STRENGTHENING OF RC CONTINUOUS PRESTRESSED BEAM USING CFRP

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Abstract

Continuous posttensioned concrete beams might require strengthening to cope with higher demands. An analytical investigation was held on RC continuous prestressed beams strengthened by Carbon Fibre Reinforced Polymer (CFRP). The objective of this work was to study the flexural behavior, deflection and load carrying capacity of beams strengthened through different means like plates, sheets, strips and U wrap subjected to static loading. A numerical nonlinear analysis was carried out for analyzing the flexural behavior of FRP strengthened prestressed beams which consisted of 12 strengthened specimens and a control beam specimen. The results of the beam with respect to various techniques of strengthening was analyzed and discussed. The U wrap is very effective in increasing the ultimate load (51.3%) and reduced beam deflection (76.07%). Finite element software ANSYS 16.2 Workbench is used for modeling and analysis by conducting non linear static analysis.

Keywords*:* CFRP, Finite Element Modeling, Structural Properties, Prestrssed Beams, Continuous beams.

I. INTRODUCTION

In recent years, the conditions of aging infrastructure have drawn great attention to the maintenance and inspection of structures.

A continuous beam is a structural component that provides resistance to bending when a load or force is applied. These beams are commonly used in bridges. A beam of this type has more than two points of support along its length. These are usually in the same horizontal plane, and the spans between the supports are in one straight line.

Although durable, buildings constructed using reinforced and prestressed concrete have a finite service life. Many structural engineers are faced with the challenge of evaluating and implementing effective and economical repair and strengthening programs. The maintenance, rehabilitation and upgrading of structural members, are perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives.

Many buildings that originally were constructed for a specific use now are being renovated or upgraded for a different application that may require higher load-carrying capacity. As a result of these higher load demands, existing structures need to be reassessed and may require strengthening to meet heavier load requirements.

Fibre reinforced polymer (FRP) systems are high-strength, lightweight reinforcement in the form of paper thin fabric sheets, thin laminates, or bars that are bonded to concrete members with epoxy adhesive to increase their load carrying capacity. These systems have been used extensively in the aerospace, automotive, and sport-equipment industries, and now are becoming a mainstream technology for the structural upgrade of concrete structures. Important characteristics of FRPs for structural repair and strengthening applications include their non-corrosive properties, speed and ease of installation, lower cost, and aesthetic appeal.

Over the last two decades, numerous studies, both experimentally and theoretically, have been conducted on RC structures strengthened with fiber reinforced plastics (FRP), including beams, slabs, and columns[11], in the form of the externally bonded reinforcement (EBR) method. Recently, a broad research program was carried out for evaluating the behavior of unbonded PC members when strengthened using external FRP composites [1]. The focus of another research is on investigating the use of CFRP for flexural strengthening of continuous unbonded posttensioned HSC structural systems [6]. Lesser studies were conducted on the analytical behaviour of prestressed continuous RC beam.

Hence the focus of this research is on investigating the use of CFRP for flexural strengthening of RC continuous bonded posttensioned beams. The program consisted of conducting numerical nonlinear analysis for predicting the flexural behaviour of FRP-strengthened bonded prestressed continuous members. The specimens were modelled using ANSYS 16.2 to obtain the load-deflection curve. This study gives the detailed study on the different strengthening techniques to be used in a continuous prestressed beam in the negative and positive regions.

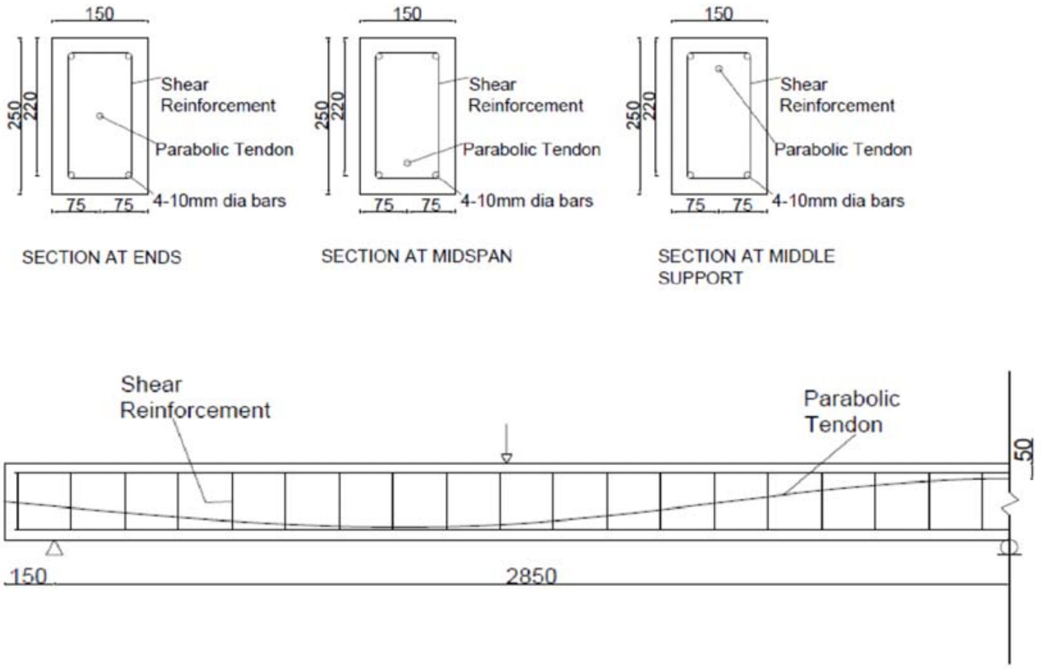

Fig. 1 Details of Specimen

II. OBJECTIVES

Strengthening of RC continuous prestressed members using CFRP will help in increasing the structural integrity of a structure and also its load capacity. The following are main objectives of the work.

1. To evaluate the behaviour of prestressed continuous RC beams when strengthened using CFRP composites
2. To identify the different ways to apply CFRP composites like plates, sheets, strips and U wrap.
3. To develop an analytical model of the prestressed continuous beam using ANSYS 16.2.
4. To conduct a parametric study
5. To compare the results obtained by various ways of strengthening

III. GEOMETRY OF THE BEAM

A total of thirteen models, including one control beam (CBP) and twelve strengthened beams were considered. Dimensions and reinforcement layout are given in Figure 1. The specimen used consisted of two spans, simply supported over a span of 2.85m. The beams had a cross-section of 150mm width by 250mm depth and a span to depth ratio (depth to the centre of tension steel) of 15. The CFRP used for strengthening was 2.2m in length and 2mm thick. The width was as same as that of the beam. The CFRP was bonded to the concrete by means of Epoxy adhesive.

In the model designation provided in Table I, the first three letters CBP and SBP stands for control beam parabolic tendon and strengthened beam parabolic tendon respectively. The next letter after the hyphen P stands for plate, S stands for sheet, St stands for strip and U stands for U wrap. The numbers 1 indicates strengthening in negative moment region, 2 indicates strengthening in positive moment region and 3 indicates strengthening in both negative and positive moment region.

TABLE I
DETAILS OF BEAM STRENGTHENING

Beam Label	**Total width (mm)**	**Thickness (mm)**	**Depth h (mm)**	**Length Lh (mm)**	**Length Ls (mm)**
CBP	-	-	-	-	-
SBP-P1	150	2	-	2200	-
SBP-P2	150	2	-	-	2200
SBP-P3	150	2	-	2200	2200
SBP-S1	150	2	-	2200	-
SBP-S2	150	2	-	-	2200
SBP-S3	150	2	-	2200	2200
SBP-St1	30	2	-	2200	-
SBP-St2	30	2	-	-	2200
SBP-St3	30	2	-	2200	2200
SBP-U1	150	2	100	2200	-
SBP-U2	150	2	100	-	2200
SBP-U3	150	2	100	2200	2200

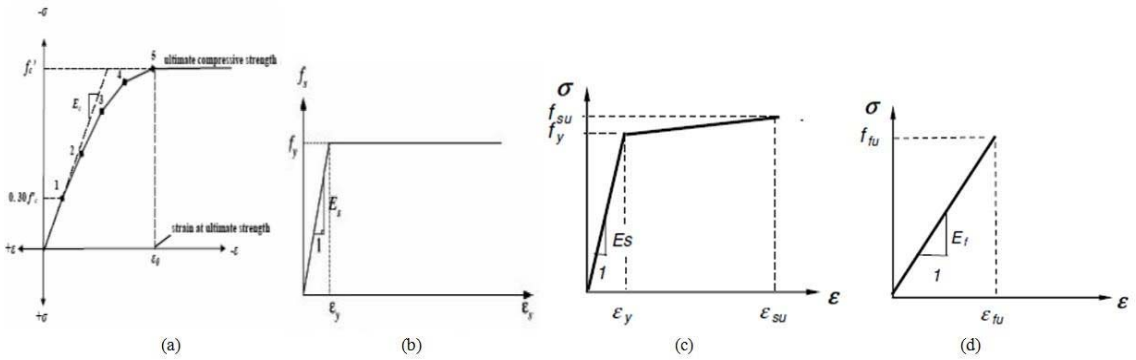

Fig. 2 Stress-Strain Behaviour of: (a) Concrete; (b) Reinforcing steel; (c) Prestressing steel; and (d) CFRP

The minimum bonded reinforcement required was provided in all specimens using 2-10mmΦ deformed steel bars at both top and bottom of the beam. The depth of the bars was 220mm for the continuous beams. The prestressing steel was Grade 270 seven-wire stress relieved strands having a diameter of 11.21mm.

IV. ANALYTICAL STUDY

A. Finite Element Analysis

Numerical nonlinear analysis was carried out for evaluating the flexural response of CFRP strengthened RC continuous beams. The beams were modeled using the finite element software *ANSYS 16.2*. The beam is considered as simply supported at both ends. The model is divided into number of small elements with a mesh size of 50mm.

B. *Element Types*

1) *Concrete:* The three dimensional 8- node brick element (SOLID65 reinforced concrete solids) was used as a model of concrete. The element has eight corner nodes and each node has three degrees of freedom translation in the X, Y, Z directions. The concrete is assumed to be homogeneous and initially isotropic.

2) *Reinforcement and Tendon:* A structural 3-D spar (or truss) element (LINK180) was used to model the reinforcements and tendon. The element has two nodes and each node has three degrees of freedom in the X, Y, Z directions. Steel reinforcement in RC beam is of grade Fe250. The steel for the finite element models has been assumed to be an elastic-perfectly plastic material and identical in tension and compression. For prestressing tendons, bilinear elasticplastic with hardening is the relationship of stress-strain, as shown in Figure 2.

3) *CFRP:* A four node structural shell element (SHELL181) was used to model the CFRP composites. The element has four nodes and each node has six degrees of freedom, translation in X, Y, Z directions and rotation in X, Y, Z directions. CFRP being a perfectly elastic material, the stress-strain behavior of the FRP laminates is composed of a linear elastic relationship until failure as shown in Figure 2.

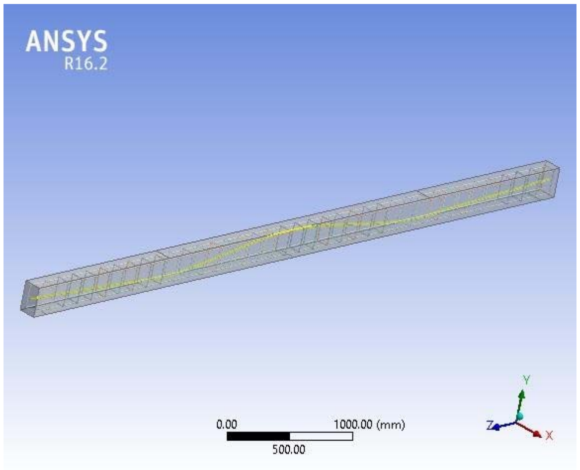

FIG. 3 Geometry of control beam – CBP

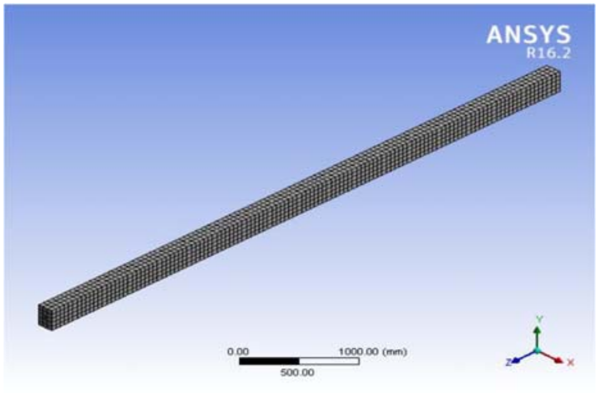

FIG. 4 Mesh in CBP

TABLE II

MATERIAL PROPERTY OF BEAM MODELS

Material	**Element type**	**Material properties**		
Concrete	SOLID65	**Linear Isotropic**		
		EX	20000MPa	
		PRXY	0.2	
		Mu ltilinear Isotropic		
		No	Strain (mm/mm)	Stress (MPa)
		1	0	0
		2	0.005	15.3125
		3	0.001	26.25
		4	0.0015	32.8125
		5	0.002	35
Reinforcement	LINK180	**L inear Isotropic**		
		EX	200000MPa	
		PRXY	0.2	
		Yield strength	250 N/mm ^{2}	
Tendon	LINK180	**L inear Isotropic**		
		EX	195130MPa	
		PRXY	0.2	
		Yield strength	1600 N/mm ^{2}	
CFRP	SHELL181	**Orth otropic properties**		
		EX	2.09E5MPa	
		EY	9450MPa	
		EZ	9450MPa	
		PRXY	0.27	
		PRYZ	0.4	
		PRXZ	0.27	
		GXY	5500MPa	
		GYZ	3900MPa	
		GXZ	5500MPa	

The material properties include elastic modulus and Poisson’s ratio as given in the Table II and the FE model is shown in Figure 3.

C. Loading

All models were analyzed under single-point loading using two symmetrical concentrated loads at the centre of each span. The loading provided was displacement controlled and the corresponding load capacity was found out. The own weight of the specimen was applied as a static uniformly distributed load. The effective prestress values varied between 47% and 54% of the ultimate strength of the strands.

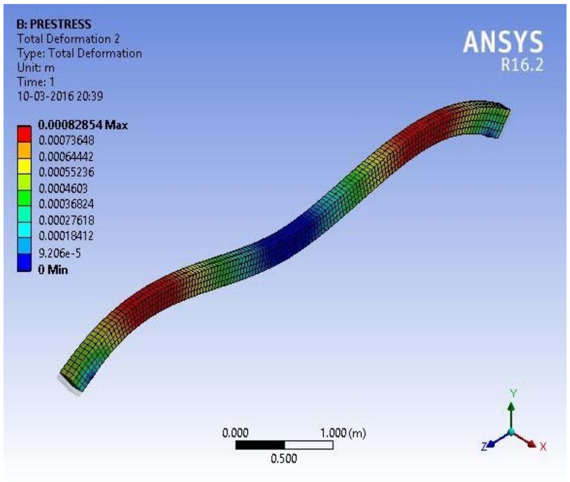

Fig. 5 Prestress in CBP

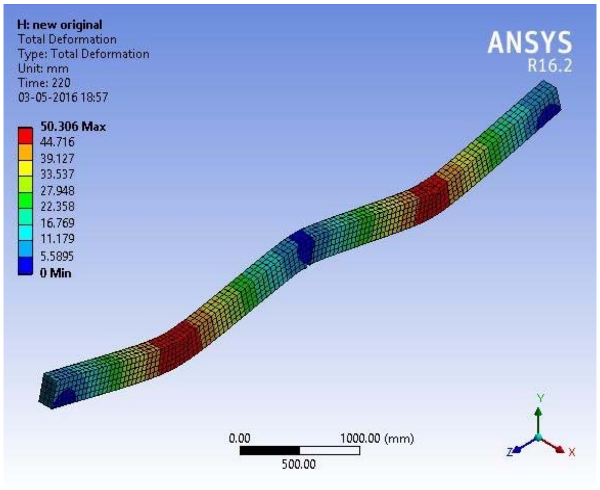

Fig. 6 Deflection of CBP

TABLE III
LOADING

Time (s)	Displacement (mm)
0	0
40	-5
80	-10
120	-15
160	-25
200	-30
210	-40
220	-50

TABLE IV ANALYTICAL RESULTS

Beam Label	Load (N)	Deformation (mm)	% Decrease	Deformation (mm)	Load (N)	% Increase
CBP	1.43e+05	50.306	0.00%	50.306	1.43E+05	0.00%
SBP-P1	1.43e+05	30.146	40.07%	50.358	1.53E+05	6.87%
SBP-P2	1.45e+05	19.06	62.11%	50.31	1.83E+05	27.49%
SBP-P3	1.42e+05	15.046	70.09%	50.346	1.89E+05	31.83%
SBP-S1	1.43e+05	26.12	48.08%	50.37	1.55E+05	7.90%
SBP-S2	1.44e+05	15.043	70.10%	50.33	1.93E+05	34.30%
SBP-S3	1.42e+05	12.037	76.07%	50.359	1.97E+05	37.27%

SBP-St1	1.43e+05	30.149	40.07%	50.361	1.53E+05	6.94%
SBP-St2	1.42e+05	17.051	66.11%	50.326	1.85E+05	29.07%
SBP-St3	1.44e+05	15.049	70.09%	50.358	1.91E+05	32.92%
SBP-U1	1.43e+05	22.085	56.10%	50.339	1.69E+05	18.14%
SBP-U2	1.40e+05	13.538	73.09%	50.316	2.11E+05	47.54%
SBP-U3	1.45e+05	12.04	76.07%	50.334	2.17E+05	51.13%

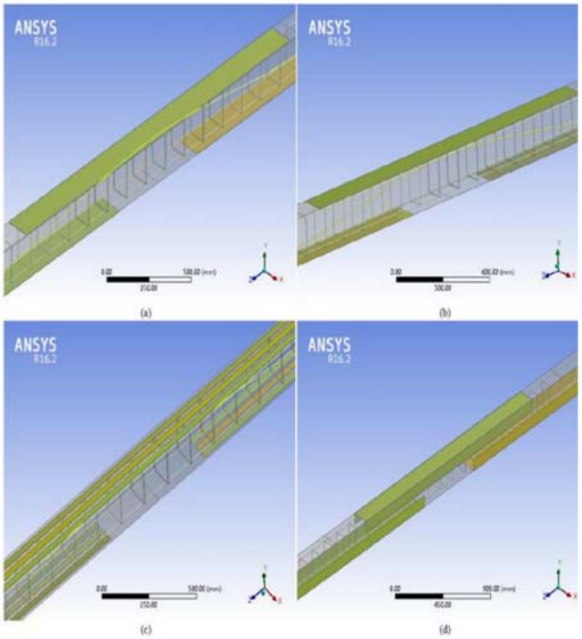

Fig. 7 Strengthening methods: (a) Plates; (b) Sheets; (c) Strips; (d) Uwrap

V. ANALYSIS RESULTS

The load-deflection response and the load-strain response of the models were found out. The specimens were subjected analytically to incremental increase in displacements (displacement controlled mode) for simulating the load applied on the various specimens. The models were subjected to the loading mentioned above to the different types of strengthening. The values obtained by these models were compared against ways in which they were strengthened, that is, strengthening done in the negative moment regions, positive moment regions and both the positive and negative moment region. The positive moments in a continuous beams leads to sagging moment while the negative moments lead to hogging moment. As these sagging and hogging moment areas are strengthened the deflection and the load capacity of these specimens are found out.

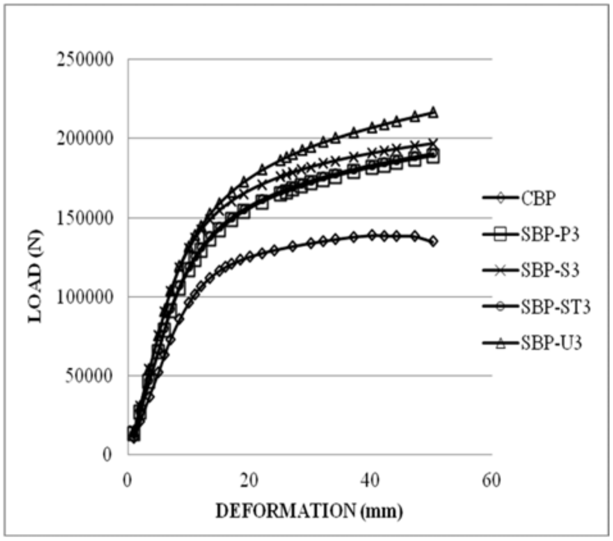

Fig. 8 Load vs Deformation Both Sagging and Hogging Moment Regions

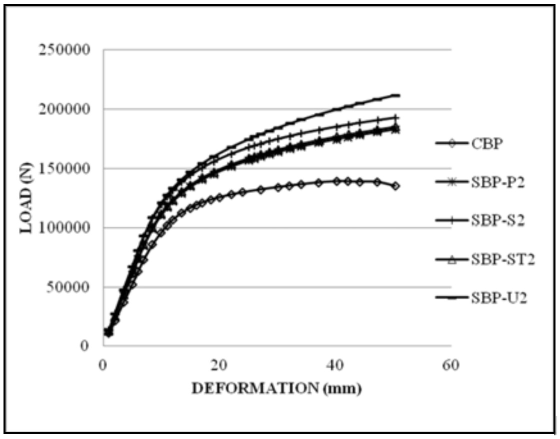

Fig. 9 Load vs Deformation Sagging moment region only

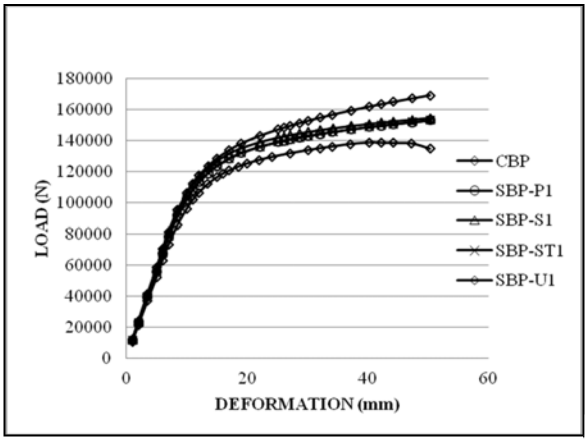

Fig. 10Load vs DeformationHogging moment region only

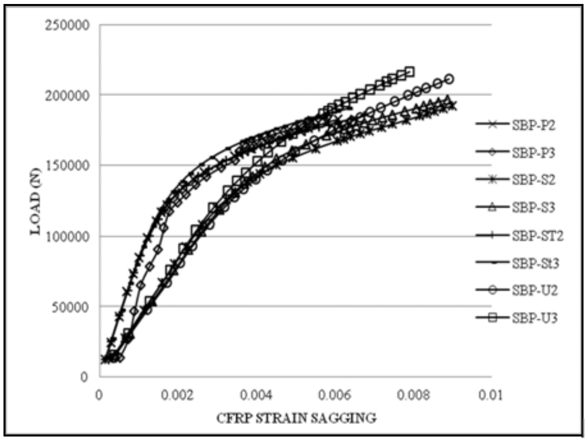

Fig. 11 Load vs CFRP Strain (sagging moment region)

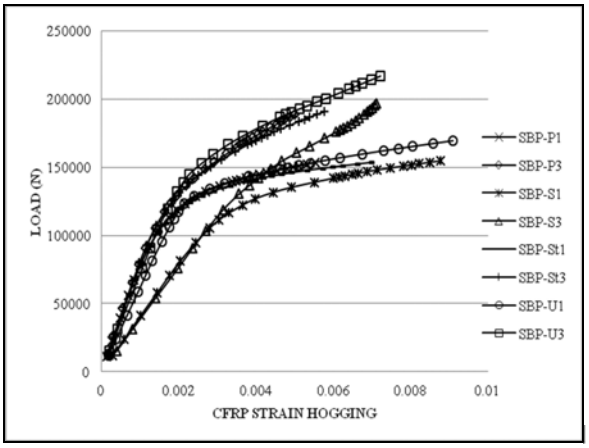

Fig. 12 Load vs Strain(hogging moment region)

A. Effect on Deformation due to Strengthening

The prestressed continuous beams were strengthened with CFRP by the following ways: plates; sheets; strips and Uwrap. The following deformation occured due to the load applied was studied. The load capacity of the control beam, that is CBP was found to be approximately 143kN. The deformation occuring due to this load was 50.306mm.The deformation occuring to the sthrengthened beams due to this corresponding load was studied and compared with the CBP. The lowest deformations were found in the beams SBP-S3(12.037mm) and SBP-U3(12.04mm). This decrease in deformation is due to the way of application of the CFRP. The sheets and Uwrap has more bonding property than as compared to the plates.

B. Effect on Load Capacity due to Strengthening

The load capacity of the beams were studied. The ultimate

load capacity of the control beam CBP was found to be 140kN having a deformation of 50.306mm. The load capacity of the beams to have a defomation of 50mm was found out. It was studied that the beams strengthened by wrapping showed much increase in load capacity than by any other means. The load capacity was strengthened upto 51% (SBP-U3) having a load of 217kN. The corresponding increase in load capacity was also found in beams strengthened in the sagging and hogging moment region respectively. The graphs plotted shows a clear increase in the load capacity of the beam.

C. Effect on FRP Strain due to Strengthening

The CFRP strain in the sagging and hogging moment regions were found out from *ANSYS16.2*. The graphs for these strain to the loads were plotted and the FRP strain was compared. The plates showed lesser strain while Uwrap and sheets showed higher straining.

VI. SUMMARY OF RESULTS

The summary of analysis of result summarized as show in Figure 13 and Figure 14. The increase in load capacity and the decrease in deflection are represented by a bar chart.

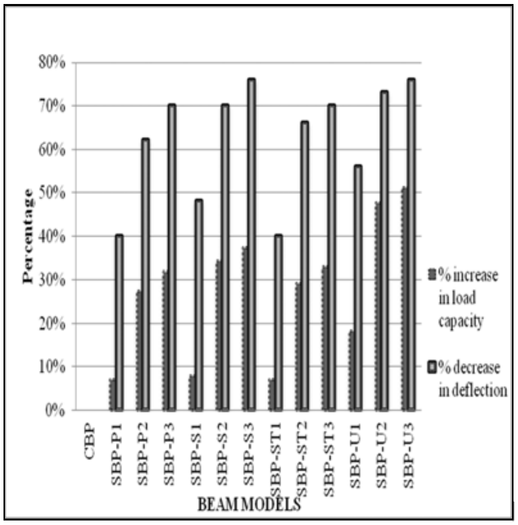

Fig. 13 Percentage Difference in Load Capacity and Deflection

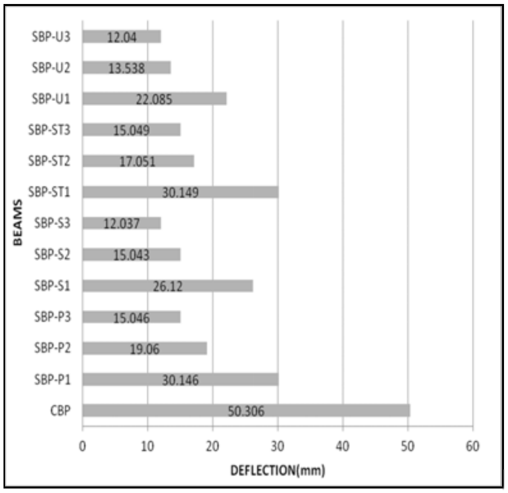

Fig. 14 Variation in Deflection

VII. CONCLUSION

This paper presents the methods in which the reinforced concrete continuous beams are strengthened and the effective way in which the strengthening can be carried out. In the analysis 13 beams, that is twelve strengthened including one control beam was modelled where a numerical nonlinear flexural analysis was carried out for predicting the flexural response of the beams.

- The study on prestressed continuous beams was carried out and the modeling of these beams was done in *ANSYS 16.2 Workbench*.
- The externally strengthened reinforced concrete continuous prestressed beams with bonded CFRP showed significant increases in their load capacity. An increase in ultimate load reached up to (51% for Uwrap).
- The reinforced concrete continuous prestressed beams strengthened with CFRP sheets and Uwraps showed a lower deflection at corresponding loads than those of unstrengthened beam about (40% - 76%) due to the presence of CFRP sheets.
- From the analysis carried out it was found that the sheets and Uwrap found to be the most effective way in strengthening having higher load capacity and lesser deformation

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