Behaiour of Post-tensioned Beams Stengthened by CFRP And GFRP Wrapping

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Abstract

Generally prestressed concrete beams are used for construction of long span bridges. These prestressed concrete (PSC) members need to be upgraded to increase their load carrying capacity to overcome the loss of prestressing force which may occur due to various loading conditions such as construction load, moving load on bridges etc. Sometimes complete replacement and construction of bridges are not economical and it's not feasible. In such circumstances repair, rehabilitation or retrofitting is best option rather than the complete replacement and construction.

This paper present an experiment investigation of 21 number of post- tensioned beams to study the strengthened effect of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) under flexural behavior, deflection, cracking pattern and ultimate load carrying capacity of the beams under the static loading, using wrapping technique. The CFRP and GFRP were wrapped as strips for full length for 6 beams, 6 beams were wrapped at soffit of beam and 6 beams were U-wrapped for full length of beams by wet lay-up technique. From the experimental results it was revealed that the initial crack strength and ultimate load carrying capacity are found to be increased. The design and the behavior of the strengthened beams are considered at various service loads.

Key words- Post tensioned beams, Strengthened, CFRP, GFRP.

I. INTRODUCTION

The Prestressed concrete members are used for construction of long span bridges. These prestressed concrete members are losing their prestressing forces over a period of construction. This is may be due to the increase of live load, increase of traffic density, thermal stress, accidental damages, explosion etc. Sometimes complete replacement and construction is not possible depending upon location of structure, important of structure and economy. Under such circumstances strengthening is best option.

The earliest FRP materials used glass fibers embedded in polymeric resins that were made available by petrochemical industry following World War II. FRP systems were first applied to reinforced concrete columns for providing additional confinement in Japan in 1980s. Sudden drastic increases in use of FRP were observed in Japan after HyogoknNanbu earthquake in 1995. The research activities lead to FRPs material in many fields. The many research are under taken in worldwide, the countries like Europe, Japan, Canada and United States in fields of retrofitting and rehabilitations project using as FRPs used as construction material. FRP materials are now finding wider acceptance in the characteristically conservative infrastructure construction industry [1].

New trends in construction engineering, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) are used as construction material for the retrofitting and strengthening of RCC and PSC structural members. The use of CFRP and GFRP has gained creditability as a strengthening option for reinforced concrete structural members, yet only few studies have been undertaken to determine their effective use in strengthening of pre-stressed concrete members. These types of materials have the advantage of large strength to weight ratio, corrosion resistance, fatigue properties, and are relatively simple to install. Today FRPs are available in the form of bars, stripes, tendons and sheets. The FRP sheets are applied in any shape for the structure by wet lay-up wrapping technique. In this work CFRP and GFRP Sheets were used as strengthening materials and they were applied to the beams by wet lay-up wrapping technique.

This paper present an experiment investigation of 21 number of post- tensioned beams to study the effect of CFRP and GFRP as a external strengthening material on flexural behavior, deflection, cracking behavior and ultimate load carrying capacity of the beams under the static loading, using wrapping technique. Where three are controlled beams other twenty-one beams are strengthened beams. The CFRP and GFRP were wrapped at soffit of beams for six beams, U-strips wrapped for full length and reaming six were U- total length wrapping by wet lay-up technique as shown in figure 1.

II. EXPERIMENTAL STUDIES

The experimental study was conducted on the Post-Tensioned beams. A series of twenty-one numbers of Post-Tensioned beams were cast. All the beams were designed according to IS 1343 specification, as same size of 100mmX165mmX1700mm and tested under four point loading case. Four number of 4.5 mm diameter tendon were placed at an eccentricity of 40 mm, Four bars of 8mm diameter were provided as nominal steel and 8 mm strips were provided at 120 mm center to center as shear reinforcement. Materials were used in experiment and their property are shown in Table I

TABLE I: MATERIAL PROPERTIES

Prestressing steel	Properties	Spring steel of Grade-II
	Wire diameter	4.5 mm
	Cross-sectional area	15.90 mm^2
	Ultimate tensile strength	1755.30 N/ mm^2
	Ultimate strength	27.91 kN
	Young's Modulus	2.05 N/ mm^2
Nominal steel	HYSD bars	Fe-415
	Diameter	8 mm
	Yield strength	415 N/ mm^2
	Young's Modulus	2.10 N/ mm^2
Stirrup	Same as nominal steel	
Concrete M40	Compressive strength	40 N/ mm^2
	Fiber orientation	Uni-directional
	Weight of fiber (g/m^2)	230
	Fiber thickness (mm)	0.131
	Ultimate elongation (percentage)	21
	Primary fiber tensile strength (N/mm^2)	4900
Glass fiber Nitrowrap EP (CF 230)	Fiber orientation	Uni-directional
	Weight of fiber (g/m^2)	920
	Fiber thickness (mm)	0.9
	Ultimate elongation (percentage)	21
	Primary fiber tensile strength (N/mm^2)	3400

A. Casting of Beam Specimens

Form works were made by using two channel sections and two end plates. In end plate (100mm X165 mm) four number holes of 10 mm dia. were made in two row, first row of holes at distance of 30 mm from soffit and second row 50 mm from of the beam. Through that 8 mm plastic pipe were placed and tendons were passed through that pipe so to achieve 40 mm eccentricity. Hence eccentric pre- stressing occurs and the end plates were fixed to the channel sections with the help of bolts and nuts. Concrete grade of M40 was poured into channel section in two layers carefully so that the pipes should not dislocate. After each layer it was compacted using needle vibrator, the top layer of the concrete was finished by using trowel. Formwork was removed after 24 hour and cured for 28 days in curing tank.

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 4.5 mm diameter was stressed by a force of 22.5 kN 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 CFRP and GFRP Wrapping

In particular, out of 21 beams, three beams were used as control beams. Six beams (3 by CFRP and 3 by GFRP) strengthened by U shape strip FRP wrapping (50 mm strips wrapped at 50 mm c/c). Another six (3 by CFRP and 3 by GFRP) beams were strengthened only at bottom for full length. Remaining six beams were strengthened by (3 by

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CFRP and 3 by GFRP) U shape for full length FRP wrapping as shown in below.

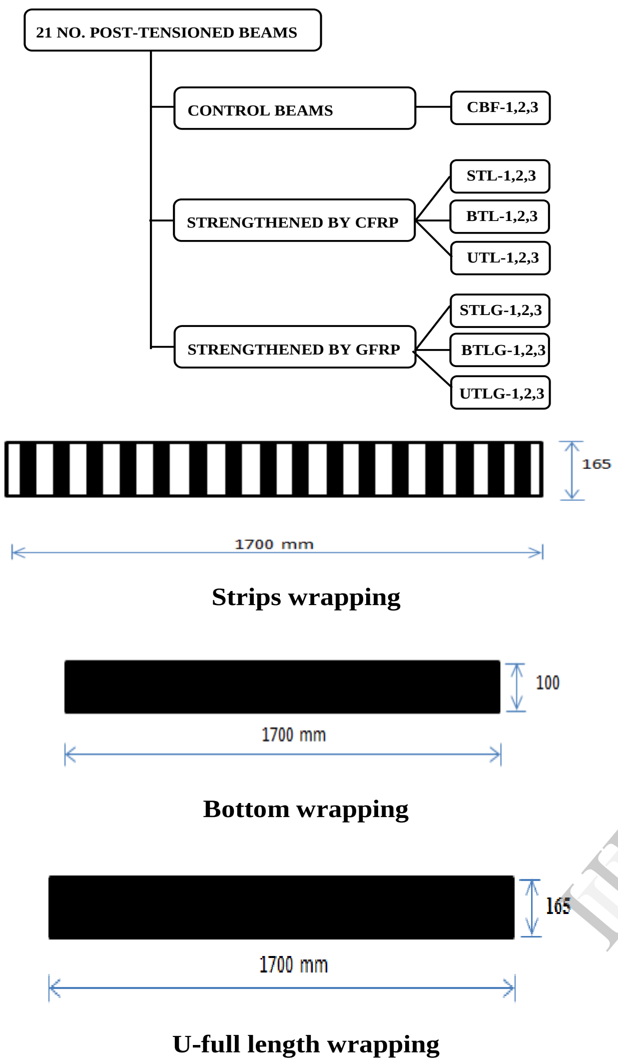

Fig.1 Schematic diagram of wrapping technique and designation of the beams

1) Surface preparation

Beam surfaces were treated, and made free from oil residues, demounding agents and protrusions**.** And also by grinding sharp edges were made into round edges

2) *CFRP and GFRP wrapping*

A thin layer of epoxy primer (Nitowrap -30) was applied on the prepared and cleaned beam surface using a paint brush. After the epoxy primer is applied the concrete surface was allow to dry for 24 hours before the fiber sheets were wrapped. Cut the polymer fabric sheet for required dimension. A thin layer of (at 250 microns) Saturant (Nitowrap- 410) was applied over the primer coat before the FRP sheet are wrapped. FRP sheet wrapped to beam carefully, also the entrapped air was removed by rolling operation. One more coat of Nitowrap- 410 Saturant was applied over the polymer sheet (at 250 micron) after time lapse of 30 minutes. And this was to cure for about 6 days.

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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 3. The deflection was measured at mid span of the beams. The load is applied at a 2 kN increment up to ultimate load. At each increment of load, deflections were noted also crack development were observed and marked on beams.

Fig. 3 Test set-up under loading frame

III RESULTS AND DISCUSSION

A. Control Beams- CBF

These beams were used for the comparative study without FRP wrapping. The CBF-1,2,3 were loaded with two point load and the deflection was measured at mid span using digital dial gauge. The initial crack was developed at 29.3 kN, 27.3kN, 31.3kN for CBF-1, CBF-2 and CBF-3 respectively. The ultimate at load of these three beams were 67.3 kN 63.3kN and 67.3kN, and cracking pattern of beam is show in Fig. 4. All the beams were failed in pure flexure. The deflection at ultimate load and crack at service load are tabulate in Table II, also plotted the load v/s deflection curve shown in Fig. 12.

B. Total Length Wrapping by CFRP strip

These beams were strengthened as the flexural strip total length wrapping is designated as STL-1,2,3. Initial minor cracks appeared at 37.3 kN, 41.3kN, 33.3kN and as the load reached the ultimate state at 87.3kN, 93.3kN, 81.3 kN, the concrete crushed in unwrapped zone resulting beam failure in flexure. The failure was characterized by typical flexure failure which is the most critical failure mode in the Post-Tensioned beams and notice that there are no cracks are appeared in wrapped zone. The cracking pattern of beam is show in Fig. 5. The deflection at ultimate load and crack at service load are tabulate in table-2, also plotted the load-deflection graph for the specimen and shown in Fig. 13.

C. Bottom Wrapping by CFRP

The beams were strengthened by CFRP were wrapped for total bottom length of beam and was designated as BTL-1,2,3. Initial minor cracks appeared at 37.3 kN, 43.3kN, 41.3kN (BTL-1,2,3) and as the load reached the ultimate state, beam failed in flexure. The failure was characterized by typical flexure failure. The concrete crushed at loading point and crack propagation observed as similar to CBFs and also, noticed that CFRP peel out from the surface of beam when the load near to ultimate load. The cracking pattern of beam is show in Fig. 7. The deflection at ultimate load and crack at service load are tabulate in table-2, also plotted the load-deflection graph for the specimens and shown in Fig. 14

D. Full Length of Wrapping by CFRP

The beams were strengthened by CFRP for full length of beam. The wrapped beam is designated as UTL-1,2,3. Here there was no cracks were observed because of CFRP covered complete beam. Initially some knocking occurs at 83.3 kN,79.3kN,91.3kN at edge of the beam, it an indication of CFRP start to yield and de-bonding of CFRP occurs at 94 kN, 90kN, 98kN and finally failed at 111.3 kN, 103.3kN, 107.3kN in UTL-1,2,3 respectively. The failure pattern of beam is show in Fig. 8. The deflection at ultimate load and crack at service load are tabulate in Table II, also plotted the load-deflection graph for the specimens is as shown in Fig. 15

E. Total Length Wrapping by GFRP strip

These beams were strengthened as the flexural strip total length wrapping is designated as STLG-1, 2, 3. Initial minor cracks appeared at 35.3 kN , 33.3 kN, 29.3 kN and as the load reached the ultimate state at 79.3kN, 77.3kN and 73.3 kN. The cracking pattern of beam is show in Fig. 9. The deflection at ultimate load and crack at service load are tabulate in table-2, also plotted the load-deflection graph for the specimen and shown in Fig. 16.

F. Bottom Wrapping by GFRP

The beams were strengthened by GFRP were wrapped for total bottom length of beam and was designated as BTLG-1,2,3. Initial minor cracks appeared at 37.3 kN, 35.3kN, 33.3kN and as the load reached the ultimate state, beam failed in flexure. The failure was characterized by typical flexure failure. The cracking pattern of beam is show in Fig. 10. The deflection at ultimate load and crack at service load are tabulate in table-2, also plotted the load-deflection graph for the specimens and shown in Fig. 17

G. Full Length of Wrapping by GFRP

The beams were strengthened by GFRP for full length of beam. The wrapped beam is designated as UTLG-1,2,3. Here there was no cracks were observed because of GFRP covered complete beam. The ultimate load carried by the beams were 89.3 kN, 97.3kN, 93.3kN in UTLG-1,2,3 respectively. The failure pattern of beam is show in Fig. 11. The deflection at ultimate load and crack at service load are tabulate in Table II, also plotted the load-deflection graph for the specimens is as shown in Fig. 18

Fig.4 The cracking pattern of beam CBFs.

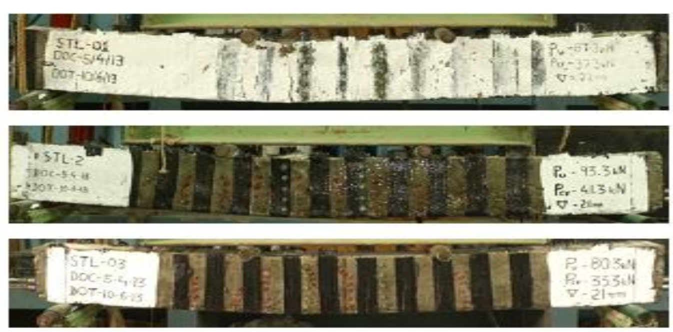

Fig.5 The cracking pattern of beam STLs

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Fig. 7 The cracking pattern of beam BTLs.

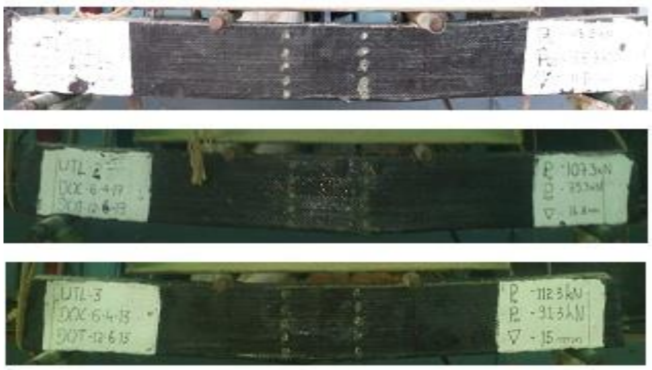

Fig. 8 The cracking pattern of beam UTL

Fig. 9 The cracking pattern of beam STLG

Fig. 10 The cracking pattern of beam BTLG

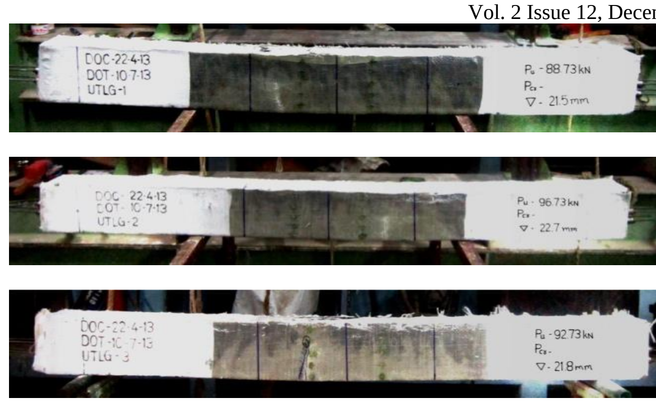

Fig. 11 The failure pattern of beam UTLG

LOADS-DEFLECTION CURVES: The load v/s central deflection curves are platted for all beams. Fig. 12-18, represent the load v/s deflection for all strengthen beams also they shows the comparison with CBFs for strengthen beams

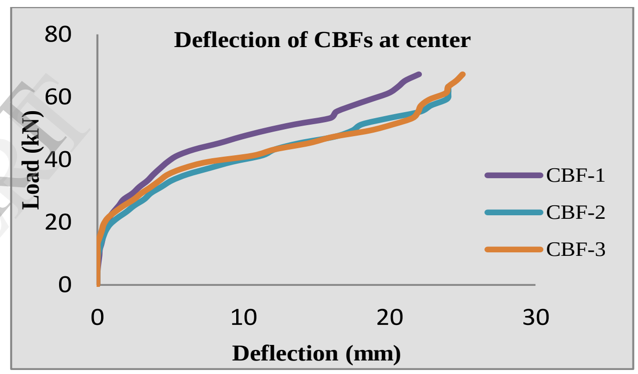

Fig.12 Central deflection of CBFs

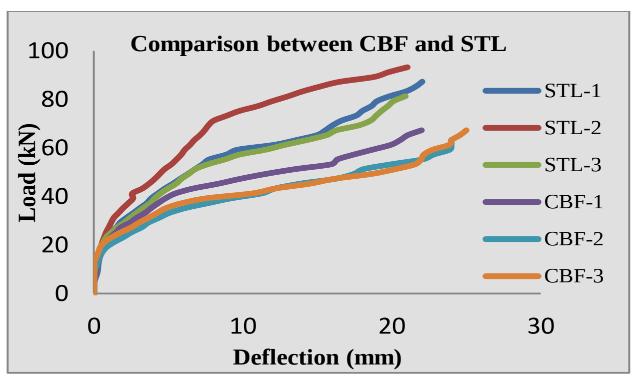

Fig.13 Central deflection of CBFs and STLs

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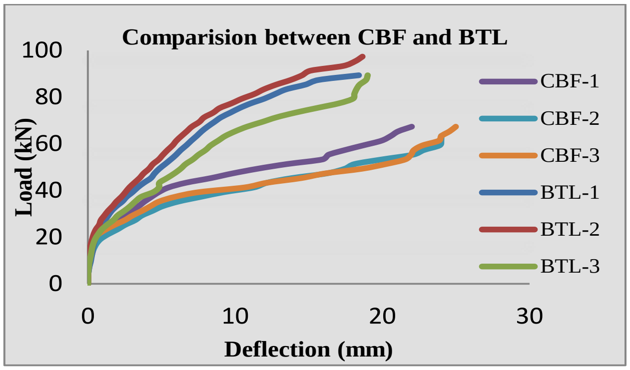

Fig.14 Central deflection of CBFs and BTLs

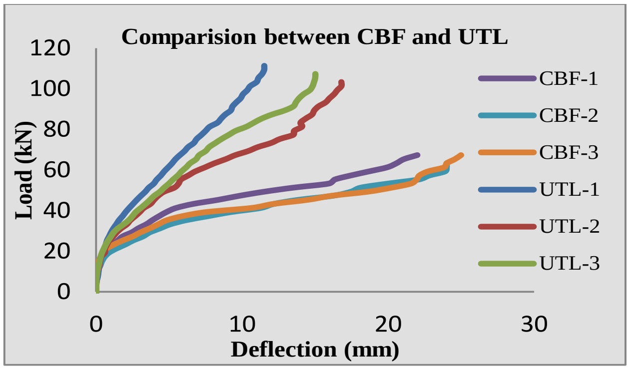

Fig. 15 Central deflection of CBFs and UTLs

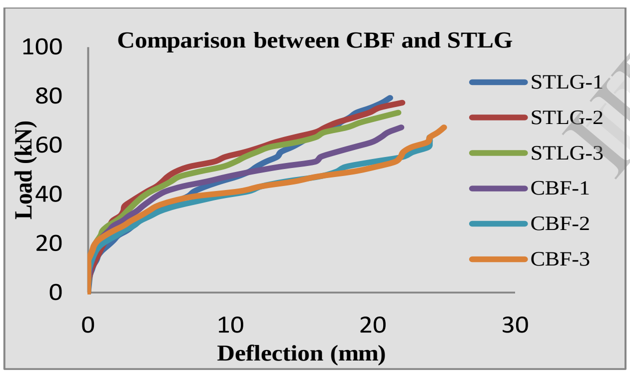

Fig. 16 Central deflection of CBFs and STLGs

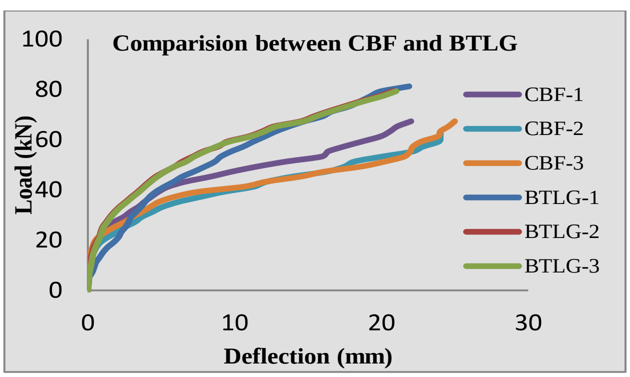

Fig. 17 Central deflection of CBFs and BTLGs

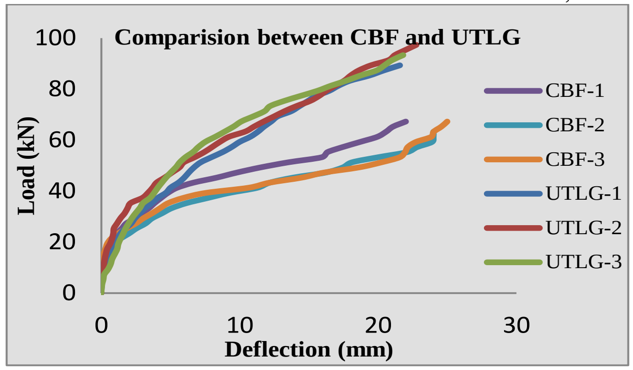

Fig. 18 Central deflection of CBFs and UTLGs

TABLE II: RESULTS OBTAINED FROM THE EXPERIMENTAL INVESTIGATION

Beam name	First crack Load (kN)	Ultimate Load (kN)	Deflection at first crack Load in (mm)	Deflection at failure Load in (mm)	Crack width at service load (mm)
CBF-1	29.3	67.3	2.43	22	0.6
CBF-2	27.3	65.3	3.207	24	1.2
CBF-3	31.3	67.3	3.68	25	0.9
STL-1	37.3	87.3	3.54	22.0	0.8
STL-2	41.3	93.3	2.38	21.0	0.7
STL-3	33.3	80.3	2.88	21.0	0.7
BTL-1	37.3	89.3	2.64	18.0	0.3
BTL-2	43.3	99.3	3.152	18.7	0.2
BTL-3	41.3	89.3	4.820	19.0	0.2
UTL-1	------	113.3	------	11.8	------
UTL-2	------	107.3	------	16.8	------
UTL-3	------	112.3	------	15.0	------
STLG-1	35.3	79.3	5.387	21.22	1
STLG-2	33.3	77.3	2.27	22.08	0.9
STLG-3	29.3	73.3	1.985	22.08	0.9
BTLG-1	37.3	81.3	4.197	21.879	0.5
BTLG-2	35.3	79.3	2.57	20.768	0.4
BTLG-3	33.3	79.3	2.24	21.004	0.5
UTLG-1	------	89.3	------	21.593	------
UTLG-2	------	97.3	------	22.776	------
UTLG-3	------	93.3	------	21.826	------

DEBONDING OF CFRP:As the loading approached ultimate load, there was a debonding of CFRP from concrete surface. And then failure of beam occurred. This kind of failure occurs in both UTL and BTL wrapped beams. But there was no debonding of GFRP in any type of wrapping technique.

Fig.19 De-bonding of CFRP from beam.

IV. CONCLUSIONS

This experimental study investigated the different possible type of CFRP and GFRP wrapping effect on ultimate load carrying capacity, deflection, crack width and stiffness of strengthen beams compared with control beams.

- All the Post-Tensioned beams strengthened with FRP in single layer were capable to take more load than the beams without strengthening (control beams).
- The Post-Tensioned beams strengthened for full length by U- wrapping using CFRP were found to be more effective and the load carrying capacity was increased about 66.9 % as compared to control specimens. And increased about 14.4% as compared to beams strengthened by U- wrapping using GFRP
- The strengthened beams UTL and BTL failed due to debonding of CFRP, that means bond failure occurred as loading approaches the ultimate load. But in STL and UFZ beams failed in unwrapped zone. 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.
- The reduction of ductility was observed in strengthened beams at ultimate load. From this we can conclude that, the increase of strength was attained with a brittle failure mode resulting in a ductility loss.
- There was increase in both stiffness and flexural moment capacity of CFRP and GFRP strengthened beams.
- Up to 18 kN load all the beams (control and strengthened) obey the same path of deflection. From this we may conclude that strengthening material takes the load after 18 kN.

  The experimental outcomes qualify the application of FRP technique, as an effective tool to restore the flexural capacity of beams.

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