Static And Fatigue Response Of High Strength Fibre Reinforced Concrete Beam 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 project work is to evaluate the static and fatigue response of HSFRC beams using MSC/NASTRAN – PATRAN software. The modeling and analysis is done using the software for HSFRC beam. The available experimental data of HSFRC 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 HSFRC beam with analytical based results of HSFRC beam.

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

1. Introduction

The principal objectives of research conducted to investigate the influence of FRP in respect of static and fatigue response of HSFRC beams.Comparing an analytical based model with the available experimental model for predicting the performance parameters of HSFRC 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. The experimental data have been carried out from the ACI structural journal in the name of Flexural Behavior of High-Strength Fiber Reinforced Concrete Beams by Samir a.Ashour and Faisal F.Wafa. In this journal, the effect of inclusion of steel fibers on the flexural behavior of high-strength concrete beams is investigated.

2. Literature Review

Samir a.Ashour and Faisal F.Wafa (1993) presented for a Flexural Behavior of High-Strength Fiber Reinforced Concrete Beams (HSFRC). In this investigation, the effect of inclusion of steel fibers on the flexural behavior of high-strength concrete beams is investigated. Eight high-strength concrete beams with different fiber contents and shear span-depth ratios were tested to study the influence of fiber addition on ultimate load, crack propagation, flexural rigiditiy, and ductility. The concrete matrix compressive strength was about 88 Mpa (12,000psi). The addition of steel fibers enhanced the strength and increased the ductility and flexural stiffness of the tested beams. A semi-empirical equation is proposed to estimate the effective moment of inertia of simply supported high-strength fiber reinforced concrete beams. The estimated deflections using this equation agree well with the experimental values. At ultimate conditions, the length of the plastic hinge developed was found to be proportional to the content.

Amer M. Ibrahim, Mohammed Sh. Mahmood(2009) presented for a reinforced concrete beams externally reinforced with fiber reinforced polymer (FRP) laminates using finite elements method adopted by ANSYS. The finite element models are developed using a smeared cracking approach for concrete and three dimensional layered elements for the FRP composites. The results obtained from the ANSYS finite element analysis are compared with the experimental data for six beams with different conditions from researches (all beams are deficient shear reinforcement). The comparisons are made for load-deflection curves at mid-span; and failure load. The load-deflection curves from the finite element analysis agree well with the experimental results in the linear range, but the finite elements results are slightly stiffer than that from the experimental results. The maximum difference in ultimate loads for all cases is 7.8%.

Meisam Safari Gorji, (2009) presented an investigation of reinforced concrete elements beams and columns are strengthened in flexure through the use of Fiber Reinforced Polymer (FRP) composites epoxy -bonded to their tension zones, with the direction of fibers parallel to that of high tensile stresses. Here, an analytical method is used to predict the deflection of rectangular reinforced concrete beams strengthened by FRP composites applied at the bottom of the beams. The validity of this experiment is to compare the results of the finite element model with energy variation method.

3. Materials and Methods

3.1 Materials

In the testing program, 20-mm Grade 60 deformed steel bars having 437 Mpa (63,400 psi) yield strength were used as flexural reinforcement. The concrete mix proportion was 1: 0.25: 2.5(cement: sand: coarse aggregate) to produce concrete with compressive strength of about 88Mpa (12,800 psi). Ordinary Portland cement (Type I), desert sand with a fineness modulus of 3.1, and coarse aggregate (crushed basalt) of 10 mm (3/8 in.) maximum size were used. Light gray densified micro silica (20 percent by weight of cement) with a specific gravity of 2.2, a bulk density of 6.0 kN/m^3 (37.4 $1b/ft^3$), and a specific surface of $23m^2/g$ was used. Hooked-ends mild carbon steel fibers with average length of 60 mm (2.36 in.),nominal diameter of 0.8 mm (0.03 in.), aspect ratio of 75, and yield strength of 1100 Mpa (159,500 psi) were used. A super plasticizer was used and enough mixing time was allowed to produce uniform mixing of concrete without any segregation.

The measured concrete strengths were based on an average value of three specimens. Six 150 × 300-mm (6 × 12-in.) cylinders were cast to determine the concrete compressive strength and splitting tensile strength. Additionally, three 150 × 150 ×530-mm (6 × 6 × 21-in.) beams were tested to find the modulus of rupture of the concrete used. The concrete was placed in three layers and was vibrated internally and externally immediately afterward. All beams and control specimens were cast and cured under similar conditions. The specimens were kept covered with polyethylene sheets until 24 hr before testing (28 days) to prevent the loss of moisture.

3.2 Details of Test Specimen

Eight high-strength fiber reinforced concrete beams were tested in this investigation. All beams were singly reinforced except at the constant moment zone. The variables were the shear span-depth (a/d) ratio and steel fiber content V_f. The cylinder strength of the concrete matrix used was about 88 Mpa (12,800psi), and the beam cross section was kept constant at 170×300 mm (7×12 in.).

Table 1. – Material Properties of Experimental HSFRC Beams

Beam No.	f_c' Mpa	f_r Mpa	f_{sp}' Mpa
1	86.14	8.93	4.91
2	87.11	9.94	5.93
3	88.11	10.60	7.38
4	90.53	13.46	7.97
5	86.14	8.93	4.91
6	87.11	9.94	5.93
7	88.11	10.60	7.38
8	90.50	13.46	7.97

4. Analytical Program

4.1 Modelling

Modeling and analysis is carried out using FEA software MSC- PATRAN / NASTRAN. 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 MSC/NASTRAN include,

- Static analysis
- Modal analysis
- Harmonic analysis
- Dynamic analysis
- Spectrum analysis

Regardless of the origin of your geometry, you can use MSC/NASTRAN to create a complete finite element model. Meshes can be created by many methods ranging from manual creation, to mapped meshing between key points, to fully automatic meshing of curves, surfaces and solids MSC/NASTRAN 4W can even work with your existing analysis models. You can import and manipulate these models using the interfaces to any of the supported analysis programs. Appropriate materials and section properties can be created or assigned from MSC/NASTRAN libraries. Many types of constraint and loading conditions can be applied to represent the design environment. You can apply loads/constraints directly on finite element

entities (Nodes and Elements), or you can apply them to geometry. MSC/NASTRAN will automatically convert geometric conditions to Nodal/Elemental values upon translation to your solver program. You may even convert these loads before translation to convince yourself that the loading conditions are appropriate for your model.
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, 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. The model is 3000mm long with a cross section of 250mm X 150mm .The entire specimen will be modeled in 3D modeling

4.2 Modeling of Beam

The beam model is 3000 mm long with a cross section of 300mm X 170mm which is described in the available material. The entire specimen will be modeled in 3D modeling.

4.3 Material Modeling

In Patran, a material is defined as a named group of material-related properties that are relevant for a particular finite element analysis. A material property consists of name of the material (steel, a composite, etc.) and defines the attributes of that material (such as density, stiffness, specific heat, elastic modulus, Poisson's ratio, and so on). Each analysis code supports a different set of materials. The properties must specify for a material depend on several factors:
• The type of analysis (such as structural or thermal).
• The analysis code (such as MSC Nastran).
• The material property definition.

4.4 Load Cases / Boundary Conditions / Properties:

Load case – STATIC & FATIGUE
Boundary conditions – Fixed supports
MSC/PATRAN 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).

TABLE 2. BEAM PROPERTIES

Beam No.	Ec Mpa	f_c', Mpa	f_r , Mpa	f_{sp}', Mpa
1	38000	86.14	8.93	4.91

Compressive Strength – 86.14 Mpa
Young's Modulus – 38000 Mpa
Modulus of rupture – 8.93 Mpa
Splitting tensile strength of concrete – 4.91 Mpa
Poission's ratio – 0.3

5. ANALYSIS

Analysis is done by the MSC/NASTRAN software which is in-corporate with MSC/PATRAN software.
The beam is modeled in the MSC/PATRAN software with all the properties according to the available source and it is proceeding with the analyzing software MSC/NASTAN. Load cases in which none of the constituent loads or boundary conditions sets has a time varying component are called static load cases. Load cases in which one or more of the loads and boundary conditions sets has a time varying component are called time-dependent, or dynamic load cases.(fatigue load cases).
MSC NASTRAN provided advanced general purpose analysis and optimization capabilities, for both linear and nonlinear structural and thermal analyses. MSC Nastran provided a broad range of solution types for analyzing stress, vibration, dynamic, nonlinear, acoustic, aeroelasticity, and heat transfer characteristics of structures and mechanical components.

5.1 Post Processing Results

All Results carried out from MSC/PATRAN software after the analysis done by the MSC/NASTRAN software.

Static load case and Fatigue load case results:

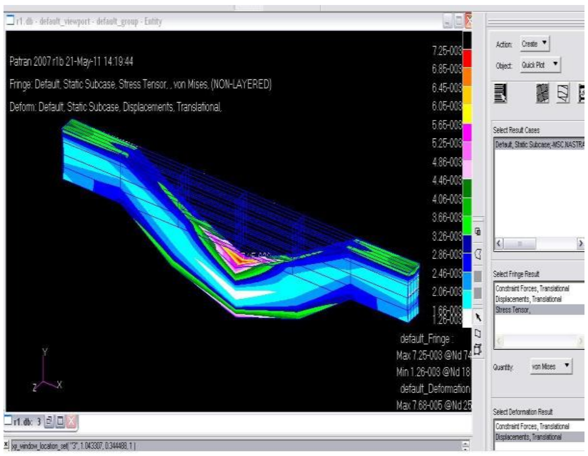

Figure 1. Static load case

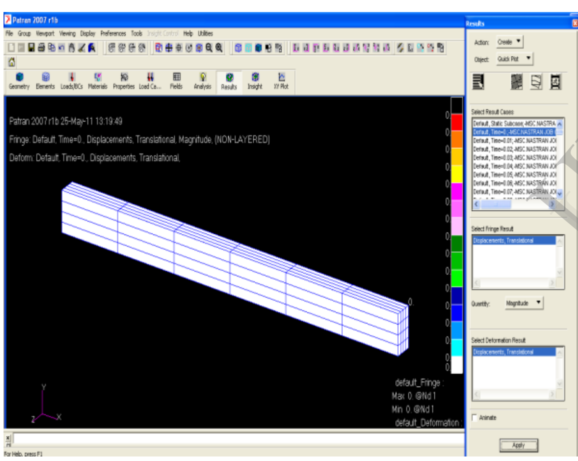

Figure 2. Fatigue Load Case – at time 0.0 sec

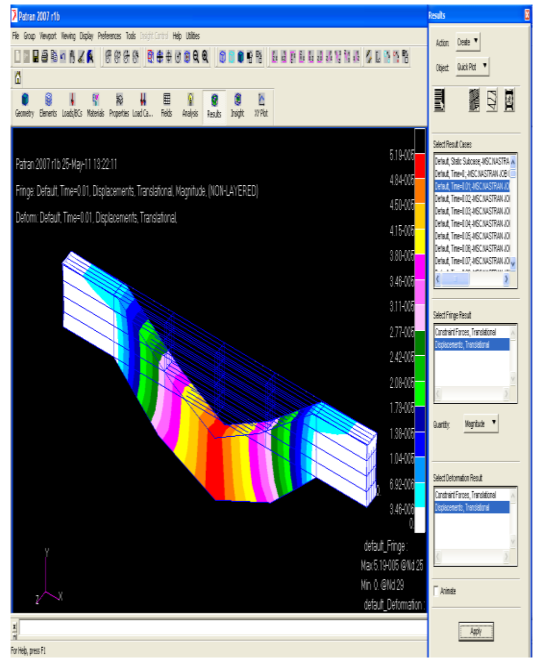

Figure 3. Fatigue Load Case – at time 0.1 sec

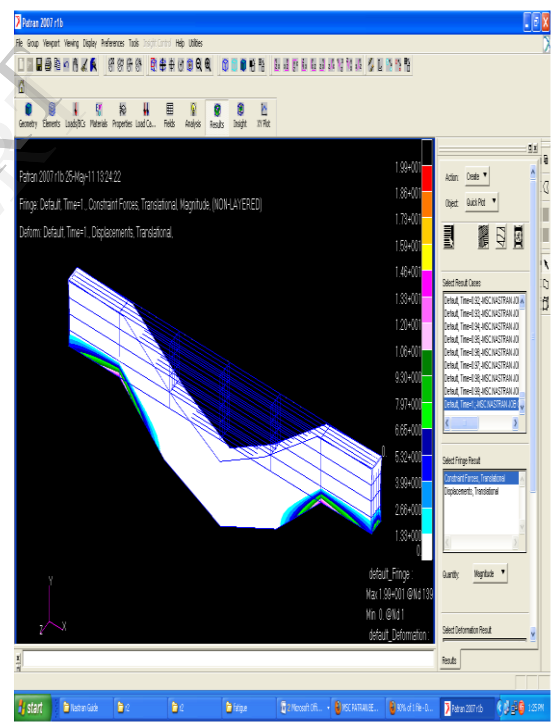

Figure 4. Fatigue Load Case – at time 0.1 sec

6. RESULTS AND DISCUSSIONS

Table 3. Comparision of Experimental Vs Analytical results of HSFRC beam under static load case

S. No	Load in kN	Deflection (Experimental) mm	Deflection (Analytical) mm	Difference in %
1	0	0	0	0
2	28.947	2.648	1.920	27.5
3	43.421	4.478	3.109	30.6
4	52.563	5.808	4.270	26.5
5	56.632	6.380	5.810	8.9
6	76.316	8.877	7.250	18.3
7	85.526	10.193	9.172	10.0
8	99.342	12.099	10.201	15.7
9	112.50	13.997	11.860	15.3
10	127.63	16.089	13.56	15.7

Table 4. Comparision of Experimental Vs Analytical results of HSFRC beam under static load case in various stages

Type of Results	Yield Stage		Ultimate stage	
	Load kN	Deflection mm	Load kN	Deflection mm
Experimental	56.56	6.380	127.6	16.089
Analytical	62.25	6.120	131.4	13.87

Average difference between experimental and analytical deflection is 16.8% lesser.

6.1 Load Vs Deflection

The comparison graph is made between FEA and experimental for Load and Deflection values Shown in Figure 5.

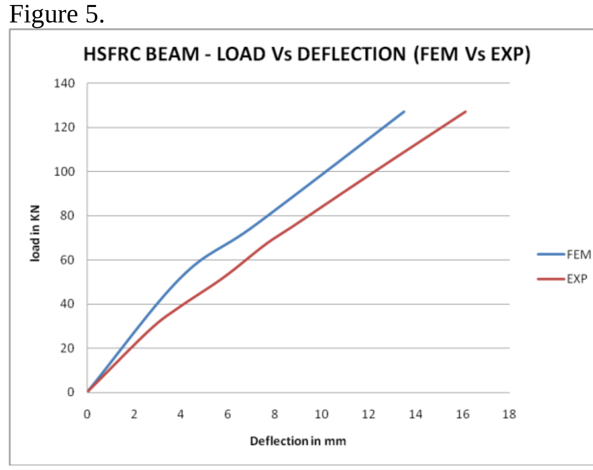

Figure 5. Load - Deflection Relationship – EXPERMENTAL Vs FEA RESULTS

From the comparison graph, the yield and ultimate stages of load and deflections are noted.

6.2 Stress Vs Strain

From the static load case results, the stress Vs strain graph is made shown in Figure 6.

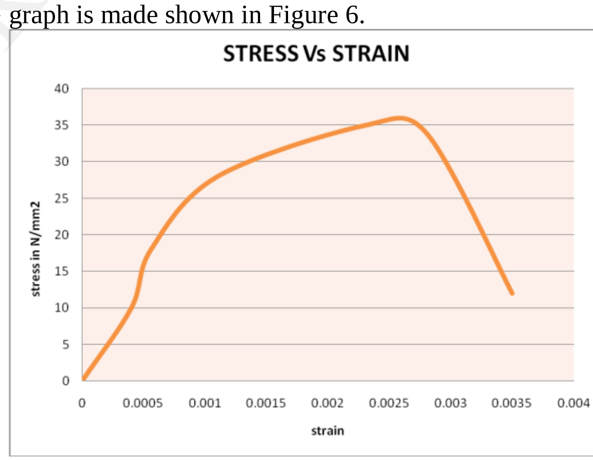

Figure 6. Stress - Strain Relationship

6.3 Stress Vs Time

For the fatigue load case the stress Vs time graph is made shown in Fig 7
From the S – N curve graph, the fatigue life can be identified.
The stress is decreased when the number of cycles of constant load increased.

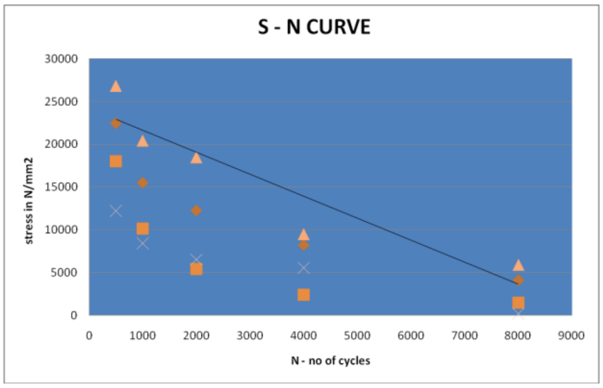

Figure 7. S – N Curve

7. CONCLUSIONS

1.) Static analysis to perform to predict the ultimate capacity of the HSFRC beam using MSC/NASTRAN – PATRAN software for monotonically increasing load up to failure.
2.) From the static results of software analysis, we concluded that the deflection of HSFRC beam is lesser than the experimental HSFRC beam values for greater ultimate load.
3.) The presence of steel fibres reduces the deflection more in FEA analysis.
4.) The lower and upper limit of the fatigue loading is derived from the ultimate capacity of the beam (working load).
5.) Fatigue analysis is performing for constant loading for various cycles of loads.
6.) Using these data S-N curve is obtained with number of cycles at a constant load.
7.) Fig shows the S-N curve simulated by MSC/NASTRAN – PATRAN software for HSFRC beams.
8.) Using this curve the fatigue life can be identified.

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