

6. El Meski, F. and Harajli, M., 2012. Flexural Behavior of Unbonded Posttensioned Concrete Members Strengthened Using External FRP Composites. *Journal of Composites for Construction*, *17*(2), pp.197-207.
7. Harajli, M.H., 2006. On the stress in unbonded tendons at ultimate: Critical assessment and proposed changes. *ACI Structural Journal*, *103*(6), 803-806.Jadhav, H.S. and Shiyekar, M.R (2011), Performance of Reinforced Concrete Beams Strengthened with GFRP Laminate Configuration, *International Journal of 3R's*, 1, 192-195.
8. Lou, T., Lopes, S.M. and Lopes, A.V., 2012. Flexural Response of Continuous Concrete Beams Pre-stressed with E ternal Tendons. *Journal of Bridge Engineering*, *18*(6), pp.525-537.
9. Lou, T., Lopes, S.M. and Lopes, A.V., 2013. Nonlinear and Time-Dependent Analysis of Continuous Unbonded Pre-stressed Concrete Beams. *Computers & Structures*, *119*, pp.166-176.
10. Ozkul, O., Nassif, H., Tanchan, P. and Harajli, M., 2008. Rational approach for predicting stress in beams with unbonded tendons. *ACI Structural Journal*, *105*(3), p.338.
11. Padmarajaiah, S.K. and Ramaswamy, A., 2004. Flexural strength predictions of steel fiber reinforced high-strength concrete in fully/partially pre-stressed beam specimens.
12. Park, H., Jeong, S., Lee, S.C. and Cho, J.Y., 2016. Flexural Behaviour of Post- Tensioned Pre-stressed Concrete Girders with High-Strength Strands. *Engineering Structures*, *112*, pp.90-99.
13. Pisani, M.A., 2009. Numerical Analysis of Continuous Beams Pre-stressed with External Tendons. *Journal of Bridge Engineering*, *14*(2), pp.93-101.
14. Wang, J., u, J. and Gao, D., 2016. Numerical Relationship between Creep Deformation Coefficients of Pre-stressed Concrete Beams. *Materials and Structures*, *49*(4), pp.1443-1453.