A study on Post Tensioned Beams Strengthened with CFRP Laminate

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Abstract - *Reinforced concrete is widely used as versatile material in construction field till now. Post Tensioned structures are not exception to this, to guarantee the stable performance of the structures. Many works has been carried out to study the performance of Post Tensioned beam strengthened with different materials. In the present work, performance of Post Tensioned beam strengthened with CFRP Laminate for ultimate load carrying capacity and deflection for different beams are carried out. That is Post Tensioned beam, Post Tensioned beam retrofitted with CFRP Laminate and post tensioned beam strengthened with CFRP Laminate subjected to two point loading. For this, beams of 1300 mm length, 150 mm width & 300 mm depth were casted and tested for M40 grade concrete with 0.4 water/ cement ratio. Further, the experimental result were compared and discussed with analytical method by creating the model using Ansys Workbench 14.5 software. In the present work Post Tensioned beam strengthened with CFRP Laminate showed better performance in both experimental and analytical method.*

Key Words: **Post Tensioned, Strengthening, Retrofitting, CFRP Laminate and Epoxy resin.**

1. INTRODUCTION:

Study shows that, strengthening of existing structures has become a major part of construction activity in our country. Many civil structures are no longer safe due to increased load specifications in the design codes. Such structures must be strengthened in order to maintain their serviceability. Strengthening refers to the reconstruction or renewal of any part of an existing building to provide better structural capacity like higher strength and ductility than the original. Various strengthening techniques include the use of advanced composite materials like Carbon fiber reinforced polymer (CFRP) Laminate, Aramid fiber reinforced polymer (AFRP), Ferro cement etc. The crucial regions in post tensioned beams are flexure zone and shear zone. In the present work, the flexure zone is strengthened with CFRP Laminate.

The CFRP Laminate as an externally bonded reinforcement used for increasing flexural strength. Result shows that, fully wrapped RC beam gives more torsional strength as compared to controlled beam (Sachin, 2018). The maximum load of Post Tensioned PSC strengthened beam with Natural Sisal Fiber Reinforced Polymer (NSFRP) showed maximum load carrying capacity compared to strengthened beam (Bharath 2015). FEM modeling is used to study the structural behavior of reinforced concrete beams and bridges strengthened with FRP laminates (Alper, 2001).

2. OBJECTIVES:

The main objective of the current work is, to study the ultimate load carrying capacity and deflection of the beams.

3. MATERIALS:

The materials used for the present work is:

3.1 Concrete: For the current study, M40 grade with 0.4 w/c ratio is used. The mix is designed as per IS 10262:2009 and the mix proportion is 1: 1.51: 2.69.

3.2 Reinforcement: The structural reinforcement of specimen consists of 2 No. of 10 mm dia at tension zone, 2 No. of 10 mm dia hanger or compression zone and two legged 8 mm dia stirrups were provided at 125 mm c/c as shear reinforcement.

3.3 Carbon fiber reinforced polymer (CFRP) Laminate:

Fig 1:- CFRP Laminate

Fig 1 shows the unidirectional pattern of CFRP Laminate. CFRP Laminate as an external reinforcement is used extensively to deal with the strength requirements related to flexure in structural systems. The manufacturing unit of good quality of fibers is Horse Structural Strengthening Materials. The modulus of elasticity of these fibers are from 120-2250Mpa, with an elongation of 1.6-6%. Their Young modulus of elasticity and tensile strength are intermediate between basalt and high modulus carbon. Their compressive strength is typically around 1/8 of their tensile strength. Post Tensioned beam is externally bonded with CFRP Laminate. Each panel is subjected to equal static loading during the experiment.

4. EXPERIMENTAL PROGRAM:

For the present study three types of beams were casted and tested. That is
1) Post Tensioned Beam.
2) Post Tensioned Beam Retrofitted with CFRP Laminate.
3) Post Tensioned Beam Strengthened with CFRP Laminate.

4.1 Post Tensioned Beams:

The experimental study comprises of casting of Post-Tensioned beam of dimension 1300 mm length, 150 mm width & 300 mm depth. The structural reinforcement of specimen consist of 2 No of 10 mm dia at tension reinforcement, 2 No. of 10 mm dia at compression reinforcement, two legged 8mm dia stirrups were provided at 125 mm c/c as shear reinforcement and tendons of 7 mm dia were placed at an eccentricity of 25 mm from the bottom surface of the beam. During casting, the vibrator was used for compaction of concrete to avoid honey comb formation. After casting, the beams were cured for 28 days. Fig-2

Fig 2:- Casting of Post Tensioned Beams

4.2 Post Tensioning Mechanism of Beams:

Once the concrete attains full strength after 28 days of curing, the pre-stressing cable or post tension tendons placed inside plastic pipe duets are pulled tight with the aid of tensioning jack and anchored against outer edges of the specimen with help of wedges and barrel steel plates. A hydraulic post tensioning hand driven jack consisting of a needle gauge is used to apply the load. Needle is inserted into tendon and pre-stressed to the required force is the basic principle behind it. Two mild steel plates of dimension 100 mm x 80 mm x 10 mm were used as end bearing plates at both the ends of the beam. Two holes were driven in each end bearing plates to accommodate the post-tensioning wires or tendons. The Wedges and Barrels were inserted at the end of steel bearing plates to avoid the relaxation of pre-stressed tendons. The tendons were anchored at one end of the beam and pre-stressing is applied at other end through jack needle. Pre-stressing force of 80kN is applied in hydraulic jack to pull the pre-stressing wire. The same is shown in Figure 3.

Fig 3:- Post-tensioning of beams

4.3 Strengthening of Beams with CFRP Laminate

Before the bonding of CFRP Laminate, the beam surface should be cleaned. Both the epoxy resin and hardener are mixed for five minutes in order to get the uniform mix asbonding agent. The CFRP Laminate is cut to the required form. As in case of strengthening, after the beam is air dried, epoxy resin is applied on beam surface and CFRP Laminate is placed on it. With help of rollers the fabric is pressed to remove the entrapped air or else it may lead to early failure. After strengthening, the beams are cured for three to four days. The corrosion of steel or deterioration of concrete must be solved before application of epoxy resin. Figure 4 shows the application of epoxy and CFRP Laminate to strengthen the beam.

Fig 4:-Leveling and Application of epoxy and CFRP Laminate

4.4 Experimental setup

The beams are subjected to two point loading under the loading frame of 500 kN capacity and all beams were tested under static loading as shown in figure 5. The load is applied at an interval of 10kN. For every incremental load of 10kN, the corresponding deformations were measured using LVDT's placed at right loading point, left loading point and at the mid span of the beam The maximum load at which the beam fails is considered as ultimate load.. The results were tabulated and discussed. Figure 6 shows the deflected shape of the beam.

Fig 5:- Test setup for Post Tensioned Beam

Fig 6:- Deflected shape of Post Tensioned Beam

5. Analysis of Experimental Result

Here an attempt is made to study the behavior of Post Tensioned beam by developing the model using the software Ansys Workbench 14.5, which enables to simulate tests or working conditions and to test in virtual environment before manufacturing prototypes of products.

5.1 Modeling of the Beam

The first step is to generate the computer graphical model of the given component which will represent the original component. Same considerations have been considered during the modeling of the component such as material properties, loading and boundary conditions. Figure 7 shows the modeling of Post Tensioned beam strengthened with CFRP Laminate. The results were tabulated and discussed and the deflected shape of the beam model is as shown in figure 8.

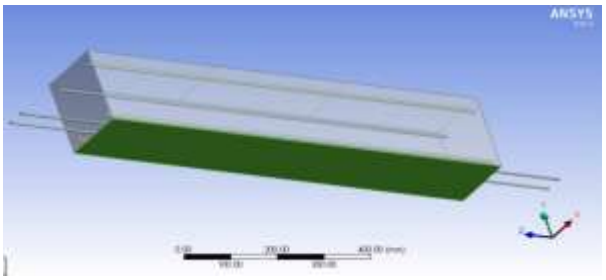

Fig 7:- Model of PT-Beam strengthened with CFRP Laminate

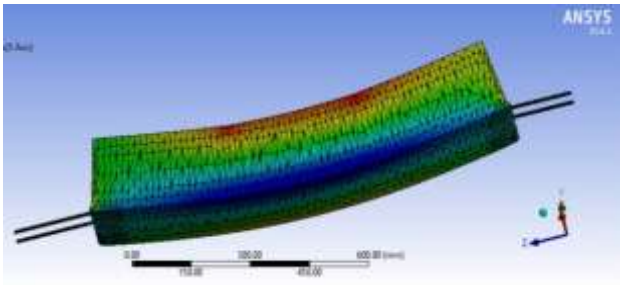

Fig 8:- Deflected shape of the beam

6. RESULTS AND DISCUSSIONS

The results obtained from experimental and analytical methods were discussed for different beams and the same is presented here.

6.1 Experimental Results:

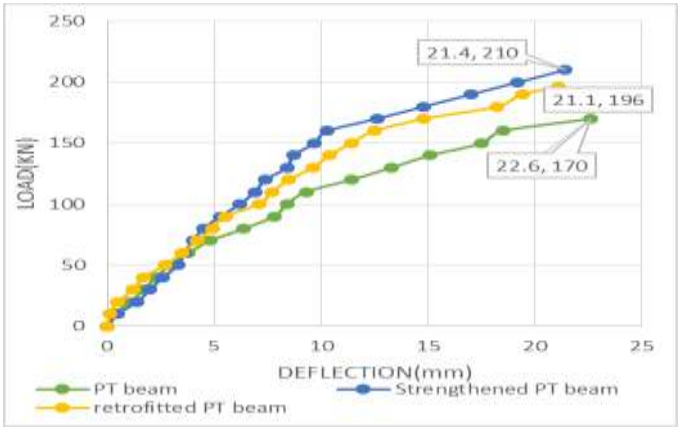

Fig 9:- Load v/s Deflection curve for different types of PT-beams

Figure 9 shows, load v/s deflection curve for different types of beams that is, Post Tensioned beam, Strengthened Post Tensioned beam with CFRP Laminate and Retrofitted Post Tensioned beam with CFRP Laminate in the experimental work. From the above figure it is observed that, the ultimate load carrying capacity of Post Tensioned Strengthened beam performed better when compared to that of Post Tensioned beam and Post Tensioned Retrofitted beam. That is at 15 mm deflection, the load of Post Tensioned Beam 139.8 kN, Post Tensioned Beam Retrofitted 180.9 kN, Strengthened Post Tensioned Beam 170.5 kN. It can also be observed that, Post Tensioned Strengthened beam shows less deflection when compared to other beams. This may be because of the CFRP Laminate used for strengthening technique.

6.2 Analytical Results:

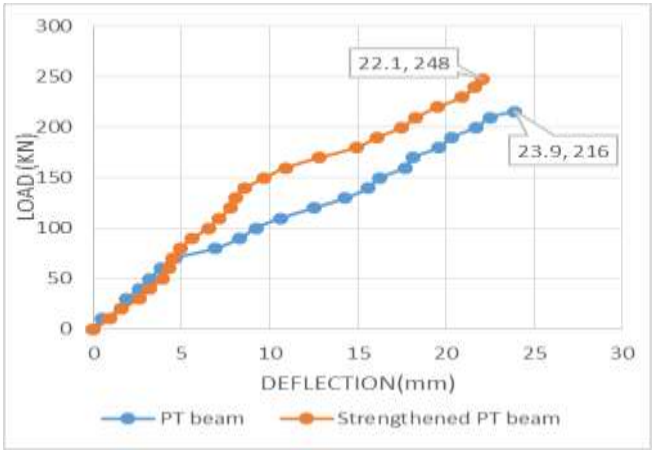

Fig 10:- Load v/s Deflection curve for different types of PT-beams

Figure 10 shows load v/s deflection curve for different types of beams used in the analytical work. From the above figure it is observed that, the ultimate load carrying capacity of Post Tensioned Strengthened beam performed better when compared to that of Post Tensioned beam. That is at 15 mm deflection, the load of Post Tension Beam was 135.38 kN, and Strengthened Post Tension Beam was 180.8 kN. It can also be observed that, Post Tensioned Strengthened beam shows less deflection when compared to Post Tension beams. Further, the deflection in analytical method is less when compared with experimental results, this may be because of the CFRP Laminate used for strengthening technique.

6.3 Comparison of Ultimate loads by Experimental & Analytical method

Figure 11 shows, the ultimate load carrying capacity of the beams used for the experimental works. It shows that, the load carrying capacity by experimental method of Post Tensioned beam is 192kN, Post Tensioned beam strengthened with CFRP Laminate is 228kN, and Post Tensioned Beam Retrofitted with CFRP Laminate is 204kN.This shows that Post Tensioned beam strengthened with CFRP Laminate performed better when compared to that of Post Tensioned beam and Post Tensioned Retrofitted beam.

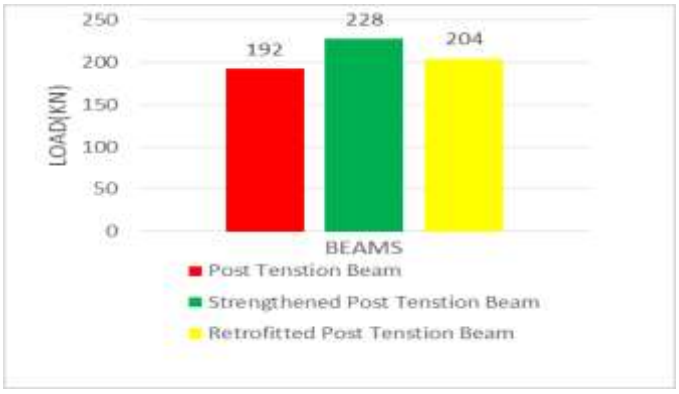

Fig 11:- Comparison of loads with different types of PT-beams by experimental method

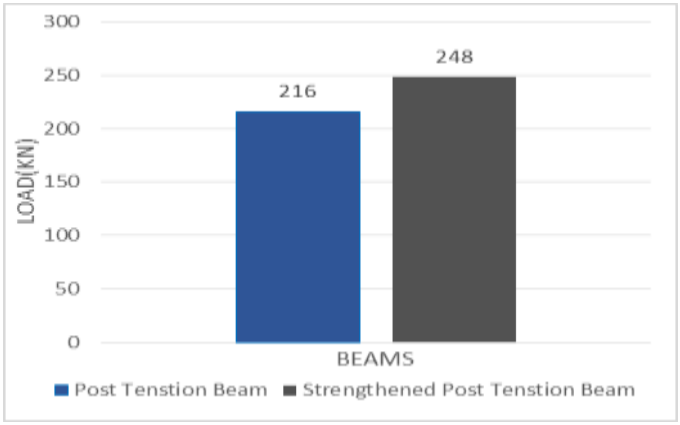

Fig 12:- Comparison of loads with different types of PT-beams by Analytical method

Figure 12 shows, the load carrying capacity of beams by analytical method. The ultimate load carrying capacity of Post Tensioned beam is 216kN and that of Post Tensioned beam strengthened with CFRP Laminate is 248kN. Here also it can be observed that, ultimate load carrying capacity of Post Tension beam strengthened with CFRP Laminate is showing good performance by carrying maximum load of 248kN. This shows that Post Tensioned beam strengthened with CFRP Laminate performed better when compared to that of Post Tensioned beam.This may be because of CFRP Laminate used at the bottom of the beam for full length.

7. CONCLUSIONS

Based upon the observations made from the experimental and analytical study, the following conclusions were drawn.

- **Experimental method:**
  - The deflection of Post Tensioned Strengthened beam and retrofitted beam with CFRP Laminate is reduced by 44.00% and 23.00% respectively when compared to Post Tensioned Beams.
  - The ultimate load carrying capacity of Strengthen Post Tensioned Beam is increased by 15.78% and 10.52% when compared to Post Tensioned Beam and Retrofitted Post Tensioned Beam.
- **Analytical method:**
  - The deflection of Post Tensioned Strengthened beam with CFRP Laminate is reduced by 7.53% when compared to Post Tensioned beam.
  - The ultimate load carrying capacity of Strengthen Post Tensioned Beam is increased by 12.9% when compared to Post Tensioned Beam.
- **In both the cases i.e, in Experimental and Analytical methods, the performance of Post Tensioned Strengthened beam showed better results with more load carrying capacity and less deflection when compared to other beams.**

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