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Cracking and Deformation Behavior of the Preloaded HSC Beams Retrofitted with CFRP Strips using NSM Technique

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Abstract – *The use of Near Surface Mounted (NSM) FRP technique is found to be an attractive and promising technique for increasing flexure and shear strength of deficient reinforced and prestressed concrete members. This technique is proved to be more superior over externally bonded techniques. This technique was used to enhance the load carrying capacity of the concrete structures by placing the strips in the slits opened in the concrete cover on the tension face of the elements to be strengthened and gluing them to the concrete with an epoxy adhesive. The FRP reinforcements used in this technique was Carbon fibre reinforced polymers (CFRP).*

The objective of this research program was to examine the structural performance of the reinforced concrete beams strengthened in flexure with NSM FRP strips by preloading the specimen up ***to the "Working load" (P_w)*** *and then strengthening the specimen using CFRP strips. A total of 9 HSC beams were being tested. The beams were broadly classified into three categories with rectangular cross section 100mmx125mm with an effective length 2500mm long. The longitudinal steel reinforcement of the beams varied from 1.25, 2.5 and 3.75 percent respectively. The effect of different parameters including the internal steel reinforcement ratio and number of NSM-CFRP strips will be discussed. The main goal of this experimental work was to investigate the parameters cracking moment, load deflection and crack width behavior of the RC beams repaired with NSM CFRP strips after preloading condition. The experimental results exhibited improved performance with increase in the number of strips in the beam specimens.*

Key Words: Near Surface Mounted technique, CFRP strips, preloaded condition, HSC beams

1. INTRODUCTION

High Strength Concrete (HSC) provides better solution to reduce the size and weight of the concrete structures by increasing the strength per unit cost, per unit weight, and per unit volume as well. Use of HSC in construction reduced the sizes of the members leading to more deformations and cracking stiffness degradation and further reduces the serviceability, in addition to that the concrete structures will become deficient during their service life due to environmental loads, corrosion deterioration, damages due to environmental and mechanical effects etc. Lack of maintenance, untimely repair and strengthening causes further deterioration of the structures. This need of strengthening may arise as a result of design or construction errors, functional changes, design code updates, damage accumulated over time, accidental overloading, fires and earthquakes. The deficient structures requires huge investments if it is to be rebuild, strengthening of structure has become the suitable way for improving the load carrying capacity and prolonging the service life and also found to achieve economy [1].

2. RESEARCH SIGNIFICANCE

A large amount of researches have been carried out aimed at strengthening of concrete structures after they undergo various deficiencies. Dealing with the strengthening of structures in this deficient stage is the challenging criteria for the designers, no codes and standards have consistently taken the influence of preload level and effective arrangement of strengthening materials because there is lack of enough experimental data for investigating the influence of the preload level on flexural performance [2]. The need for repair and strengthening of deteriorated and damaged infrastructure has become an important challenge to the engineers worldwide. This experimental investigation were carried out mainly to study the influence of preload level on flexural performance of preloaded HSC beams retrofitted CFRP strips, by varying percentage of CFRP strips for different steel percentages.

3. METHODS OF STRENGTHENING

There are several methods available for strengthening of structures, the most common and popular techniques are mentioned below,

(a)Section enlargement: "Bonded" reinforced concrete is added to the structural member in the form of overlay or jacket.

(b)Steel plate bonding: Steel plates are glued to the concrete surface by epoxy adhesive to create a composite system and improve flexural strength.

(c)External post tensioning system: Active external forces are applied to the structural member using post tensioned cables

(d)Mechanically fastened system: This method uses a powder actuated fastener to install mechanical fasteners through holes in the FRP predrilled into the concrete substrate.

(e)Near Surface Mounted Technique (NSM): Installation of FRP laminates on the tension side of the elements to be strengthened with epoxy based adhesive [3].

Out of all the above mentioned strengthening techniques, NSM technique is found to be an attractive solution for strengthening the structure both in terms of flexure and shear requirements. This technique possess the following advantages (a) Aesthetics of strengthened structure remains unchanged (b) NSM bars are less prone to debonding from the concrete substrate. (c) NSM bars can be easily anchored into the adjoining members to prevent debonding this being a very important feature in rigid jointed frames to enhance the flexural strength (d) Site installation work is reduced, because this method requires only grooving as surface preparation. (e) NSM reinforcement is easily prestressed. (f) The amount of site installation work is reduced, because the surface preparation other than the grooving is no longer required. (g) NSM bars are protected with concrete cover, so are less exposed to mechanical damage, accidental impact, fire and vandalism.

Because of the above available features the NSM FRP method is found to be superior to other externally bonded techniques.

The very few disadvantages of NSM technique are (a) FRP strengthening system involves complicated installation procedure. (b) Low deformability before failure occurs in FRP strengthening system when compared to pre-stressed steel tendons (c) FRP reinforcement is highly expensive and not readily available.

4. MATERIALS AND MIX PROPORTIONS

The mix design was obtained for HSC using method followed by R.P et al., [7] the average compressive strength obtained was 93.68MPa. The preloaded beams were retrofitted with CFRP strips having a tensile strength of 2800MPa and Nitowrap PC epoxy was used as an adhesive. All the beams were allowed for a setting time of half an hour and curing period of 7 days after retrofitting.

5. METHODOLOGY FOR STRENGTHENING

The procedure for the NSM strengthening technique is summarized as (1) Grooving of slots on tension side having the width of approximately three times and depth of one and half times of the strip, (2) Application of embedding paste and (3) Encapsulation of the groove with the bar and finishing[6] as shown in Fig -1.

Fig -1: Installation of FRP in groove on tension side and finishing with epoxy adhesive

6. EXPERIMENTAL PROGRAM

6.1 Preloading on the specimen

A total of 3 series of nine beams were cast with varying percentage of reinforcements and subjected to working load which was calculated using IS code to obtain preloaded condition as shown in Table -1, and then the beams were retrofitted with varying number of strips in the region where bending moment is predominant and subjected to loading

Table -1: Preliminary loads applied on the beams

Beam numbers	Beam dimensions	Eff. Depth	% steel	Preloading (P_w-kN)
B1, B2, B3	100x160	125	1.25	8
B4, B5, B6	100x180	125	2.5	14
B7, B8, B9	100x200	125	3.75	20

The Table -2 presents the test matrix for the beams providing information regarding number of strips, strip lengths and type of loading.

Table -2: Test matrix for the beams

Beam numbers	No. of CFRP strips	Type of Loading	Length of Strip
B1, B4, B7	1S	Two point loading	1666.7
B2, B5, B8	2S		
B3, B6, B9	3S		

The Schematic diagram of Loads and Supports and Test setup of a typical beam is shown in Fig. 2 and 3

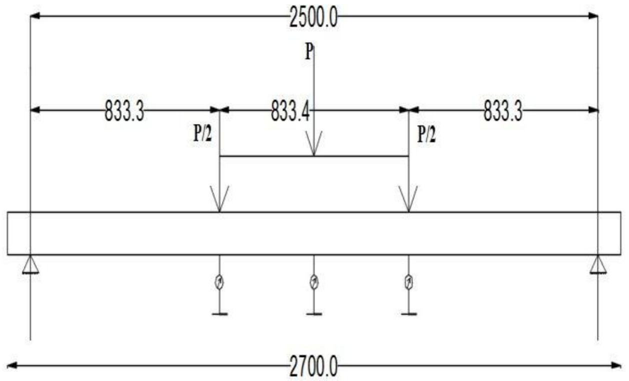

Fig -2: Schematic diagram of Loads and supports

Fig -3: Test setup of a beam subjected to Loading

7. TEST RESULTS AND DISCUSSIONS

7.1 Cracking moment

Cracking load is a very important stage in the load deflection behavior of flexural members. Generally load deflection curve will be linear up to this stage. The cracking load depends on the tensile strength of the concrete and the geometry of the specimen. The general equation to evaluate cracking moment is given by:

$$M_{cr} = f_r \times \frac{I_g}{y_t}$$

The cracking moment for different steel percentages and with increase in the number of strips are compared with various codal provisions as shown in the Chart 1 to 3.

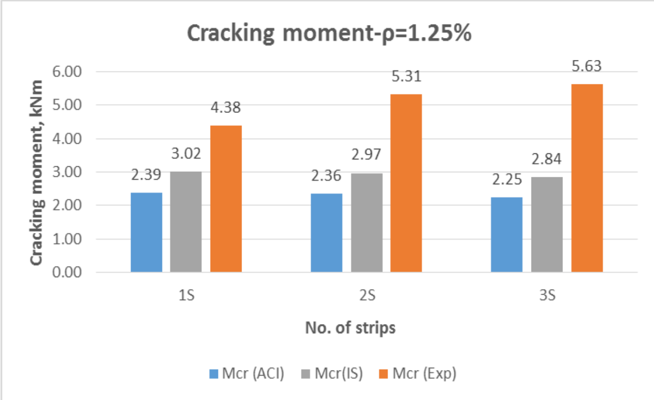

Chart -1: Cracking moment for beam with ρ=1.25%

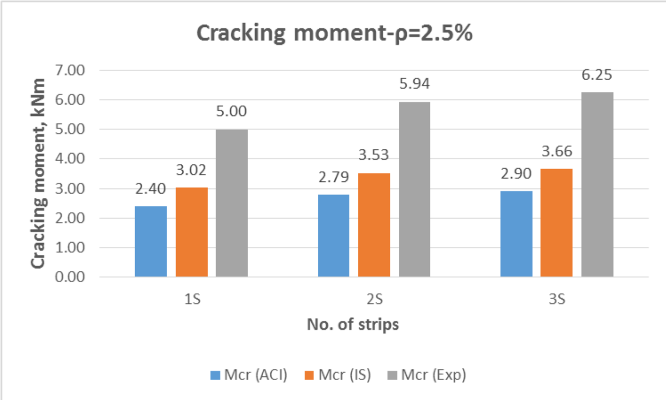

Chart -2: Cracking moment for beam with ρ=2.5%

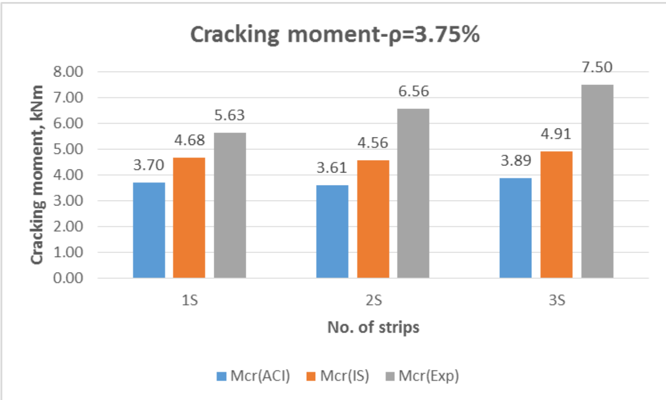

Chart -3: Cracking moment for beam with ρ=3.75%

From the Chart 1 to 3, it was observed that experimental cracking moments were increasing with increase in number of strips. It was also noted that, for beams with ρ = 1.25%, 2.5% and 3.75%, the experimental values of M_{cr} was higher compared to the calculated M_{cr} values of both the codes. Also the variation in the codal values figures out that IS code predictions are somewhat better when compared with ACI for the variation of number of strips i.e., M_{cr} value of beams increases with increase in number of strips.

7.2 Load Deflection behavior:

Load Deflection behaviour is the principle component of the flexural behavior of the HSC beams. An attempt has been made bring out the comparative studies between the beams, this was done by plotting experimental load v/s deflection diagram for varying number of strips for different steel percentages.

The load deflection behavior for different steel percentages and with increase in the number of strips are shown in Chart 4 to 6.

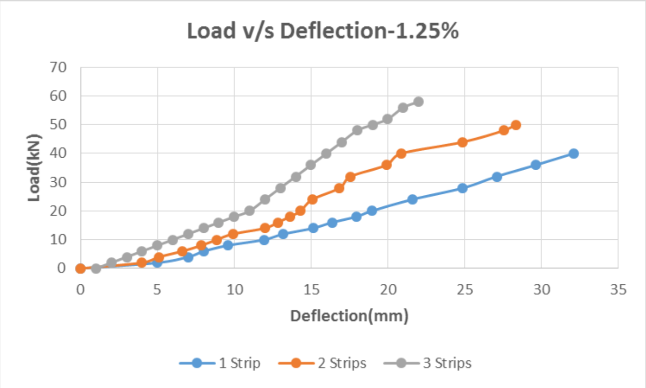

Chart-4: Load-Deflection curves for beams with ρ=1.25%

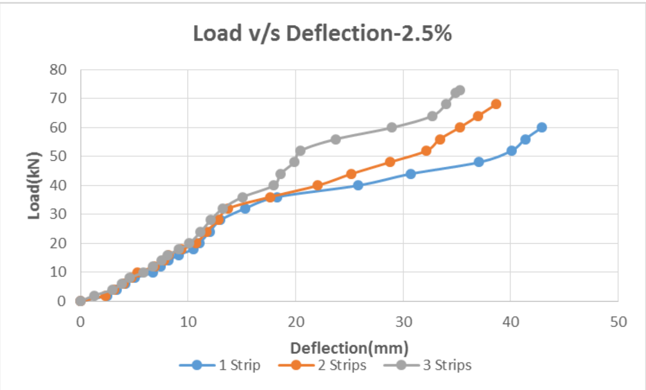

Chart-5: Load-Deflection curves for beams with ρ=2.5%

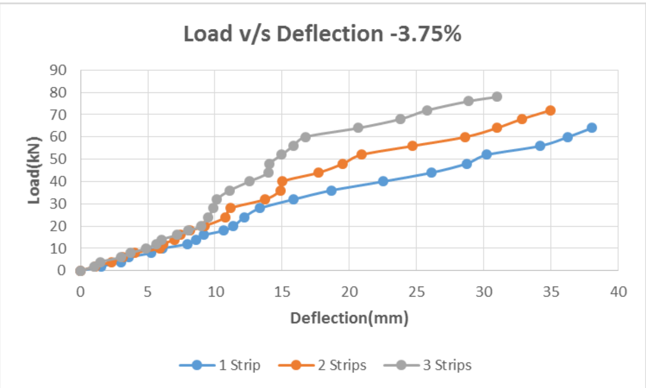

Chart-6: Load-Deflection curves for beams with ρ =3.75%

The deflection of the beams at working and ultimate loads was noted. It was observed that at any load, the deflections of the strengthened beams were significantly decreasing with increase in the number of strips. However this variation was not observed with increase in percentage of reinforcement. Thus it can be concluded that CFRP strips will be effective in the lower range of reinforcement compared over higher range of reinforcement which requires further investigations.

7.3 Crack width:

Prediction of crack width is very important for the reinforced concrete beams due to its serviceability criteria. In our experimental work the observation was made on how the crack widths and crack patterns changes with increase in reinforcement percentages along with variation in number of strips for the beams in the preloaded state. The crack widths for different steel percentages with increase in the number of strips is shown in Chart 7 to 9.

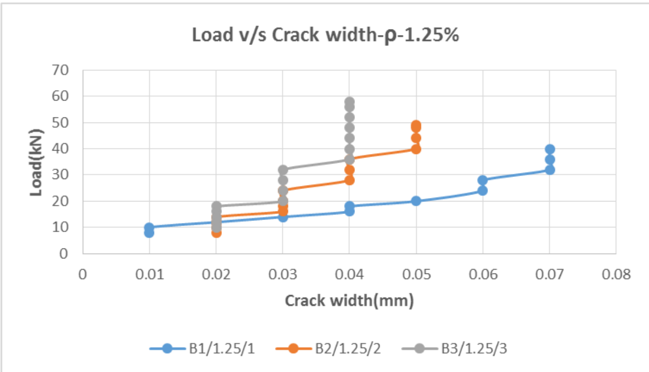

Chart-7: Load-Crack width curves for beams with ρ=1.25%

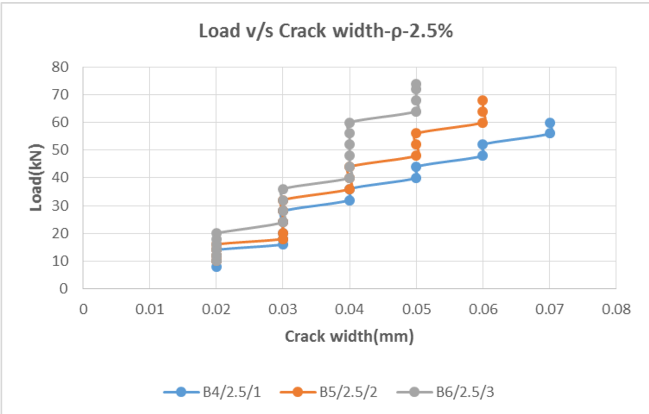

Chart-8: Load-Crack width curves for beams with ρ =2.5%

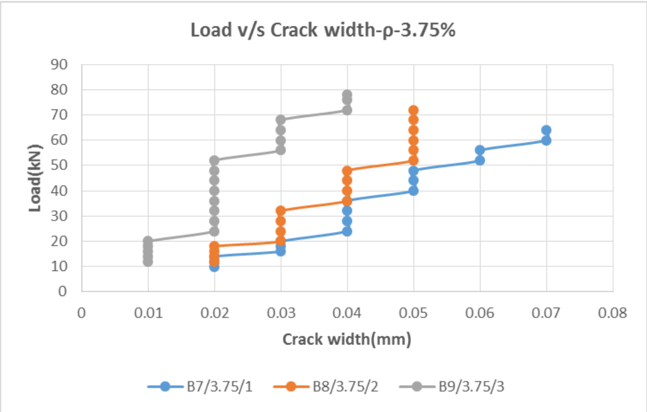

Chart-9: Load-Crack width curves for beams with ρ =3.75%

It was observed that with the increase in number of strips the crack width decreased because strips provided restriction for the cracks to open. With increase in number of strips for the beam with higher reinforcement percentage, there was further decrease in the crack width. However there was more number of cracks in the beam with higher reinforcement and 3 strips.

8. CONCLUSIONS

- The use of Near Surface Mounted CFRP strips is feasible and effective for strengthening/ repairing the reinforced concrete beams
- Cracking moment increases with increase in the number of strip and it further increased in the beams with higher reinforcement.
- Experimental values of cracking moments was higher compared to the values calculated by both ACI and IS codes.
- Strengthening with NSM strips have improved the load deflection response on the preloaded HSC beams.
- It was observed that at any load, the deflections of the strengthened beams were significantly decreasing with increase in the number of strips until working loads i.e. serviceability requirement.
- For a particular reinforcement percentage, with increase in number of strips the crack width decreased, because strips provided restriction for the cracks to open.
- Increase in number of strips for beam with higher reinforcement percentage there was further decrease in the crack width because there was a greater contribution to restrict cracks by both steel and strips.

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