A REVIEW ON FLEXURAL STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH PRESTRESSED NEAR SURFACE MOUNTED CFRP LAMINATE

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Abstract

Reinforced structures are subjected to tremendous loading, which causes early deterioration, and replacing RC structures on before the end of intended life is prohibitively expensive. The application of fiber-reinforced polymer (FRP) composites to strengthen damaged structural components is obtaining favour in the construction industry because to their better strength, durability, and compatibility with reinforced concrete structures during usage. The main purpose of this research is to examine the existing performance, problems, and further potential of CFRP-strengthened reinforced concrete structural member under various loading circumstances. FRP reinforcement outperforms in static, dynamic, and harsh environmental criteria. The most typical type of failure in reinforced beams are debonding, separation of concrete cover, and FRP rupture. Acceptance and usage of FRP in RC structure strengthening will increase further as new techniques for utilising the full strength of FRP, reducing brittleness, fire risk and damages due to accident, lowering energy consumption and during production emission of carbon, and finally reducing the initial cost are developed. This report identifies knowledge gaps as well as promising research topics for FRP-strengthened structures.

Keywords: Flexural strengthening, NSM, CFRP strip, Prestressed, Failures.

1. Introduction

Pre-existing structural strengthening has arisen as a key construction activity in order to meet new design rules and strength requirements, as well as to address environmental deterioration over time. RC structures must withstand harsh environmental conditions such as high density of traffic, high explosions, and harsh corrosive environments. As a result, reinforcement is mainly necessary in reinforced concrete constructions in order to achieve good strength and extend their service life. Traditional methods for strengthening reinforced structural members include applying an exterior layer of a plate which is of made of metalic, textile-fibre, wire mesh, post tension (PT), parental material jacketing, and injecting epoxy.

FRP reinforcement has been used for strengthening of flexural region has a externally bonded (EB) without any grooving system in the form of FRP laminate/strip pasted to the soffit (bottom part) tension part of the reinforced concrete member or as a near-surface mounted (NSM) type with the grooves in which FRP laminates enclosed inside a pre-cut groove into the concrete cover at the soffit part of the member covered with epoxy. The force transfer from the member to laminate are done through the use of an epoxy adhesive that bonds the FRP to the concrete substrate. Despite several studies and field applications, strengthening using EB-FRP has some limitations, including surface preparation, debonding of laminate, and exposure to the external harsh environmental condition.

During first field application for NSM technique Steel reinforcement were used but steel is less resistive to the corrosion due to external environment. So in order to over come the corrosion steel have been replaced by the corrosive resistive FRP material for usage in NSM technique. So in order to over the disadvantages of the EB technique, NSM technique is using popularly now days.

Some of the benefits of NSM over EB are:

- Feasibility of anchorage into members without any anchorages.
- Excellent for achieving good strength in the negative moment regions, where EB would be subordinated to mechanical and environmental damage.
- Less possibility likely to deboned from beam near ultimate capacity region.
- Limited face medication work.
- Protection of the FRP laminates in the grooves from external damage.
- Lower content of the concrete cover, which reduces the erected- in humidity, hence, avoids freeze – thaw problems.

Fig. 1. Schematic representation of flexural strengthening systems of beams: (a) EB FRP laminate; (b) NSM FRP strips; and (c) NSM FRP bars.

Factors that has to be taken into account during strengthening of RC structures by the NSM technique such as

- FRP reinforcement type: Using a FRP material of high tensile strength and high modulus of elasticity, such as carbon FRP, allows for lower FRP consumption and lower groove cross-sectional areas and as a result, less risk of interfering with internal reinforcement. FRP reinforcement of various shapes has been employed.
- Groove filler: groove filler can be of cement mortar or epoxy adhesive. Which should some mechanical properties of higher tensile and shear properties.
- Dimension of Groove: Relevant construction characteristics that influence bond performance include groove size, distance between two consecutive grooves, and distance to grooves and the beam edge. The concrete cover's depth limits the height of the groove.

In case of strengthening of member without any prestressing only a smaller percentage of strength of FRP is utilized for strengthening, so no tensile strength of FRP is utilized. So in order to make use of tensile strength of FRP prestressing is done in which stresses are induced to member, helps in improving the serviceability.

Therefore, the prestressed NSM FRP strengthening method is receiving attention from many researchers all over the world.

2. Carbon Fibre Reinforced Polymer (CFRP)

Carbon fibres are filaments formed of carbon atoms with diameters ranging from 5 to 10 microns. The most prevalent type of FRP composite is carbon FRP, which is made up of carbon fibres bonded together with a polymer matrix. Carbon fibres provide the required stiffness and strength in CFRP, while the polymer matrix (epoxy) acts as a cohesive to protect and tie the fibres together. CFRPs are the most efficient strengthening material in terms of both economy and strength for enhancing the strength of undamaged RC members or retrofitting damaged RC members because they are less in weight, have a high strength-to-weight ratio, and are stiff. The use of CFRP as a strengthening material significantly improves structural serviceability, lowering the requirement for structure maintenance.

Currently, CFRPs are commonly utilized for strengthening, repairing and maintaining RC structures due to its outstanding properties like:

- Easy to handle during the application.
- Very high tensile strength and higher modulus of elasticity.
- Highly corrosion resistant.
- Low thermal conductivity.
- High resistance to chemical attack.
- More advantageous in providing the end anchorages as the thickness is less than 1.5mm.
- Easy for supplying to site as it is packed in rolls.
- Low density and extremely lightweight hence does not require any heavy equipment's or supporting structures.
- CFRP requires least curing period, thereby strengthening application takes shorter duration.
- Installation is easy and reduces the maintenance cost.
- Faster manufacturing, reduced life cycle costs, and minimum waste production during the manufacturing process.

3. Prestressing setup and procedure:

The setup mainly consists of even floor bed, fixed pedestal, Hydralic jack and end anchorages. Fixed pedestal is fixed to the floor it should be stiff against the bending due the application the prestressing load. The beam is kept inverted in position as the laminate to be fixed to the soffit of the beam. Before that a precut groove should be made. And the end anchorage is fixed to the laminate on both the sides, care should be taken to not slip the laminate. Then the adhesive is inserted to the groves and some part on the laminate. Then insert the laminate inside the groove and the prestressing force is applied by means of Hydralic jack. This mechanism should be finished as before the setting properties of the adhesives which are provided by the company. Then the after 6-7 hrs of time in which the strength is achieved the prestressing force is released by cutting the laminates fron the anchorages. Care should be taken force

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shouldn't be released all of a sudden, by slowly force should be released. Then 7 days of curing is done for strengthened beams.

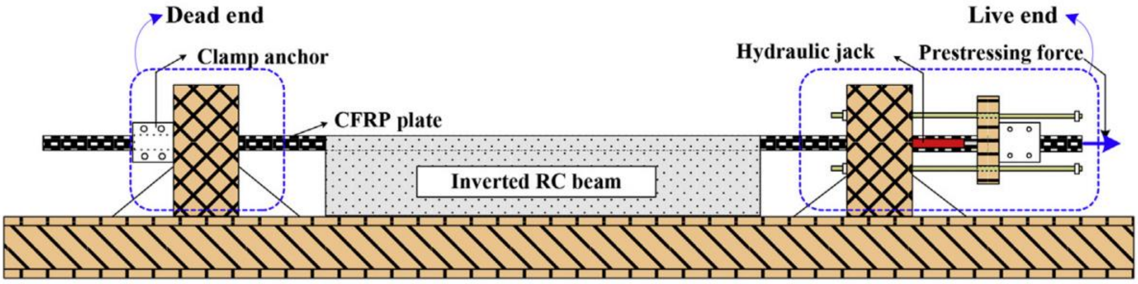

Fig. 2. Prestressing setup Bed

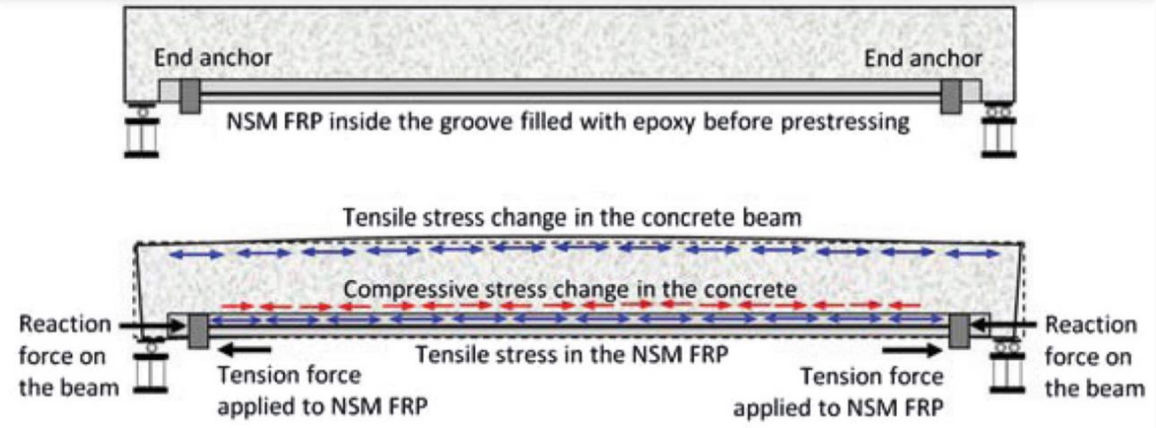

Fig. 3. Application and prestressed NSM FRP reinforcement

4. Research significance:

Figure 4 shows typically load vs deflection curves for the control beam (unstrengthen beams), Strengthen beams (strengthened with Prestressed and non-prestressed). For strengthen beams it is assumed that they don't failed in the deboning in the interface of strip and concrete and the point c indicated the ultimate response of yielding, cracks and the failures.

In the strengthened beams when we apply the prestress it will behave as the pretensioned beam. The different range of prestressing force governs behavior of the beam. It shows an increase in the prestress force there is increase in the load-carrying capacity but there is decrease in the ductility of the beam and lower in the deflection at the mid-span than the control beam.

Furthermore, there is decrease in the premature mature debonding failure in prestressed beam when compared to the non prestressed beam.

As the disadvantage of lack of ductility the structures may collapse suddenly without any warning in the prestressed beam. Here the serviceability of prestressed member is impacted due to the flexural rigidity.

In the CFRP prestressed strengthen beams after steel yielding CFRP laminate utilized its tensile strength. But in beam strengthen with non prestressed there is no proper utilization of tensile strength of CFRP laminate have been used after the steel yielding.

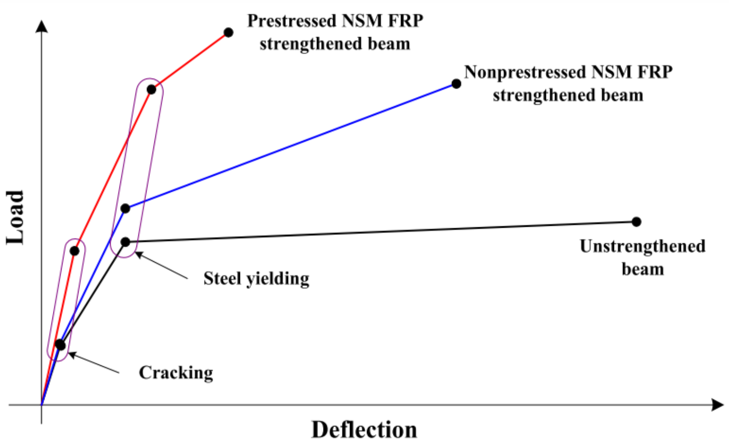

Fig. 4. Beams strengthened by prestressing NSM FRP reinforcements

5. Results and discussion:

a. Short-term prestress losses and initial camber:

It is observed that losses have been occurred when the sudden prestressing force is released from strip to the structural member i.e. to the beam. When the prestressing force is released by cutting it from the end wedges thus an negative bending moment is created which causes upward deflection i.e. negative chamber in the structural member beam due to the eccentricity of forces to the centroidal axis of the member cross section and also there is loss in the strain of the CFRP laminate/ Strip. These losses are determined by the varation of the strain the CFRP Laminate and deflection of the beam in the mid span eventually during forces releases.

It is observed that as the Prestressing force level increases the losses due to prestress will also be maximum (Mohammadali Rezazadesh, 2014)

b. Failure modes:

When the tension steel failed, the concrete in the control beam's compression zone shattered. This is a common failure mode in unreinforced concrete beams. This is the typical form of tensile failure, whereas shear failure is avoided by utilising more shear steel than is required.

When a single non-prestressed NSM CFRP plate was used to reinforce the beam, it separated prematurely after the tensile steel yielded. This delamination began in the middle of the span at the concrete/epoxy interface and progressed to one end of the beam. Unlike concrete and rebar, the initial separation failure appears to be the result of bonding performance issues between the epoxy and concrete at the NSM-CFRP panel level, leading in unprestressed incomplete synthesis between NSM-CFRP panels. Due to spalling of the concrete cover, a girder reinforced with prestressed NSM CFRP plates broke. After the tensile steel had crumbled, this began at one end of the CFRP plate. The normal stress at one end of the CFRP plate increases as the load on the prestressed beam increases, resulting in this mode. In other words, when the normal stress surpassed the concrete's tensile strength, a horizontal fracture appeared on the surface of the PC steel plate, spread to the centre of the span, and the concrete pavement peeled off. The prestressed beam's load capacity was substantially lowered and it generated a lot of noise once the concrete cover separated. This signifies that a significant amount of energy has been released. Because of the lack of the stiffening mechanism, the prestressed beam's behaviour quickly became basically identical to that of the control beam. In addition, when a particular load level was reached after yielding the prestressed beam, a V-shaped shear crack occurred on the underside of the beam. The crack subsequently spread along his NSM groove near the centre of the span to the beam's end. The failure mechanism was unaffected by TG. Beams reinforced with prestressed NSM CFRP plates failed unexpectedly, as previously stated. As a result, when employing NSM prestressed CFRP panels in the field in the near future, the problem of end fastening his CFRP panels to the ends of beams will have to be addressed. To keep the concrete cover in place, mechanical anchors can be installed on the borders of the CFRP panels.

c. Effect of the prestress on the load and deflection:

In this section, we present and examine the impacts of prestress level, bond length, and partial prestress on the load-displacement behaviour of NSM GRP strips. Increasing the preload of the CFRP laminate enhances the beam's elastic stiffness capacity. Prestressing, on the other hand, adds stress between the steel tension rods and the surrounding concrete, increasing the possibility of the beam end capping off. As a result, as the CFRP prestress increases, the beam's ultimate load-bearing capability falls.

Increasing the bond length of the CFRP strips, according to our findings, could improve the bending behaviour of these reinforced beams. By comparing the force-displacement curves of fully and partially prestressed specimens with varied CFRP bond lengths, the influence of the proposed partially prestressed NSM-FRP reinforcing method was examined. The ultimate load is greater for partially prestressed specimens than for fully prestressed specimens. The non-prestressed CFRP section specimens had the maximum breaking load and stiffness. The load-bearing capability of the beam increased by more than 19% when compared to completely prestressed NSM-FRP specimens with the same bond length and prestress force. Similarly, for a given CFRP bond length, partially prestressed beams had higher ultimate loads than completely prestressed beams.

d. Strain behavior:

Strain profiles as a function of beam depth are based on mid-span strain measurements for concrete, steel, and CFRP rebar. These results are based on individual strain gauge recordings for concrete, compression steel, tension steel and CFRP plate. As observed, the results increased proportionally to the load distribution of his CFRP plate after tensile steel yielding. That is, the tensile force caused by the load applied to the prestressed rebar was shared by the tensile steel and his CFRP plate. However, when the yield of the tensile steel makes it impossible to split the tensile force, most of the tensile force is absorbed by his CFRP laminate. In addition, higher preload levels increase the stresses that cause tensile steel to yield. However, regardless of the prestress level, the failure of each prestressed beam was dominated by spalling of the concrete cover, and after spalling occurred in the beam prestressed with NSM CFRP panels, the composite section was Converted to non-composite section. The CFRP plate, similar to the unreinforced beam, could not withstand any tensile force and exhibited constant ultimate strength without a significant increase in load.

6. Conclusions:

The following findings were reached:

- Non-prestressed strengthen beams showed premature debonding of laminate failure at the interface between the NSM CFRP laminate and concrete. However, beams strengthen with prestressing Concrete cover separation and rupture of the laminate which mainly depends on the bond length.
- The mid-span deflection and loading impact on the strengthened beams are affected by the prestressing force of the FRP laminate. When the prestress was increased, the cracks expanded and the final ultimate load increased when compared to the control beam.
- When the prestressing force is released by cutting CFRP from the end wedges, a negative bending moment is created, causing upward deflection, i.e. negative chamber, in the structural member beam due to the eccentricity of forces to the centroidal axis of the member cross section.
- According to the load-displacement and load-strain response data, increasing the prestressing force of the CFRP strip can increase the beam stiffness in the elastic phase and retard cracking. However, tests

performed for this study show that increasing the preload force increases the likelihood of end cap dislodgment and decreases the load capacity of the beam.

- The composite length of the CFRP strips has a great influence on the bending behavior of the reinforced beams. Increasing the bond length greatly increases the load-bearing capacity, stiffness, and ductility of the beam. Both the load-bearing capacity and ductility reach maximum values in static tests when the compound length of the GRP strip is extended to the full width.
- Increasing the number of CFRP strips does not necessarily result in a corresponding increase in bending strength of the RC part. Especially when breakage is controlled by separation of the CFRP strips from the beam.
- Using the same amount of CFRP strips but distributing them in two grooves instead of one will significantly reduce the crack width and increase the breaking load.
- Flexural cracks dominated the crack pattern in beams. When compared to the normal control beam, the beam strengthened with the NSM-CFRP laminate without prestressing lengthened the crack zone, while increasing the prestress level lengthened the fracture zone. This tendency was reversed by the decline. The reinforcement system, as compared to the control bar, reduced the average crack spacing regardless of prestress level.

It is advised that when placing prestressed NSM CFRP laminates on concrete beams, the prestress level be kept below 50% of the elongation at break to optimize the energy absorption capacity. This recommendation is primarily based on the findings of this study, and more research is required before wider implications can be drawn.

More research is required to describe the behaviour of RC beams reinforced with NSM-FRP strips, including fatigue-related damage, and to develop a realistic and accurate model that allows fatigue life to be evaluated. Furthermore, because reinforced beams may be exposed to fire and corrosive environments, a comprehensive model must address durability concerns.

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