# External Pre-Stressing Using Carbon Fiber Laminate With Case- Studies

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## Introduction

In today's growing economy, Infrastructure development is also raising its pace. Many reinforced concrete and masonry buildings are constructed annually around the globe. With this there are large number of them which deteriorate or become unsafe to use because of changes in use, changes in loading, change in design configuration, inferior building material used or natural calamities. Thus repairing and retrofitting these structures for safe usage of these structures has a great Market.

Depending on the desired properties, usage and level of damage involved members can be repaired and/or strengthened by several widely used methods. Some of widely used repair techniques are presented below.

Concrete jacketing can be applied to locally damaged or heavily damaged structures. When concrete is slightly damaged, the loose concrete is removed the surfaces are roughened and the dust is cleaned. Now depending on the amount of concrete removed, some additional ties or reinforcement can be added and jacketing is carried out i.e. new concrete is filled. Non shrinkage concrete or concrete with low shrinkage properties should be used. Special attention is paid to achieve a good bond between old and new concrete.

Jacketing should be also applied in cases of heavy damaged columns or in cases of insufficient column strength. This is actually a strengthening procedure but can be used for repair purposes. The additional concrete and reinforcement added contribute to strength increase.

Concrete jacketing has alot of limitations. The jacket should be of minimum thickness 100mm. The size of members are increased and the free available usable space becomes less also adding a huge dead mass and increasing the stiffness which reduces the efficiency of the structure. Its durability has also often found to be limited. Furthermore the whole process is slow and takes lot of time for completion.

Jackets may also be made of steel. Its a popular technique to use steel plates bonded with epoxy to external surfaces of beams and slabs. This technique is simple and effective as far as both cost and mechanical performance is concerened, But suffers major disadvantages. Corrosion of steel plates hurdles its use in structures in/near river, lake and sea. Furthermore difficulty in manipulating heavy steel plates in tight construction sites, need for scaffolding, and limitations in available plate lengths which results in need of joints. Sometimes steel's

high young's modulus causes it to take large portion of axial load  resulting in premature buckling.

The conventional jackets, sheets, plates may be replaced with FRP fabrics, sheet and laminates in view of above limitations. The following are major pro's and con's of using Composites

Advantages

1. Corrosion proof.
2. Easy in transportation, can be easily rolled.
3. Higher UTS and young's modulus
4. High fatigue resistance
5. Light weight. Hence, very high strength to weight ratio.
6. Joints can be easily avoided as they are available in desired length.

Disadvantages

1. Low ductility value and fickly plastic behaviour.
2. Susceptible to local unevenness.
3. High cost.

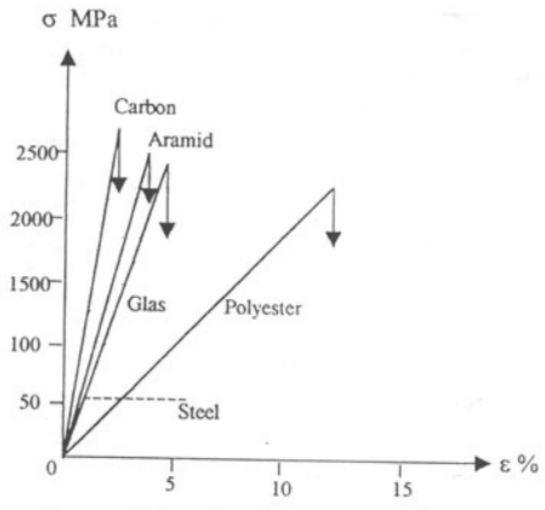


Fig 1. The comparative strength of different materials

FRC's can be used in the concrete structures in following forms.

1. Plates- at the face to improve the tension capacity.
2. Laminates- below beams and slabs to improve load taking capacity.
3. Bars- as reinforcements in beams and slabs replacing the steel bars
4. Cables- can be used as tendons and post- tension members in suspension and bridge girders.
5. Wraps- around concrete members i.e. columns, beams, slabs etc for confinement.

We know the pre- stressing of concrete is a very effective way of using the high compressive strength property to much greater extend. Moreover, permenant deformations in the structure can be recovered by this technique. This technique of prestressing concrete is possible only in new structures. External prestressing with other materials of the existing structures have always been difficult especially in view of the materials to be used, reinforcement corrosion, lateral instability, end anchorages and ofcourse space constraints.

The advantages of resistance to corrosion and high specific strength make these materials ideal for reinforcing existing structures with minimum intrusion. Popular method adopted is bonding them adhesively to concrete structures. However, we can seldom fully use the superior strength properties of these FRC's due to poor capacities of concrete and interfaces formed. Pre-stressing of these materials allow us to better utilization of its properties.

The execution of pre- stressing of CFC laminates consists of following steps

Pre- stressing system

1. Surface preparation is the basic treatment necessary before any application process. For this purpose surface is thoroughly grinded to make it clean and also it is important for strong bonding between concrete and laminate.

2. Marking for plate and machine area. Marking should be precise and free from even small approximations otherwise it can cause damage to laminate and machinery. Meanwhile, the grinded area is also applied with primer to further smoothen the surface.

3. The ends plates i.e Anchor plates, which are used to avoid the pre-stressed laminates to peel off from ends when kept in stressed position perpetually, are fastened to the concrete surface with the help of heavy- duty anchor bolts which are bolted in after drilling sufficiently deep into concrete and aligned properly.

4. Behind the anchor plate a clamping device on both sides is present with supporting L-Clamps is present which holds the laminate with the help of high tension bolts.

5. The laminate is cut according to the required length so that it can be clamped in the clamping devices at both ends.

6. The laminate is now fixed, with adhesive applied along its length, and the piston body is put into position after which the clamping device is pushed back to achieve the required design load.

7. After the final setting of adhesive the mobile anchorage(clamping device and L-clamps) is removed and excess laminate length is cut off.

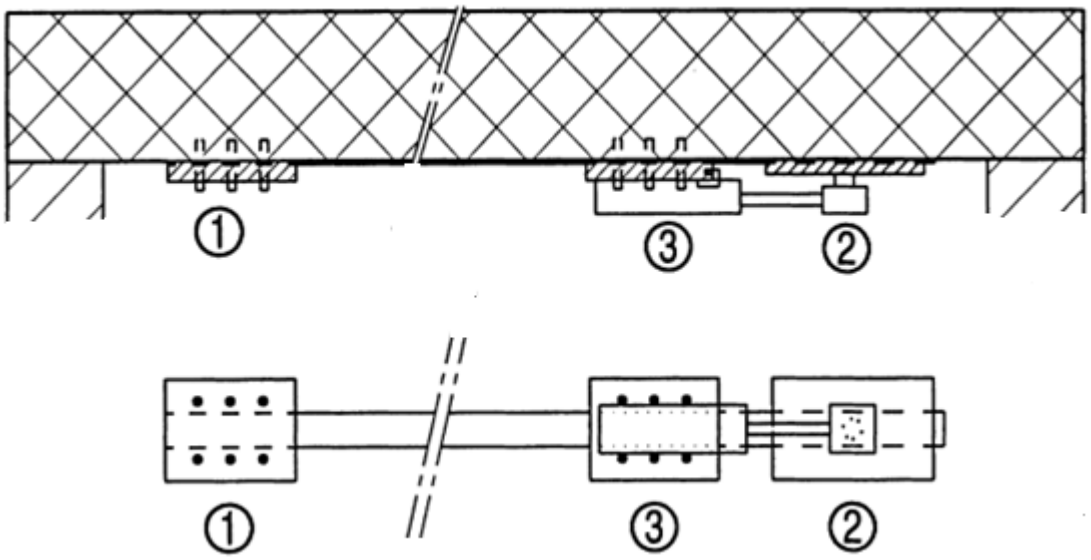


Fig-2 Pre-stressing System 1) fixed anchor 2) mobile anchor 3)pre-stressing system

Many times, to provide more strength against avoiding peeling, at the ends laminates are further secured by means of CFRC sheet. The fibre wraps are aligned 90 degrees to the lognitudnal axis of member.

The first repair work of a concrete bridge using these CFC laminates has been carried out at IBach Bridge, lucerene, Switzerland. The 228m long bridge was designed as a continuous beam of span 39m. Prestressing tendons prevented the bridge from operating at full capacity hence further improving the strength. The bridge was repaired with 2 x 150 mm CFRP laminates. The major observations noted were as follows.

- Due to its very low weight 175Kg of steel was just repaired with 6.2 kg of CFC.
- Hence the scaffolding was avoided and the whole project was carried out with hydraulic lift alone.
- Composites were postioned and held with help of vaccum bags, hence avoiding big closets for steel plates.
- Eventhough CFC laminate was 40 times more expensive than steel plates. It saved 20% cost due to ease in execution of project.

For effective bonding of concrete and the strengthening element ssadatmandesh and ehsani found that epoxies should have suffiecient stiffness and strength to transfer the shear force between the composite plate and concrete. It should also prevent brittle bond failure as a result of cracking of concrete. Thus, they recommended use of rubber toughened epoxies for this purpose.

Prestressing has many observed advantages as it increases the effective usage of composite properties.

- They are effective in closing the crack in damaged structures and therefore increasing the life of structure further.
- Also prestessing reduces the stress developed in the structural members reinforcing steel by giving a back force to structure. This is of great use when the Rebars are weakened due to corrosion.
- Another significant advantage of pre-stressing will be that it reduces the tendency of delamination at the crack front.

## Jawaharlal Nehru Port Trust (JNPT), Navi Mumbai.

JNPT decided to take up the rehabilation work of the Karal Railway Over Bridge (ROB). It got functional in 1991. There are 36 spansof varying lengths having 37 expansion joints in this bridge and the length is 700m. During the heavy rains in july, 2005 the wearing coat and expansion joints were severly damaged. These damaged coats and joints were subsequently repaired and re-laid. But the bridge was still not working satisfactorily. The vibrations of bridge during the vehicle movement were becoming more and more noticeable. The major observation during the site visit are as follows...

1. Expansion joints were not functioning properly. In the original design there was no provision of appropriate expansion joint.
2. Slab area of expansion joint was found to be damaged severly due to heavy vehicular movement. The gap between two spans has become significant and concrete had deteriorated.
3. The neoprene/elastomeric bearings provided in bridge were inadequate for heavy vehicle movements. They appear to be bulging out and damaged.
4. There was a visible sag in the superstructure in many spans. The typical structural failure cracks in the girders were observed.
5. The new expansion joints could not last long due to excessive vibrations and the poor quality of deck concrete at the end of span.

6. The substructure/piers appeared to be sound.


In view of above observations it seemed that the structural health of the bridge was not very good. The proposed strengthening measures by the consulting team are as follows.

1. Strengthening of girder by steel truss system-
   The girders and slabs are to be strengthened by placing additional steel truss systems which will support the bridge deck/slab/girders with M32 high strength bolts. This was designed to take about 50% of load carrying capacity of girders.

2. Replacement of bearings-
   The existing neoprene/elastomeric bearings should be replaced by new elastomeric bearings. Shore-a-hardness hardness of rubber material used should be 60.

3. Provision of new expansion joints-
   It was recommended to replace the expansion joints with Wabocrete Strip Seal Expansion Joint System. It is a superior joint system which can be rapidly installed in failed expansion joints and also is suitable for heavy vehicle bridges.

4. Pre-Stressing and Carbon fibre wrapping of girder and slab-
   To further increase the structural strength of the bridge, it was recommended to strengthen the bridge using the carbon fibre composite wrapping around the girder and slab. At the bottom of each girder 3 Pre-stressed Carbon Fibre Composites (CFC) laminates i.e. 2- 80/1.4mm and 1- 50/1.4mm was proposed to be placed. The load to be given to prestressed laminates should be 8-9 tons. The deck slab was also recommended to be strengthen by putting CFC laminates 80/1.4 at 50 mm c/c at the bottom. The properties of required laminates and wrap were specified.

Tests conducted before strengthening

For confirming the results of the strengthening process the initial testing of bridge was conducted which were NO LOAD, STATIC and DYNAMIC LOAD TEST. These were also conducted after the completion of strengthening work. The results showed that the vehicle carrying capabilities of bridge has increased.

Hence the girders were treated with pre-stress technology which gave a back uplift force to girders at a load of 8-9 tons using CFK laminates and high tensioned non corrosive end anchor plates.
After prestressing of laminates the girders were fully confined with C- Fiber UD-300 & G-Fiber BD-80 as per the specified design for better strength and the ends were locked with fiber anchors to avoid peeling and long lasting.

## BIAL strengthening of over pass Skew box.

The two flyovers, one from devanahalli and airport and the other from airport to Bangalore were constructed for connecting the newly constructed Bangalore International Airport to the highway in record time of 6 months.

After a few months the slab has developed a sag and on inspection hair cracks were observed. The cracks were inserted with glass pieces to check whether the cracks are live or stable.

After some days it was observed that many glass pieces had fallen down and many have become loose. Hence, it was inferred that the cracks were live and hence need to be immediately delt with.

The following was proposed as repair and strengthening measures.

For repairing the slab epoxy grouting with Teflon nozzles was proposed to close the cracks.

For strengthening of slab following two techniques were proposed

I. Full concrete jacketing of the slab by removing the existing loose concrete and encapsulating it with new layer of concrete and reinforcement.

II. Strengthening of slabs using CFK laminates with non- pre-stressing and pre-stressing technology according to the design discussed in a moment. The design

Finally it was decided to go with Pre-Stressing technology to rehabiliate the bridge.

The design consisted of both Pre-Stressing and non-Prestressing technology for the slab.