# Advanced Active Prestressed CFRP In RCC Structures

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Abstract. The need for rehabilitation of reinforced concrete structures is rapidly increasing. Fibre reinforced polymer (FRP) composite materials for concrete structures have high strength-to-weight ratios that can provide high prestressing forces while adding minimal additional weight to a structure. They also have good fatigue properties and exhibit low relaxation losses, both of which can increase the service lives and the load carrying capacities of reinforced concrete structures. Carbon fiber reinforced polymer (CFRP) composite system is integrated system based on carbon fibres and epoxy resins. By prestressing the CFRP laminates, the material is used more efficiently as a part of its tensile capacity is utilised and it contributes to the load bearing capacity under both service and ultimate load condition. This is an ideal technique as it combines the advantage of using noncorrosive and lightweight advanced composite material in the form of FRP laminates with high efficiency offered by external prestressing. An innovative mechanical anchorage system was developed to prestress the FRP laminates directly by jacking and reacting against the RCC structure. This paper describes the use of Prestressed CFRP laminates for strengthening of RCC structures including practical applications on slabs and bridges. Also it elucidates the post strengthening testing carried out for the validation of this technique.

## Introduction

Carbon fiber reinforced polymer (CFRP) composites are being widely used for enhancing the load carrying capacity of R.C.C structural members. These composites consist of high strength fibres bonded in a resin matrix with the fibres acting as the main load carrying elements whereas the resin or polymer matrix acts as load transfer medium and protects the fiber from environmental damage. The increasing applications of these materials are owing to the advantages it offers with respect to

the other conventional methods of strengthening. They are effective for strengthening materials as they are light weight, non corrosive, have high tensile strength, high fatigue resistance, low density, high stiffness and durability. Also, these materials can be made into any size and geometry and require less efforts in installing in comparison with other conventional materials of strengthening. The structures can be strengthened using these materials in relatively less amount of time without causing any hindrance to the normal functionality or affecting the aesthetic point of view.
This method of strengthening has been extensively studied and various codes and guidelines have been published for the ease of application of this method in actual structures [1,2]. CFRP can be used for strengthening of concrete, masonry, timber and steel structures. Extensive research has been carried out on their successful use in strengthening of RCC slabs and beams to increase their flexural and shear capacity [3] and increase of confinement in axially loaded columns [4]. Also, it has been found that application in masonry structures have reduced cracking and produced increase in the load carrying capacity and ductility [5].

## Conventional Non Prestressed CFRP system and Prestressed CFRP system

Non prestressed CFRP sheets and laminates are externally bonded on the structural members with the help of epoxy resin to enhance their load carrying capacity. Strengthening using non prestressed CFRP sheets and laminates is one of the easiest in application as it requires least equipments and can be done in a short period of time. It offers the advantages of being light weight, having high strength to weight ratio, non corrosive and non magnetic in nature. Innovations in the field of application of FRP namely by using prestressed laminates are gaining importance in recent times. The benefits obtained by the use of non prestressed FRP composites are relatively less in comparison with prestressed system where the properties are better utilized. Several researchers have carried out studies on various methods of prestressing FRP and have found that bonding of FRP laminates and prestressing increases the load carrying capacity of the member in service and dead load condition [7]. It has also been found that using prestressed FRP laminates on the tensile face of the flexural member improves the serviceability to a greater extent. Proper end anchorages after prestressing operation of laminates on beams helps in eliminating debonding failure mode and can increase the service life of the structure [8]. **Fig.1** below shows the typical load-deflection curves for RCC beams strengthened with non prestressed and prestressed FRP composite laminate system.

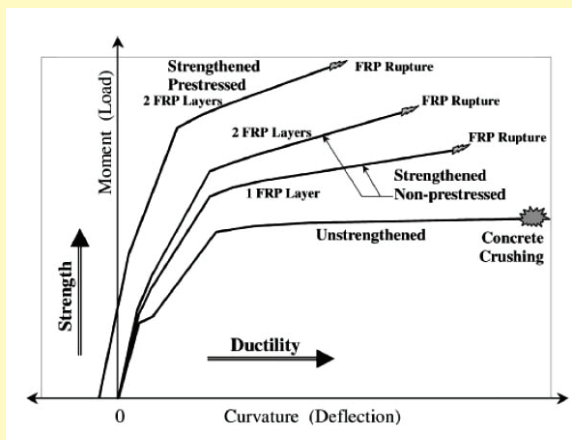


***Fig.1** Typical load-deflection curves [7]*

*Fig.2* ***Application of Non prestressed FRP laminates in slabs***
*(Courtesy:- M/s R & M International Pvt Ltd)*

Various different techniques have been developed to induce prestress in the CFRP composites for flexural and shear strengthening of flexural members and for increase of confinement and axial load carrying capacity of compression members. This prestress can be induced either on the surface of the strengthened structure or outside of the structure. Also, the amount of prestress to be applied is carefully selected as it affects the strengthening behaviour. In case the prestress force applied is very high it can lead to failure of the beam. Hence, it is required to apply proper amount of force at the ends of the laminates. Prestressing forces upto 50% of the ultimate strength of the laminates should not be exceeded [2]. Minimum level of prestress 25% of the ultimate strength may be necessary to improve the strength properties [7]. Also, proper end anchorages should be provided to transfer the stresses. Anchors are placed at the ends of FRP laminates to avoid failure due to debonding of laminates. It can also be used to prevent or delay crack opening at the onset of failure of the concrete substrate. Mechanical anchors in the form of metallic plate can be used to provide sufficient anchorage to the laminates. Gradient anchors can also be used for the same.
Prestressing of CFRP laminates can be done indirectly by cambered beam system or by inducing prestress against external steel frame followed by bonding on the structural member to be strengthened [7]. But tensioning of CFRP laminates against the beam to be strengthened is one of the most widely used methods of prestressing. In this method, the FRP laminates are bonded on the member to be strengthened followed by application of prestress in the beams with the help of prestressing jacks at the ends of laminates. It is kept in the stretched position till the curing of the adhesive is complete. After this the hydraulic jacks are removed and the laminate transfers the stresses to the concrete. Proper anchorages need to be placed at the ends to avoid debonding failures. This method of strengthening is highly effective and can be applied both on field as well as laboratory. It is seen that in comparison with this direct method the indirect method finds less use in field applications as it is cumbersome and the prestress induced is comparatively less [7].

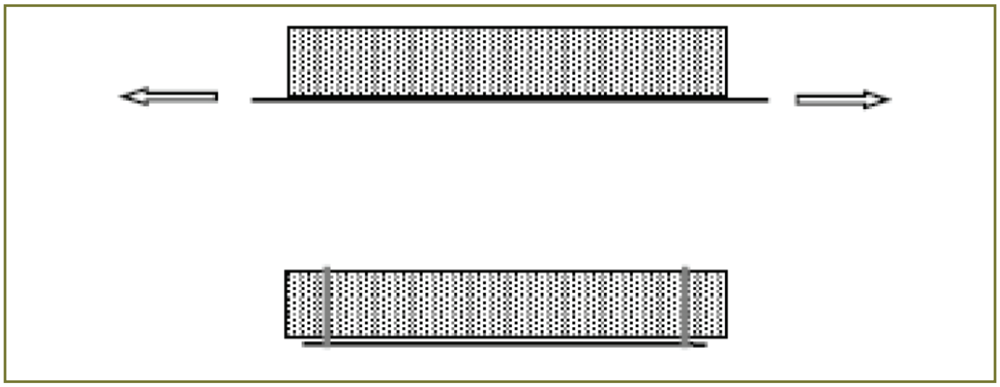

*Fig.3* ***Strengthening with prestressed FRP laminates [2]***

*Fig.4* ***Pressure gauge applied for checking of prestress level applied***
*(Courtesy:- M/s R & M International Pvt Ltd)*

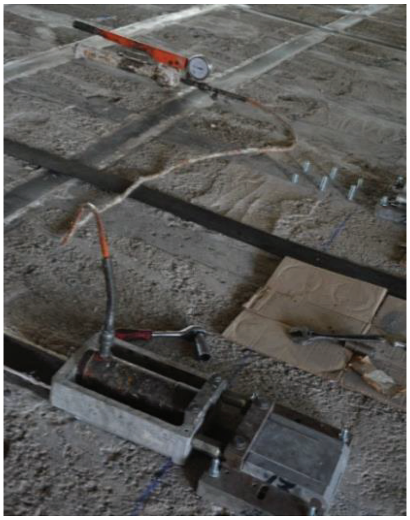

*Fig.5* ***Prestressing operation in slab***
*(Courtesy:- M/s R & M International Pvt Ltd)*

## RCC Building structures strengthened using Prestressed FRP system

An RCC commercial building structure having G+11 storeys situated in Thane district of Maharashtra state, India required strengthening of slab panels due to excessive deflections and cracking. The construction of the building was carried out in two stages with the G + 8 storeys being constructed in the first phase followed by addition of two more storeys after a gap of two years. The top two floor levels showed signs of cracking and excessive deflection in the flat slab panels. The deflection in the slab panels ranged from 20 mm to 100 mm with crack pattern running along the column drop region and progressing further in the column strip.

***Fig. 6* Excessive deflections observed in midspan of flat slab panel**
*(Courtesy:- M/s R & M International Pvt Ltd)*

Few of the slab showed severe distress and had acquired saucer shape. Core tests were carried out on the slab panels which proved that the grade of concrete was as required by design. It was observed on inspection that at column drop interface region the negative moment reinforcement was terminated abruptly and cracks were observed in this region. Also at the negative moment regions of middle strip regions there was no reinforcement provided. After carrying out analysis of the RCC structure it was decided to provide Prestressed CFRP laminates in alternate manner at the negative moment regions at the tension face with a prestressing force of 5 Ton applied. The properties of the materials used in strengthening are as per Table 1 below.

## Table 1: Material properties of FRP composite system used

| Type of laminates | Thickness of laminate (mm) | Width of Laminate (mm) | Ultimate Tensile strength (MPa) | Ultimate strain (%) |
|---|---|---|---|---|
| Alternate Prestressed CFRP laminates | 1.4 | 100 | 3200 | 1.5 |

*Fig.7* ***Application of Prestressed FRP laminates in slabs***
*(Courtesy:- M/s R & M International Pvt Ltd)*

After carrying out the strengthening of the slab it was subjected to load testing using water load. The slab was subjected to loading as per specifications given in IS 456: 2000. The loading was applied in stages so as to avoid any untoward mishap due to distress in structure. After full loading was applied the readings of deflections and strain were measured and after keeping the load on the slab for 48 hours the readings were further monitored. To check the rebound of the slab the dewatering was done in stages and readings was recorded at consecutive intervals of time.

*Fig. 8* ***Load testing on strengthened slab panel***
*(Courtesy:- M/s R & M International Pvt Ltd)*

The recovery observed in strengthened flat slab panel even after 48 hours loading post strengthening is 80.97% thereby indicating that the proposed method of strengthening has worked effectively.

## Bridge structures strengthened using Prestressed FRP system

The Rail Over Bridge at Karal junction in Navi Mumbai was structurally designed for Indian Road Congress (IRC) 45R loading. As per the revised recommendations of IRC and Codal provisions the bridge is required to sustain much higher load i.e. of IRC Class 70 R in the current scenario. Also, the structure showed signs of distress and excessive deflections and vibrations respectively required immediate strengthening. To provide the additional flexural strength to the girder and slab prestressed CFRP laminates was placed at the bottom of girder. The prestress load given for strengthening was 8 ton. For enhancing the shear strength of the girders carbon fiber composite wrapping was provided. Also the structure was repaired at the various locations showing deterioration.

***Fig. 9* Rail Over Bridge (ROB) at Karal junction of JNPT [9]**
*(Courtesy:- M/s R & M International Pvt Ltd)*

***Fig. 10* Prestressing of CFRP laminates at bottom of girder [9]**
*(Courtesy:- M/s R & M International Pvt Ltd)*

***Fig. 11* Prestressed laminates with anchor plates at the ends [9]**
*(Courtesy:- M/s R & M International Pvt Ltd)*

Instrumentation system was installed on the bridge structure before and after strengthening and its behaviour was observed under both static and dynamic load tests. Out of total 30 spans strengthened and retrofitted 14 spans of the bridge were subjected to monitoring before and after strengthening.

**The following measurements were made on the selected spans before and after strengthening:**

1. Measurement of deflection using linear potentiometer at the locations of maximum deflection in the girder which is an indicator of strengthening effect.
2. Measurement of flexural strain with the help of Omega type displacement transducer for maximum strain readings at the location of centre of girder.
3. Measurement of shear strain and crack width with the help of Omega type displacement transducer for maximum strain readings near the support of girder.
4. Measurement of vibration using piezoelectric accelerometers at the centre spans of the girder.

The parameters monitored and analysed were strain, deflection and vibration on the structure. It was observed that there was an average reduction in deflection of 26 %, flexural strain of 53% and shear strain reduction of 56.8% is observed [9]. Also, there has been a significant reduction in vibration observed.

## Economics

Strengthening using FRP products is the most economical solution in many cases. This is owing to the ease of application of these materials requiring reduced labour costs. Also, it doesn't require specialized construction equipments in comparison with other conventional methods and materials. In case of prestressed CFRP laminates due to higher load carrying capacity the quantity of FRP material required for strengthening is less in comparison with that of non prestressed thus resulting in reduced costs. It may initially appear that use of non prestressed CFRP would be the most economic option in comparison with prestressed one but due to saving in FRP laminates and resin thus reducing the labour costs and hence proving to be the most economical solution.

## Future of Prestressed FRP

This paper details on the effective use of prestressed CFRP laminates for strengthening of flexural members. It offers the advantages of utilizing the benefits of light weight non prestressed CFRP system with the high efficiency offered by external prestressing. This method of prestressing the FRP can be used even for strengthening of columns. But it is not commonly used due to lack of experimental studies on the same. This is an area of further research which can be further worked on.

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