An Analytical Study on Static and Fatigue Analysis of High Strength Concrete Beams with FRP Laminates

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Abstract :- **In recent years FRP stands as a better alternative to restore and upgrade deficient structures. The deficiency may be due to change in design standards, improper construction practices (or) adverse environmental conditions. Under such circumstances, adoption of appropriate technique for restoring the structure becoming challenging task. The objective of this thesis work is to evaluate the static and fatigue response of HSC beams with externally bonded FRP laminates using ANSYS software. The modeling and analysis is done using the software for HSC beam. The beams were strengthened with FRP laminates. The models are provided with carbon types of Fiber Reinforced Polymer (FRP) laminates. The available experimental data of HSC beam in flexure behavior is the source material of this analysis work. All the relevant data are taken from that source material. The static and fatigue load cases are applied and the results are discussed. The comparison is made between the available experimental results of HSC beam with analytical based results of HSC beam.**

Keywords : beams(supports); compressive strength; fracturing; deflection; ductility; fibers; flexural strength; high-strength concretes; moment of inertia; reinforced concrete; rigidity.

1. INTRODUCTION

The response of high strength concrete under static and fatigue loading has received importance in the coming years because of the increased adoption of high strength concrete in multi storey structures, concrete basements or pavements and liquid retaining structures. Investigation has taken place by the structural researchers for understanding the cracking resistance of high strength concrete due to fatigue or impact load. The principal objective of research conducted to investigate the influence of FRP in respect of static and fatigue response of HSC beams. Comparing an analytical based model with the available experimental model for predicting the performance parameters of HSC beams. The analytical based model have been analysed for static and fatigue load cases and the results have been compared with the available experimental model. A Finite Element Model for predicting the performance parameters of High Strength Concrete beams with FRP laminates in ANSYS Software program is developed. The experimental data have been carried out from the Australian Journal of Basic and Applied Sciences journal in the name of Flexural Behavior of High-Strength Fiber Reinforced Concrete Beams by Reza Mahjoub, Seyed Hamid Hashemi. In this journal, the effect of inclusion of steel fibers on the flexural behavior of high-strength concrete beams is investigated.

2. LITERATURE REVIEW

S.H. Hashemi (2009) has presented in the Bending Response of HSC beams with externally bonding FRP laminates. The repair and strengthening of RC structures has become a major problem for civil engineers in the past few decades. However, bonding steel plates to concrete presents disadvantages, including corrosion of the steel/adhesive joints and the heavy weight of the material. These problems increase installation and maintenance costs. The bonding of Fiber Reinforced Plastics (FRP) to structures provides an attractive alternative to steel plates. This material is corrosion resistant and lightweight, has a high strength-to-weight ratio and possesses nonconductive properties. The use of Fibre Reinforced Plastics (FRP) in repairing and strengthening RC beams has been researched in recent years. In particular, attaching unidirectional FRP to the tension face of RC beams has provided an increase in the stiffness and load capacity of the structure. However, due to the brittle nature of unidirectional FRP, the ductility of the beam decreases. Consequently, the safety of the structure is compromised, due to the reduction in ductility. The purpose of this research is to investigate the behaviour of high strength reinforced concrete beams strengthened with FRP sheets. The major test variables included the different layouts of CFRP sheets and the tensile reinforcement ratio. More particularly, change in the strength and ductility of the beams, as the number of FRP layers and tensile reinforcement bar ratios are altered, is investigated. Eight under-reinforced concrete beams were fabricated and tested to failure. With the exception of the control beam, one or four layers of CFRP were applied to the specimens.

S.H.Hashemi, A.A.Maghsoudi and R.Rahgozar (2009) This test represented The strengthening of R.C structures using F.R.P. this material is corrosion resistant and light weight , has a high strength to weight ratio and possesses non conductive properties. the purpose of this research is to investigate the behavior of high strength reinforced concrete beams strengthened with FRP sheets. In this testing flexural of HSRC beams strengthened with different amounts of cross ply

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FRP sheets with different amount of tensile reinforcements. In this test the strengthening reduced the crack width in beams at all load levels. The compressive strain of concrete fiber in the strengthened beam, with the increased the number of CFRP layers. Compared to the RC beams an adequate deformation capacity in spite of brittle mode of failure. As the amount of tensile steel reinforcement increases the additional strength provided by CFRP. The flexural strength of a lightly reinforced beam by more than 44.4% but only increased the strength of a moderately reinforced beam by 11.7%.

K.Harries (2005) the fatigue behavior of FRP retrofit members is presented. The review is to identify behavior associated with FRP de-bonding subjected to fatigue loading conditions. The eventual fatigue failure is similar to that of un retrofit companion specimens, and it is controlled by the fatigue behavior of longitudinal steel reinforcement. De-bonding behavior should be manifest in changes in the stress range in both the internal steel and the FRP. The extant studies report only the stress range from the initial fatigue cycle or a calculated target stress range and the approach accurately captures the fatigue behavior of bonded FRP systems. Loading geometry affects the de-bonding behavior and consequently the apparent S-N behavior. Applications prone to intermediate crack induced de-bonding appear to be more critical in terms of their fatigue behavior than those experiencing end peel de-bonding. Provided scale proportionality is maintained, moderate scale test specimens may be used to establish S-N relationships for bonded FRP systems.

Oral Buyukozturk, and Brian hearing (1998) In this research the addition FRP laminates bonded to the tension face of concrete girder is becoming an attractive solution to the rehabilitation and retrofit of damaged structural systems. Physical models of reinforced concrete beams with variation in shear strengths bonded laminate lengths, and epoxy types are pre-cracked the retrofitted with GFRP and CFRP and tested in experimental programs. This research analysis of failure mechanisms of laminated RC beam. It is short term behavior of strengthened with FRP on the bottom. Similar approaches may apply for other geometric configurations. In this research flexural failure, shear failure and also the bonding failure were analyzed. The effect of material compatibilities and their resistances to degradation through both environmental and load cycles and the assessment of retrofitted system integrity through the use of non destructive evaluation. These methods have the potential provide quantitative verification of elements essential to effective rehabilitation such as adherent thickness, crack and de-lamination identification and void deduction.

3. MATERIALS AND METHODS

3.1 Material Properties

The concrete beams were designed for mean 28-day cube strength of about 100 MPa. For each beam, three 100 mm x100 mm x100 mm concrete cube specimens were made at the time of casting and they were kept with the beams during curing. The average 28-day concrete cube strength (f_{cu}) was 96.2 MPa. The average compressive strength (f_c) was 77 MPa. The measured yield and maximum tensile strength of the 10 and 16 mm rebars were 420.6, 634.1 and 412.5, 626.4 MPa, respectively. The density and thickness of the CFRP material was 1.78+ 0.1 gr/cm3, 0.045 mm and 2600 mm long for both of them. The Young's modulus (Efu), ultimate tensile stress (ffu) and elongation ("fu) of the FRP sheets were 230 GPa, 3850 MPa and 1.7+ 0.1% for CFRP . FRP sheets were externally bonded to the tension face of the concrete beams using a two component structural epoxy at a 1:1 ratio. Strengthened concrete beams were cured for at least seven days at room temperature before testing.

3.2 Details of Test Specimen

The length, width and depth of all beams where kept as 3000x150x250 mm. each concrete beams was reinforced with two 16 mm dia for our beams for tension, and 2 numbers of 10 mm dia bars in compression zone, along with 10 mm dia bars at spacing of 90mm center to center for shear reinforcement. The CFRP sheets of width of 150 mm and length of 2600mm are provided in the tension face of the HSC beams. The spacing of stirrups and maximum and minimum reinforcement ratios are in accordance with the provisions of the American Concrete Institute (ACI).

Table 1. Material Properties of Experimental HSC Beam TEST SPECIMEN

Test Beam	A_S	A'_S	A_{SV}	AFRP (mm^2)	FRP Details
AH4	2# 16dia	2# 10dia	10dia@90mm	450	3mm x 150mm

4. ANALYTICAL PROGRAM

4.1 Modelling

Modeling and analysis is carried out using FEA software ANSYS. Structural analysis is probably the most common application of the finite element method. The term structure implies not only civil engineering structures such as bridge and buildings, but also naval, aeronautical and mechanical structures such as ship hulls aircraft bodies and machine housings as well as mechanical components such as pistons, machine part and tools. Various type of analysis performed in ANSYS include,

- Static analysis
- Modal analysis
- Harmonic analysis
- Transient dynamic analysis
- Spectrum analysis
- Explicit analysis

The behavior of reinforced concrete beams were studied by full-scale modeling investigation. The results are compared to other software calculations that estimate deflections and internal stress/strain distributions within the beams. Finite element analysis can also be used to model the behavior numerically to confirm these calculations, as well as to provide a valuable supplement to the laboratory investigations, particularly in parametric studies. Finite element analysis, as used in structural engineering, determines the overall behavior of a structure by dividing it into a number of simple elements,

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each of which has well-defined mechanical and physical properties. Modeling the complex behavior of reinforced concrete, which is both non-homogeneous and anisotropic, is a difficult challenge in the finite element analysis of civil engineering structures. Most early finite element models of reinforced concrete included the effects of cracking based on a pre-defined crack pattern. With this approach, in the models the load were increased; therefore, the ease and speed of the analysis were limited. In the smeared cracking approach, cracking of the concrete occurs when the principal tensile stress exceeds the ultimate tensile strength. The elastic modulus of the material is then assumed to be zero in the direction parallel to the principal tensile stress direction. The beam will be modeled by layered approach

4.2 Modeling of Beam

The beam model is 3000 mm long with a cross section of 250mm X 150mm which is described in the available material. The entire specimen will be modeled in 3D modeling.

4.3 Material Modeling

Nearly all finite element analysis models today are built using a solid model. This CAD-type mathematical representation of the structure defines the geometry to be filled with nodes and elements, and can also be used to facilitate applying loads or other analysis data. However, the solid model does not participate in the finite element solution. All analysis is done on the FEA model consisting of nodes and elements.

The beam will be modeled by layered approach. The model is 3000mm long with a cross section of 250mm X 150mm .The entire specimen will be modeled in 3D modeling. SOLID 65 is used for the 3-D modeling of solid with or without reinforcing bars (repair), and SOLID layered 46 is used for FRP material elements. Those solid elements are capable of cracking in tension and compression in concrete applications. And those elements are defined by eight nodes having three degrees of freedom, each node translations in the nodal x, y, and z directions. The most important aspect of this element is the treatment of nonlinear material properties; the concrete is capable of cracking (in three orthogonal direction), crushing, plastic deformation and creep. The FRP Laminates are allowed stiffening of stress. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep.

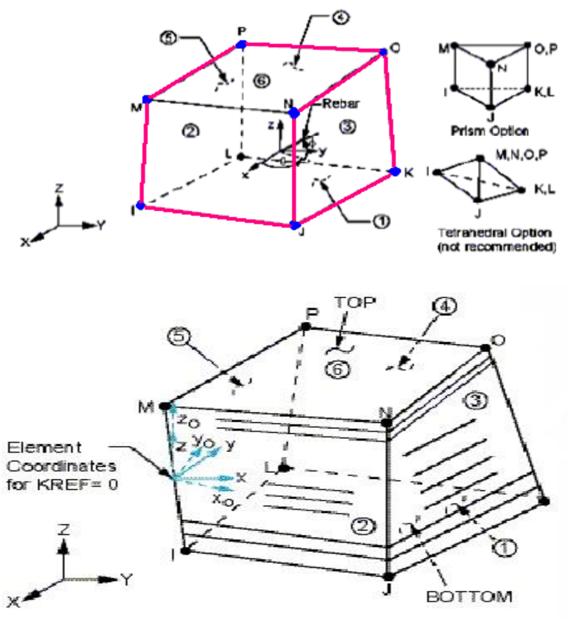

Figure 1. Solid 65 & Solid 46 Elements

4.4 Load Cases / Boundary Conditions / Properties:

Load case – STATIC & FATIGUE
Boundary conditions – Fixed supports
For concrete, ANSYS requires input data for material properties as follows:

1) Elastic modulus (E_c).
2) Ultimate uniaxial compressive strength (f'_c).
3) Ultimate uniaxial tensile strength (modulus of rupture, f_r).
4) Poisson's ratio (ν).
5) Shear transfer coefficient (β_t).
6) Compressive uniaxial stress-strain relationship for concrete.

Table 2. Input data for material properties of Concrete

Beam	Ec (Mpa)	f'_c (Mpa)	f_r	ν	β_t
Flexure Beam	50000	100	7	0.2	0.2

For FRP, ANSYS requires input data for material properties as follows

1) Number of layers.
2) Thickness of each layer.
3) Orientation of the fiber direction for each layer.
4) Elastic modulus of the FRP composite in three directions (E_x, E_y and E_z).
5) Shear modulus of the FRP composite for three planes (G_{xy}, G_{yz} and G_{xz}).
6) Major Poisson's ratio for three planes (ν_{xy}, ν_{yz} and ν_{xz}).

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Table 3. Input data for material properties of FRP Laminates

Laminate	Density (N/mm^2)	Young's Modulus (N/mm^2)	Tensile strength (N/mm^2)	% of elongation
CFRP	0.0178 $\pm$ 0.01	230000	3850	1.7 $\pm$ .01%

5. ANALYSIS

5.1 Static load analysis

The two point load is applied on the beam with increasing up to the ultimate load obtain the ultimate strain value of the concrete as shown in figure 2**.**

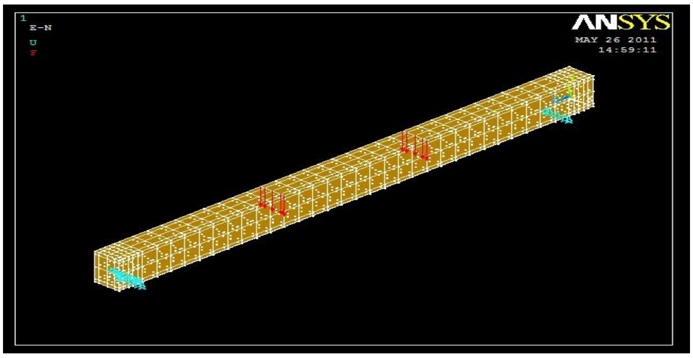

Figure 2. Static (Two point load) load applied on the element

5.2 Fatigue load analysis

There are 2 common input decision topics upon which your fatigue results are dependent upon:

- ❖ Fatigue Analysis Type
- ❖ Loading Type

5.2.1Fatigue Analysis Types

- ❖ Strain Life (Available in ANSYS Fatigue Module)
- ❖ Stress Life (Available in ANSYS Fatigue Module)

Within the ANSYS fatigue module, the first decision that needs to be made in performing a fatigue analysis is which type of fatigue analysis to perform – Stress Life or Strain Life. Stress Life is based on empirical S-N curves and then modified by a variety of factors. Stain Life is based upon the Strain Life Relation Equation where the Strain Life Parameters are values for a particular material that best fit the equation to measured results.

In this research Stress Life Analysis Type Fatigue Module is used for Fatigue Analysis.

5.2.2 Loading Types

- ❖ Constant amplitude, proportional loading
- ❖ Constant amplitude, non-proportional loading
- ❖ Non-constant amplitude, proportional loading
- ❖ Non-constant amplitude, non-proportional loading

In this research Constant amplitude, proportional loading is used for Fatigue Analysis.

Four load cases are applied at one- third of the beam:

1. 25 KN at each corner. The time at the end of the load step is 3.6 seconds.
2. -25 KN at each corner. The time at the end of the load step is 7.2 seconds.
3. 35 kN at each corner. The time at the end of the load step is 10.8 seconds.
4. -35k N at each corner. The time at the end of the load step is 14.4 seconds

6. RESULTS AND DISCUSSIONS

Table 4. Comparison of Experimental Vs Analytical results of HSC beam under static load case

SOURCE	YIELD STAGE		ULTIMATE STAGE	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
EXPERIMENTAL	64.7	9.83	117.3	32.85
FEM	66	9.67	120.5	37.23

In this work effect of CFRP laminates on the FRC beams have been studied. A comparative study of flexural strength of control beam and strengthened beam is presented in the succeeding sections.

From the results tabulation, the analytical deflection is 11.8 % higher than the experimental deflection is noted.

- ❖ From the FEA results, the yield load is 66kN and the corresponding deflection is 9.67 which is lesser than the experimental yield stage is tabulated (Table 4).
- ❖ The Ultimate load is 120.5kN and the corresponding deflection is 37.23mm in the FEA analysis is tabulated (Table 4).

6. 1.Load Vs Deflection

The comparison graph is made between FEA and experimental for Load and Deflection values Shown in Figure 3.

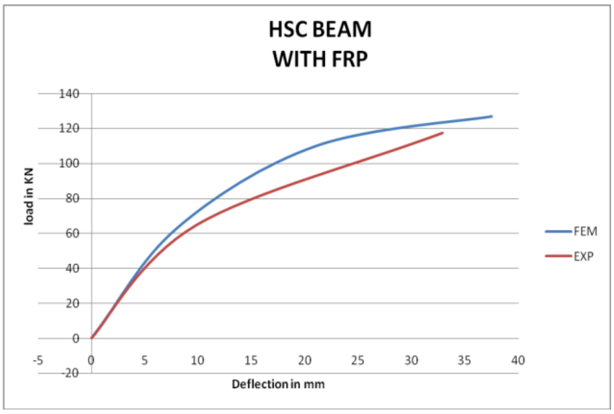

Figure 3. Load Deflection Relationship for Experimental Vs Analytical Results

6.2 Stress Vs Strain

From the static load case results, the stress Vs strain graph is made shown in Figure 4

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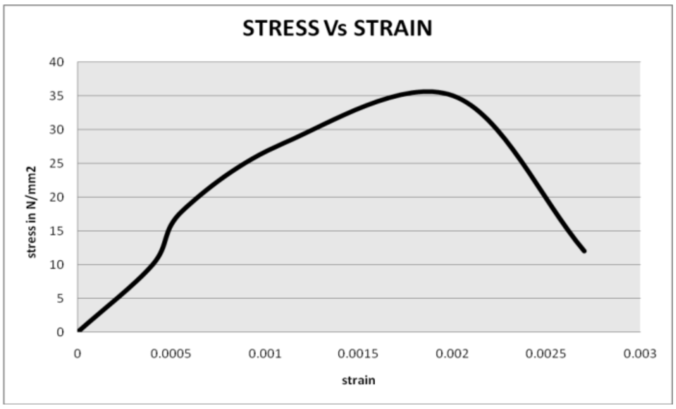

Figure 4. Stress strain Relationship

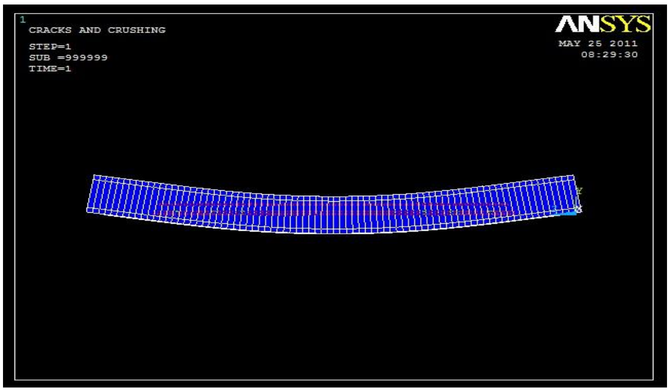

Figure 5. Crack Pattern

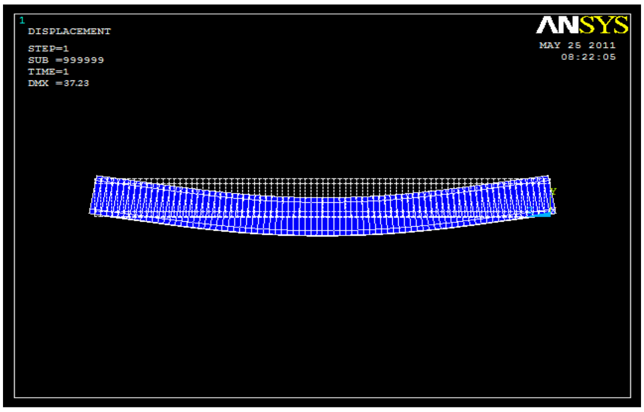

Figure 6. Deformed Shape of Loaded Beam

6.3 Stress Vs Time

6.3.1 Steps to perform the Fatigue Analysis

Definitions used in performing a fatigue analysis:

Location: a node in the model for which fatigue stresses are to be stored.
Event: a set of stress conditions that occur at different times during a unique stress cycle.
Loading: one of the stress conditions that is part of an event.
Stress Locations
NLOC = ***1***
NODE = ***22***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***2***
NODE = ***44***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***3***
NODE = ***60***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***4***
NODE = ***82***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***5***
NODE = ***24***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***6***
NODE = ***46***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***7***
NODE = ***62***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

NLOC = ***8***
NODE = ***84***(node along the surface at the load zone)
TITLE = Load zone & **Apply**

6.3.2 Fatigue Store Stresses
From rst File
NODE: ***22***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***44***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***60***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***82***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***24***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***46***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***62***
Event: ***1***
Loading: ***1*** &**Apply**

NODE: ***84***
Event: ***1***
Loading: ***1*** &**OK**

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6.3.2. Assign Events

NEV = ***1***
CYCLE = ***500000***
TITLE = ***Load 1*** &**Apply**

NEV = ***1***
CYCLE = ***50000***
TITLE = ***Load 1*** &**Apply**

NEV = ***1***
CYCLE = ***5000***
TITLE = ***Load 1*** &**Apply**

NEV = ***1***
CYCLE = ***500***
TITLE = ***Load 1*** &**ok**

For the fatigue load case the stress Vs time graph is made shown in Fig 7

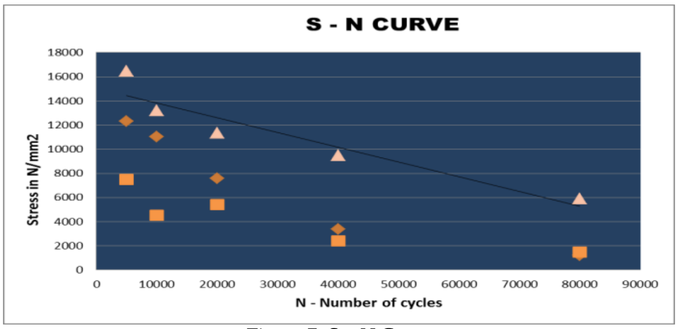

Figure 7. S – N Curve

Location: 1 Node 22 at the Load zone.

The combination of event 2, load 1 and event 2, load 2 produces an alternating stress intensity of 13692 N/mm^2. The beam was subjected to 5000 cycles while from the S-N Table, the maximum number of cycles allowed at that stress intensity of 100 N/mm2. The partial usage value, 50 is the ratio of cycles used/cycles allowed.

The combination of event 1, load 1 and event 1, load 2 produces an alternating stress intensity of 5973.82 N/mm2. The spring was subjected to 500,000 cycles while from the S-N Table; the maximum number of cycles allowed at that stress intensity is 100 N/mm2. The partial usage value, 4950 is the ratio of cycles used/cycles allowed.

The Cumulative Fatigue Usage value is sum of the partial usage factors

7. CONCLUSIONS

The major conclusions derived from this study are given as follows:

1. The finite element model results show good agreement with observations and data from the experimental full-scale beam tests.
2. This numerical study can be used to predict the behaviour of reinforced concrete beam strengthened with FRP more precisely by assigning appropriate material properties to develop design rules for strengthening RC member using FRP.
3. The results are performed in this study indicate that significant increase in the flexural strength can be achieved by bonding CFRP sheets to the tension face of high strength reinforced concrete beams.
4. It was found that for all strengthened experimental beams of the tensile steels strains were always higher than the CFRP strains when compared with the FEA program.
5. When compared with the experimental results the failure should increasing value but there was not a significant difference between both the results.
6. The lower and upper limit of the fatigue loading is derived from the ultimate capacity of the beam (working load).
7. Fatigue analysis is performing for constant loading for various cycles of loads.
8. Using these data S-N curve is obtained for various values of N.
9. Fig shows the S-N curve simulated by ANSYS software for HSC with FRP Laminate beams.
10. Using this curve the fatigue life can be identified.

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