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An Experimental and Analytical Investigation of Post-Tensioned Concrete Beam Strengthened Using GFRP Sheet.

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Abstract *- An analytical and experimental investigation was held on post-tensioned concrete beams strengthened by Glass Fiber Reinforced Polymer (GFRP) sheets. The objective of this work was to study the flexural behavior, deflection and load carrying capacity of strengthened beams subjected to static loading. To achieve this 6 number of post-tensioned beams of size 100mm x 150mm x 1000mm were tested analytically and experimentally under two points loading condition. Conclusions were drawn based on the plot of load-deflection and moment-curvature graph. Here analytical and experimental measurements are compared based on numerous tests available on the literature and published by different authors. The finite element simulated response agrees remarkably with the corresponding experiment results. Finally, it was concluded that load carrying capacity as well as initial stiffness of post-tensioned beams can be increased by using GFRP wrapping technology.*

Key words- GFRP, Finite element modeling, Post tensioned beams and Strengthened beams.

I. INTRODUCTION

Many existing Pre-stressed concrete (PSC) structures across the world are suspected of being unstable to carry current loads as a result of over load, poor quality of construction methodologies, construction materials, substandard design, exposure to adverse environment damage due to natural disasters such as earthquakes and hurricanes, stress loss due to deterioration of structures. Also, it is important for structural members to have adequate strength and stiffness so as to assure stable performance of structures. As a result, large numbers of existing structural members are in need of strengthening by retrofitting, rehabilitation or replacement. Pre-stressed concrete (PSC) structures are not exception to this.

Strengthening of the PSC structures is an important issue that involves economic and social aspects in different areas of the world. In fact, the PSC beams designed without proper codal provisions are often characterized by an unsatisfactory structural behavior due to loss of prestress in strands and lack of strength hierarchy including global failure mechanisms. The critical regions in the PSC beams are flexure and shear zones, these zones may be strengthened by retrofitting externally by using Fiber Reinforced Polymers (FRP) wrapping techniques in order to keep structures operational. Strengthening by retrofitting using FRPs have emerged as an alternative to traditional technique available like externally bonded steel plates, Steel or Concrete jackets and external post tensioning.

Fiber-reinforced polymers (FRPs) systems is used as additional tensile reinforcement and is defined as the fibers and resins used to create the composite laminate, all applicable resins used to bond it to the concrete substrate, and all applied coatings used to protect the constituent materials. FRP materials are lightweight, noncorrosive, and exhibit high tensile strength. Use of FRP systems is the knowledge gained from a comprehensive review of experimental research, analytical work, and field applications.

This paper present an experimental and analytical investigation of post- tensioned beams to study the effect of GFRP as an external strengthening material on flexural behavior, deflection and ultimate load carrying capacity of the beams under the static loading, using wrapping technique.

II. EXPERIMENTAL STUDY

The experimental study was conducted on the Post-Tensioned beams. This program was conducted to evaluate results obtained from analytical study. Six numbers of Post-Tensioned beams were cast. All the beams were designed according to IS 1343 specification and tested under two point loading condition. This study restrict for flexure failure only. i.e., shear failure have been exclude in this present study.

A. Casting of Beam Specimens

Six number, post-tensioned beams of size 100mm X 150mm X 1000mm were considered for the study. The effective length was 900mm. The test beams are provided with non-prestressing steel cage. A flexible rubber tube of 10mm diameter was placed along the length of the mould then high tensile wires of 4 nos. of 7mm diameter each are inserted into tube in order to avoid the compression of the rubber tube during casting. Two plates with 4 holes are provided at the ends of the wires.

Concrete of grade M30 was poured from a height less than 1m into mould. It was thoroughly compacted using vibrator. After the initial setting of the concrete the wires were moved to and fro in order to confirm that there was no setting of wires with concrete. After 24 hours beams were de-mould and cured by covering wet gunny bags with water.

The end plates are fixed on both the ends of the beams. The plates are made of mild steel of size 80mm X 80mm X 10mm with required holes drilled into it, these plate acts as bearing plates. The barrel is fixed first and then a two piece wedge was inserted into it for each wire on both side of the specimen as shown in the fig (1).

Fig. 1 Wires with end plates, barrel and wedge.

B. Pre-Stressing of Beams

Two mild steel plates of 80mmX80mmX10mm were used as the end bearing plates. The four holes were driven in each end bearing plate to accommodate post-tensioning wire for the designed concentric post-tensioning. High tensile wires were placed through the holes drives in the mild steel plate from one end to another end in respective ducts. The each wire of 7 mm diameter was stressed by hand operated hydraulic pre-stressing jack, as shown in Fig. 2. The anchorage system used was Gifford-Udall system

Fig. 2 Application of stress

C. Strengthening of Beams by GFRP Wrapping

Out of Six beams, two beams were controlled post-tensioned beams, 2 beams were strengthened by GFRP sheets for the full length at the bottom side and remaining two beams were strengthened by GFRP sheets for flexure length at the bottom. Nitowrap 30 epoxy primer is applied over the prepared and cleaned surface. This was allowed for drying for about 24 hours before application of saturant. Nitowrap 410 saturant was applied over the primer. The wet film thickness shall be maintained at 250 microns. GFRP sheets shall be cut to required size and then pressed over primer by a surface roller to remove air bubbles as shown in fig 3.

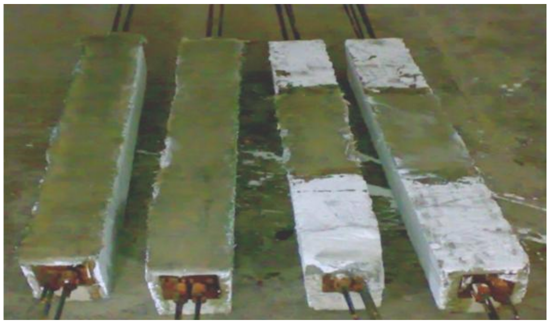

Fig 3. Beams strengthened by GFRP sheets at the bottom

Fig. 4 Test set-up under loading frame

D. Testing of beams

All the beams were tested statically, under loading frame of capacity of 50 T, the loading setup was as shown in Fig 4. The deflection was measured at mid span of the beams. The load is applied at a 1.35 kN increment up to ultimate load. At each increment of load, deflections were noted.

III. ANALYTICAL STUDY

Here, the blocks are built using ANSYS top down approach. Due to symmetry of the element, only half the geometry was built. The eight noded SOLID 45 element was chosen for modeling the concrete beam. The reinforcing steel was modeled as LINK 8 element assuming perfect bonding between concrete and reinforcing steel. Four number of 7mm diameter high tensile bars were used for experimental work. In analytical work, this was represented by LINK 8 element with initial loading specified as initial strain. FE Model of control beam with inner reinforcement is as shown if Fig.5. Four noded SHALL 63 elements were used for meshing, which represents wrapping of GFRP at the base. Fig. 6 shows the FE model of the GFRP wrapping at base for total length. Fig.7 shows the FE model of GFRP wrapping at the base for flexure length. Cracking behavior in tension is represented by a stress of 3.8 Mpa which was calculated theoretically for M30 grade of concrete.

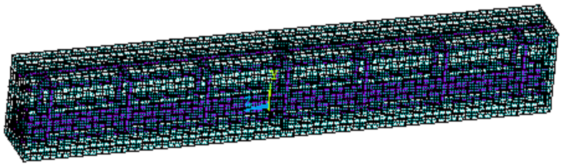

Fig. 5 Control beam model with inner reinforcements

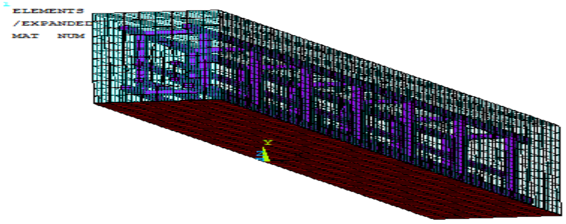

Fig. 6 Full Wrapping with GFRP at the base of the beam

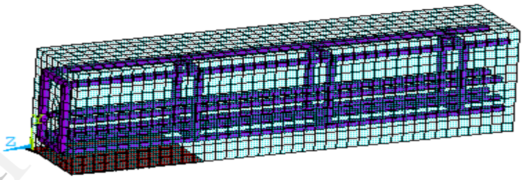

Fig. 7 Flexural length wrapping of the beam by GFRP.

The symmetric boundary conditions are applied as shown in Fig 8. The loads are applied at right side bottom region of a span of 50mm is supported in the vertical direction.

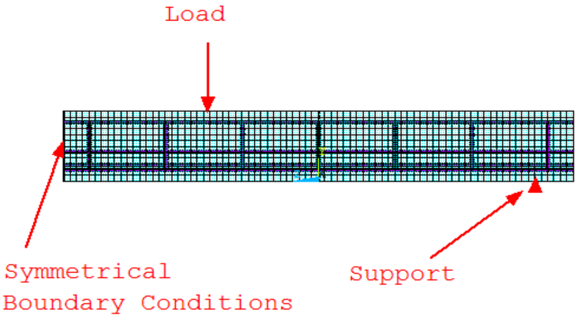

Fig. 8 Boundary conditions Plot

IV RESULTS AND DISCUSSION

[1] **FROM EXPERIMENTAL WORK**

A. Control Beams- CB

These beams were used for the comparative study without FRP wrapping. The CB-1 and 2 were loaded with two point load and the deflection was measured at mid span using digital dial gauge. Both specimens tested under this categoty failed in pure flexure mode. No cracks were observed outside the middle third region. All the cracks in the flexure zone were almost perpendicular to the axis of the beam. The initial crack was developed at 39.15 kN and 44.55 kN for CB-1 and CB-2 respectively. The ultimate at load of these two beams were 75.6 kN and 76.95kN, and cracking pattern of beam is show in Fig. 9 and 10. The deflection at ultimate load is tabulate in Table I, the load v/s deflection and moment v/s curvature is shown in Fig. 15 and Fig 17 respectively.

It is interesting to note that the design load carrying capacity was 40kN while specimens stood upto 75.26kN and 76.16kN. The average initial stiffness of these specimens is 140 X 10^3 N-m/radians

B. Flexure Length Wrapping by GFRP sheet

These beams were strengthened only at flexure zone at bottom and these beams are designated as FGFRP-1 and 2. Both the specimens developed only flexure cracks within the middle third region. The ultimate load carried by these beams were 87.75kN and 86.4kN, which is more than the load carried by control beams. And also deflection is more than the control beams. It is interesting to note that the initial crack load (i.e., 40.5kN) is same for both beams. But the average initial stiffness of these specimen is 108.33 x 10^3 N-m/radians

During last stages of loading delamination of GFRP sheet occurred for both the specimens.

The cracking patterns of these beams are show in Fig. 11 and Fig 12. The deflection at ultimate load and initial stiffness are tabulate in table-I, also plotted the load v/s deflection and moment v/s curvature graph for the specimens are shown in Fig. 15 and Fig 18 respectively.

C. Bottom Wrapping by GFRP

The beams were strengthened by GFRP were wrapped for total bottom length of beam and was designated as TGFRP-1 and 2. The ultimate load carried by these beams were 110.7kN and 103.95kN which is more than the control and FGFRP beams. And it is noted that this load is almost 3 times the design load carrying capacity. And also deflection is more than the other beams. These specimens had average initial stiffness about 325 X 10^3 Nm/Radians, which is more compared to other specimens. The better peformance of the these beams could be realized by the moment-curvature relationships obtained. Even crushing of concrete occurred on top suface below the loading point for TGFRP-2. It is amazing to note that the initial crack loads (56.7kN and 52.65kN) are more than the design load.

Unlike the crack patterns noticed in the control specimens, these beams developed initial cracks outside of the flexure zone. However subsequent cracks were in the flexure zone and these were the typical flexure cracks.

The cracking patterns of these beams are show in Fig. 13 and Fig 14. The deflection at ultimate load and initial stiffness are tabulate in table-I, also plotted the load v/s deflection and moment v/s curvature graph for the specimens are shown in Fig. 16 and Fig 19 respectively.

Fig.9 The cracking pattern of beam CB-1

Fig.10 The cracking pattern of beam CB-2

Fig. 11 The Cracking pattern or FGFRP-1

Fig. 12 The Cracking pattern or FGFRP-2

Fig. 13 The Cracking pattern or TGFRP-1

Fig. 14 The Cracking pattern or TGFRP-2

LOADS-DEFLECTION CURVES: The load v/s central deflection curves are platted for all beams. Fig. 11 and 12, represent the load v/s deflection for all strengthen beams also they show the comparison with CB.

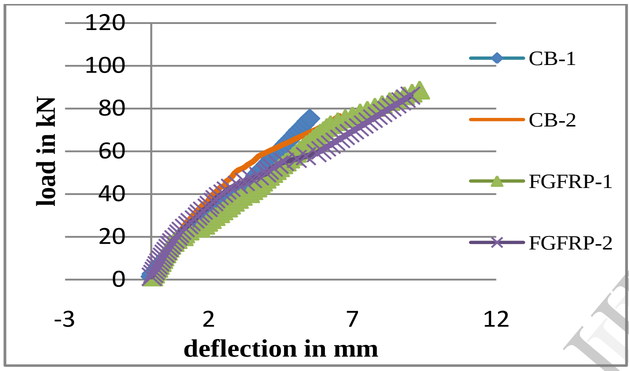

Fig.15 Load - deflection relationship for control and FGFRP beams

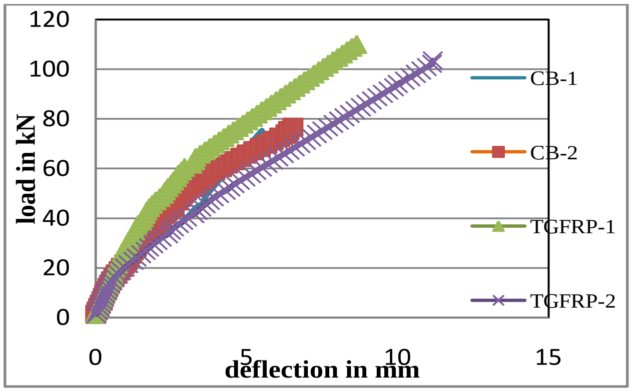

Fig.16 Load - deflection relationship for control and TGFRP beams

MOMENT V/S CURVATURE: Moment v/s curvature is developed for all beams. Fig. 13-15, represents the moment v/s curvature for control and strengthened beams.

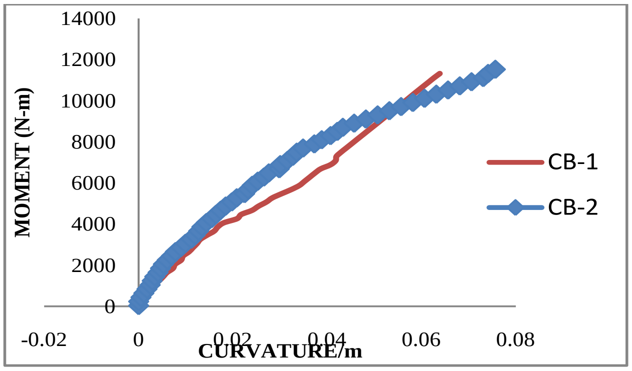

Fig. 17 Moment-Curvature relationship for control beams

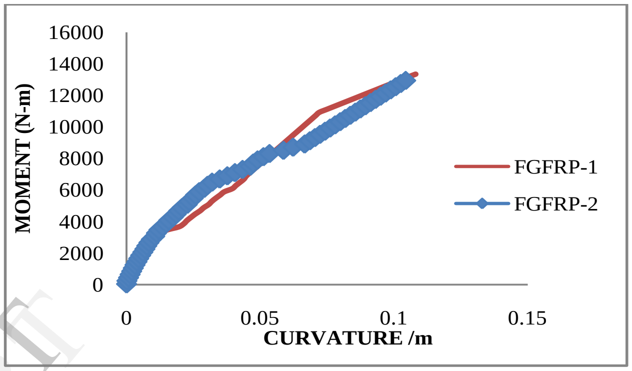

Fig. 18 Moment-Curvature relationship for FGFRP beams

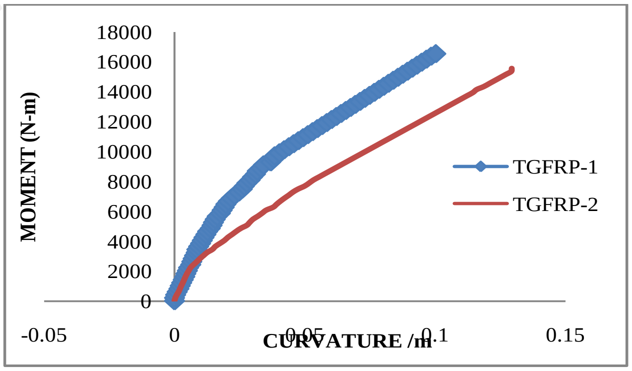

Fig. 19 Moment-Curvature relationship for TGFRP beams

TABLE I: RESULTS OBTAINED FROM THE EXPERIMENTAL INVESTIGATION

Beam name	Initial crack Load (kN)	Ult. Load (kN)	Deflection at Ult. Load in (mm)	Avg. Initial Stiffness (Nm/Radians)	Type of Failure
CB-1	39.15	75.6	5.512	$140x10^3$	Flexure
CB-2	44.55	76.95	6.535		
FGFRP-1	40.5	87.75	9.333	$108.3x10^3$	Flexure
FGFRP-2	40.5	86.4	9.012		
TGFRP-1	56.7	110.7	11.53	$325x10^3$	Flexure & Shear
TGFRP-2	52.65	103.95	11.16		

[2] **FROM ANALYTICAL WORK**

A.Control beam

The load is applied through incremental procedure up to the failure of the structure. Load step option through ramped load is used to obtain the ramped nature of the load. The figure 20 shows principal stress plot at the starting of crack and load acting on the beam structure. Initial crack load is 14498N. So a full load of 2*14498= 28996N is required for the start of the crack. The load 30767N or a total load of 2*30767=61534N is required for final failure of the structure. The load values are obtained by calculating reaction load acting on the structure

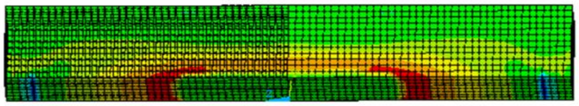

Fig. 20 Principal stress of CB at the initial crack

Figure 21 shows the displacement plot of the control beam at the maximum safe load. The red colour (at centre) in the figure shows the maximum displacement whereas blue colour (at edges) shows the minimum displacement.

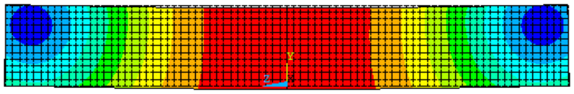

Fig. 21 Displacement of control beam at maximum load

B.Flexure Length Wrapping by GFRP sheet

Once stress exceeding the tension cracking stress, crack will start in the structure. The figure 22 shows principal stress development in the beam strengthened at flexure zone only. This shows crack pattern and load requirement for the beam. Half symmetrical load of 17241 N or full load of 2*17241=34482 N is required for the start of the crack.

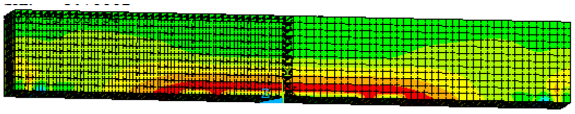

Fig 22 Principal stress plot for FGFRP beam at initial crack

The figure shows complete crack pattern and load requirement. A load of 34616N or a full load requirement of 2*34616= 69232N is required for full failure of the structure. This figure shows the displacement of flexural length strengthened beams using GFRP wrapping.

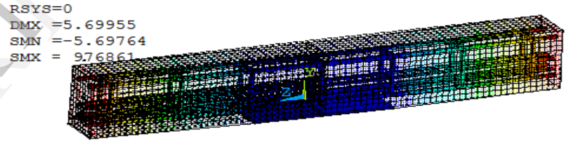

Fig 23 Displacement at the time of final failure in FGFRP beam

TABLE II: RESULTS OBTAINED FROM THE ANALYTICAL INVESTIGATION

Beam name	Initial crack Load (kN)	Ult. Load (kN)	Deflection at Ult. Load in (mm)
CB	28.99	61.53	5.59
FGFRP-1	34.45	69.23	9.786
TGFRP-1	52.00	88.28	12.53

C. Bottom Wrapping by GFRP

A load of 2 x 26004= 52008 N is required for the start of crack in the post-tensioned beam strengthened by GFRP. The figure 24 shows complete failure with crack pattern and load requirement.

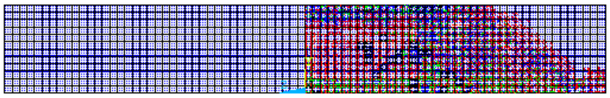

Fig 24 Final failure and half symmetrical load requirement of TGFRP beam

A full load of 2*44139= 88278 N is required for the complete failure of the structure. The figure 25 shows the maximum deflection of the beam strengthened by GFRP wrapping for full length at bottom.

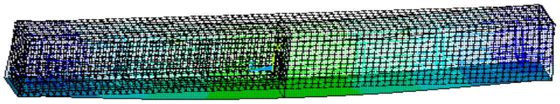

Fig 25: Maximum deflection in the TGFRP beam

IV. CONCLUSIONS

Based on the experimental observation and analytical modeling, following conclusions are drawn on the effect of the GFRP wrapping as a strengthening material on ultimate load carrying capacity, deflection and initial stiffness.

- Both analytical and experimental work shows that, strengthening of post-tensioned beams by FRP wrapping technique method enhances load carrying capacity significantly.
- The analytical model failed to predict the failure modes observed in the final static test, i.e., de-bonding of the FRP sheets in FGFRP
- The Post-Tensioned beams strengthened for full length of bottom was found to be more effective and the load carrying capacity was increased about 40.53 % as compared to control specimens. And increased about 22.19% as compared to beams strengthened only at flexure zone.
- The strengthened beams FGFRP failed due to debonding of GFRP, that means bond failure occurred as loading approaches the ultimate load. But there was no debonding in TGFRP. From this we can conclude that the continuous wrapping is best wrapping technique and to restore the ultimate flexural capacity of strengthened beams it could be necessary to prevent fiber debonding.
- There was increase in initial stiffness strengthened beams as compared to control beam.
- The analytical and experimental outcomes qualify the application of FRP technique, as an effective tool to restore the flexural capacity of beams.
- The deflection of the beams both in analytical and experimental method found to be similar with less difference.
- The analytical model proposed should be validated by different test data with different cross section and prestressing.

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