Non Linear Finite Element Analysis of Steel Fibre Reinforced Concrete Beams

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Abstract-The plain concrete normally contains numerous micro and macro cracks and it will begin to propagate in the matrix when load is applied. The addition of randomly spaced, discontinuous steel fibers helps in arresting the propagation of cracks and it cannot be achieved by continuous reinforcement. Thus fibers will help to improve the strength of concrete. In beams, steel fibers are used in combination with conventional reinforcement which improves both the load bearing capacity and the stiffness of the structure. In this project, non-linear finite element analysis is carried out to study the behaviour of steel fiber reinforced concrete beams. The strength of reinforced concrete beam is studied by varying the percentage of steel fibers in concrete. The analysis is done using ANSYS workbench 16.1. The ultimate load carrying capacity and deformation of the steel fibre reinforced concrete beams are investigated. Total of thirty beams are modeled and analysed. Ten beams are reinforced with steel bars and steel fiber of proportions 0%, 1%, 2%, 3%, 4% and next ten beams are reinforced with basalt fibre reinforced polymer (BFRP) bars and steel fibers of proportions 0%, 1%, 2%, 3%, 4% and remaining ten beams are reinforced with carbon fibre reinforced polymer (CFRP) bars and steel fibers of proportions 0%, 1%, 2%, 3%, 4% by volume of concrete with and without shear reinforcement are modeled and compared the strength of all beams and it is found that the beams reinforced with CFRP bar and 4% steel fiber with shear reinforcement has high load carrying capacity and less deflection compared to all beams.

Keywords: Steel fibers; finite element analysis; Concrete beams; ANSYS; CFRP bars; BFRP bars

I. INTRODUCTION

Steel fiber reinforced concrete (SFRC) has superior resistance to cracking and crack propagation. Fiber composites posses increased extensibility and tensile strength. The transformation from a brittle to a ductile type of material would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeatedly applied shock or impact loading. Satisfactory improvement in various strengths is observed with the inclusion of steel fibers in the plain concrete. Maximum gain in strength of concrete is found to depend upon the amount of fiber content. Steel fiber technology actually transforms a brittle material into a more ductile one. The benefits of using steel fibres reinforcement for shear resistance, however, have not been fully exploited yet, primarily due to lack of understanding of the role which steel fibres play on the shear behaviour of beams with and without stirrup reinforcement. In recent times development of new materials and production methods have increased within the field of construction. One example is the use of steel fibres for various applications. Due to its ability to distribute and prevent cracks from appearing steel fibres have proved rather effective as crack controlling reinforcement, particularly in slabs. By replacing parts of the conventional reinforcement by steel fibres a new, more rational way of production has been developed. The favourable properties provided by fibres have led to increased research efforts aiming at finding other areas of application for steel fibres reinforced concrete. One area where steel fibres may prove effective is as shear reinforcement in concrete beams. Steel fibre when added to concrete, steel fibres. Significantly improve its post-cracking tensile resistance and toughness. SFRC has been used extensively in construction of industrial floors, bridge deck overlays, airport runways, highway pavements, tunnel linings, spillways, dams, slope stabilizations, and many precast products. Fiber reinforced polymer (FRP) composites have gradually gained wide acceptance in civil engineering applications due to their unique advantages including their high strength to weight ratio and excellent corrosion resistance.

II. LITERATURE REVIEW

Komatla Gowtham (2016) observed the natural frequency and damping ratio of a concrete cantilever beams with varying steel fiber percentages and with varying depth of beam by Harmonic analysis using ANSYS. Many research works are conducted on different type of materials under dynamic loading. This paper presents the variation of dynamic characteristics of a steel fibre concrete cantilever beam in which steel fibers are used as a damping material. With increase in fiber percentage at constant depth damping ratio increases. This means the resisting capacity of the material increases. With increase in depth of the beam at constant fiber percentage damping ratio remains constant.

Sumaiya Khatun et al (2014) found out the strength and load deflection behavior of the steel fibre reinforced concrete beams. Two different types of aggregates are used to make SFRC and plain concrete beam specimens, i.e. brick and stone. Three types of beam specimens, i.e. single shear, double shear and flexural shear are modeled and analysed using ANSYS. Enlarged steel fibre is used in this analysis. Results shows increase in shear capacity of 30 to 170% by using steel fiber of 1.5%. Finite element models are analyzed and validated with experimental stress strain behaviours by optimizing poissosn ratio, modulus of elasticity, tensile capacity and stress strain behaviour.
Finite element analyses are conducted to model the tensile capacity of steel fiber-reinforced concrete (SFRC). For this purpose, specimens are casted and tested under direct and uniaxial tension. The fiber volume ratio is maintained at 1.5%. Total 8 numbers of specimens are made and tested in a 1000-kN capacity digital universal testing machine (UTM). Then, the strain data are synthesized with the load data obtained from the load cell of the UTM. The tensile capacity enhancement is found to be 182–253% compared to control specimen to brick SFRC, and in case of stone SFRC, the enhancement is 157–268%. Fibers are found to enhance the tensile capacity as well as ductile properties of concrete that ensures to prevent sudden brittle failure. The specimens are modeled in the ANSYS 10.0 finite element platform and analyzed to model the tensile capacity of brick and stone SFRC. The SOLID65 element is used to model the SFRC as well as plain concretes by optimizing the Poisson’s ratio, modulus of elasticity, tensile strength, and stress–strain relationships as well as failure pattern and failure locations. Last of all, the finite element outputs are found to hold good agreement with the experimental tensile capacity which validates the FE modeling.

III. METHODOLOGY

This project carried out on beams reinforced with steel bars and steel fibre of proportions 0%, 1%, 2%, 3%, and 4% by volume of concrete with and without shear reinforcement and beams reinforced with FRP bars and steel fibre of proportions 0%, 1%, 2%, 3%, and 4% by volume of concrete with and without shear reinforcement modeled to compare strength of each beam.

A. Review of Literature

Various literatures were studied and reviewed, and the research gap was identified.

B. Research Gap Identification

In all the reviewed literatures, concrete beams reinforced with steel fibre and steel bars were modeled and analyzed. Here, in this project, non-linear finite element method using the software ANSYS workbench is used to determine the ultimate load carrying capacity and deformation of thirty beams of size 1500x200x250mm reinforced with steel fibres of proportions 0%, 1%, 2%, 3%, and 4% and FRP bars are modeled with and without shear reinforcement by volume of concrete to compare strength of each beam.

C. Validation

The validation on the referred paper, "Finite Element Analysis on the Steel Fiber Reinforced Concrete" is done.

D. Modeling and Analysis

In this project, different models are prepared. Analysis is carried out by non-linear static analysis. A two-point static loading technique was utilized to examine the simply supported beam. Models are prepared using ANSYS workbench 16.1. In ANSYS, the models provided with different percentage of steel fiber with and without shear reinforcement. Beam of size 1500x200x250 mm reinforced with 0%, 1%, 2%, 3%, and 4% steel fibre and steel bar, beam of size 1500x200x250mm reinforced with 0%, 1%, 2%, 3%, and 4% steel fibre and BFRP bar and beam of size 1500x200x250mm reinforced with 0%, 1%, 2%, 3%, and 4% steel fibre and CFRP bar with and without shear reinforcement are modeled and analyzed.

E. Comparison of parameters

The parameters such as ultimate load carrying capacity and corresponding deflection of different concrete beam models are compared.

F. Results and discussions

Results obtained are analyzed and discussed.

IV. MODELING AND ANALYSIS

Analysis is carried out by non-linear static analysis. A two-point static loading technique was utilized to examine the simply supported beam. Models are prepared using ANSYS workbench 16.1. These models are prepared by providing different percentage of steel fibers with and without shear reinforcement. Beam of size 1500x200x250mm is modeled as shown in fig.1.

Fig.1 ANSYS model
A. ANSYS
ANSYS is a general purpose finite element modeling package for numerically solving a wide variety of mechanical problems. These problems include static or dynamic structural analysis (both linear and non-linear). ANSYS consists of two working platform called APDL and workbench. ANSYS offers a easy and flexible platform for performing finite element analysis of structures or models with great accuracy.

B. Finite element analysis
The finite element approach a numerical method for solving differential equation generated by theories of mechanics such elasticity theory and strength of materials. The basis of a finite element method is the representation of the body or a structure by an assemblage of subdivisions called finite elements. It is common practice to use approximate solutions of differential equation as the basis for structural analysis. This is usual done using numerical approximation in structural analysis is the finite element method(FEM). FEM is best understood from its practical application known as finite element analysis(FEA). FEA as applied in engineering is a computational tool for performing engineering analysis. Non linear analysis gives enhanced data of serviceability and ultimate strength.

C. Modeling
The software ANSYS offers a variety of material models for different materials and purposes. The most important material models in ANSYS for RCC structure are concrete and reinforcement. Workbench 16.1 has been used to model the concrete beams. Different models considered are shown in table 1.

| TABLE 1 BEAMS REINFORCED WITH STEEL BAR, BFRP BAR, CFRP BAR AND DIFFERENT PERCENTAGE OF STEEL FIBERS WITH AND WITHOUT STEEL REINFORCEMENT. |
|---|---|---|---|---|---|
| Without shear reinforcement | With shear reinforcement |
| Model no: | % of steel fibres | Type of bars | Model no: | % of steel fibres | Type of bars |
| 11 | 0 | BFRP | 26 | 0 | BFRP |
| 12 | 1 | CFRP | 27 | 1 | CFRP |
| 13 | 2 | Steel | 28 | 2 | Steel |
| 14 | 3 | BFRP | 29 | 3 | BFRP |
| 15 | 4 | CFRP | 30 | 4 | CFRP |

D. Details of the specimen
The dimension of the beam is taken as 1500x200x250mm. Diameter of the reinforcement bar is 8mm. Diameter of the stirrups provided for beams with shear reinforcement is 6mm and is spaced at 120mm c/c.

E. Properties of the materials
1. Concrete
The grade of concrete (fck) is M30 and Fe 415 (fy) grade of steel is used.
Modulus of elasticity of concrete (Ec) is 27386.13 MPa
Poisson's ratio of concrete (µ) is 0.15.
2. Steel
The grade of steel is Fe250 is used.
Modulus of elasticity of steel is 200000 MPa
Poisson's ratio of steel is 0.3.
3. BFRP
Tensile strength is 2900MPa
Modulus of elasticity is 86000 MPa
Poisson's ratio is 0.2
4. CFRP
Tensile strength is 2300MPa
Modulus of elasticity is 165000 MPa
Poisson's ratio is 0.3
5. Steel fibre
i) For 1% steel fibre
Compressive strength is 43.33 MPa
Flexural strength is 6.01MPa
Modulus of elasticity is 33041.64MPa
ii) For 2% steel fibre
Compressive strength is 44.67MPa
Flexural strength is 6.11MPa
Modulus of elasticity is 33417.81MPa
iii) For 3% steel fibre
Compressive strength is 46MPa
Flexural strength is 6.21MPa
Modulus of elasticity is 33911.65MPa
iv) For 4% steel fibre
Compressive strength is 44.67MPa
Flexural strength is 7.01MPa
Modulus of elasticity is 33417.81MPa

F. Element type and mesh type
1. Concrete - Solid 65 which has no real constants.
2. Bar - Link 180 which has real constants.
3. Meshing - Mapped meshing done using hexahedron meshing element as shown in figure 2.

G. Loads and boundary condition
Modeling of boundary condition are must in ANSYS analysis and the most critical aspect in achieving sensible, reliable data from a finite element method. Therefore simply supported beam is taken for analysis. Loading and supports are shown in figure 3.

V. RESULT AND DISCUSSION
Analysis of beam reinforced with 4% steel fibre and steel bar without shear reinforcement is done. The deformed shape of the beam is shown in fig 4.

Fig. 4 Total deformation developed in concrete beam with 4% steel fibre and steel bar without shear reinforcement.

Analysis of beam reinforced with 4% steel fibre and BFRP bar without shear reinforcement is done. The deformed shape of the beam is shown in fig 5.

Fig. 5 Total deformation developed in concrete beam reinforced with 4% steel fibre and BFRP bar without shear reinforcement.
Analysis of beam reinforced with 4% steel fibre and CFRP bar without shear reinforcement is done. The deformed shape of the beam is shown in fig.6.

![Fig.6 Total deformation developed in concrete beam with 4% steel fibre and CFRP bars without shear reinforcement.](image)

Analysis of beam reinforced with 4% steel fibre and steel bar with shear reinforcement is done. The deformed shape of the beam is shown in fig. 7.

![Fig.7 Total deformation developed in concrete beam reinforced with steel bar and 4% steel fibre with shear reinforcement.](image)

Analysis of beam reinforced with 4% steel fibre and BFRP bar with shear reinforcement is done. The deformed shape of the beam is shown in fig.8.

![Fig.8 Total deformation developed in concrete beam with 4% steel fibre and BFRP bars with shear reinforcement.](image)

Analysis of beam reinforced with 4% steel fibre and CFRP bar with shear reinforcement is done. The deformed shape of the beam is shown in fig.9.

![Fig.9 Total deformation developed in concrete beam reinforced with 4% steel fibre and CFRP bars with shear reinforcement.](image)

Load deflection curve is plotted for beams reinforced with CFRP bar and different percentage of steel fibers without shear reinforcement is shown in fig.10.

![Fig.10 Load deflection curve for beam reinforced with CFRP bar and different percentage of steel fibers without shear reinforcement.](image)
A. Comparison of results

Beams reinforced with steel bar and 1%, 2%, 3%, 4% steel fibre is compared with beams reinforced with steel bar and 0% steel fibre, beams reinforced with BFRP bar and 1%, 2%, 3%, 4% steel fibre is compared with beams reinforced with BFRP bar and 0% steel fibre, beams reinforced with CFRP bar and 1%, 2%, 3%, 4% steel fibre is compared with beams reinforced with CFRP bar and 0% steel fibre with and without shear reinforcement is shown in table 2 and table 3.

**TABLE 2 COMPARISON OF ULTIMATE LOAD AND DEFLECTION OF BEAMS REINFORCED WITH STEEL BAR, BFRP BAR, CFRP BAR AND DIFFERENT PERCENTAGE OF STEEL FIBERS WITHOUT SHEAR REINFORCEMENT.**

<table>
<thead>
<tr>
<th>Type of bar</th>
<th>% of steel fibre</th>
<th>Load (N)</th>
<th>% increase in load</th>
<th>Deflection (mm)</th>
<th>% decrease in deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bar</td>
<td>0%</td>
<td>147590</td>
<td>14.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>156460</td>
<td>12.91</td>
<td></td>
<td>10.41</td>
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<td></td>
<td>2%</td>
<td>168380</td>
<td>12.45</td>
<td></td>
<td>13.60</td>
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<tr>
<td></td>
<td>3%</td>
<td>176500</td>
<td>11.75</td>
<td></td>
<td>13.46</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>185520</td>
<td>9.01</td>
<td></td>
<td>37.47</td>
</tr>
<tr>
<td>BFRP bar</td>
<td>0%</td>
<td>140330</td>
<td>21.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>151180</td>
<td>19.48</td>
<td></td>
<td>9.52</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>163180</td>
<td>17.34</td>
<td></td>
<td>19.46</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>174430</td>
<td>16.38</td>
<td></td>
<td>23.92</td>
</tr>
<tr>
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<td>4%</td>
<td>183280</td>
<td>12.31</td>
<td></td>
<td>42.82</td>
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<tr>
<td>CFRP bar</td>
<td>0%</td>
<td>206190</td>
<td>9.03</td>
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</tr>
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<td>1%</td>
<td>218290</td>
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<tr>
<td></td>
<td>2%</td>
<td>229940</td>
<td>8.66</td>
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<td></td>
<td>3%</td>
<td>234230</td>
<td>8.47</td>
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<td>6.20</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>250580</td>
<td>21.53</td>
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<td>20.93</td>
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</tbody>
</table>

**TABLE 3 COMPARISON OF ULTIMATE LOAD AND DEFLECTION OF BEAMS REINFORCED WITH STEEL BAR, BFRP BAR, CFRP BAR AND DIFFERENT PERCENTAGE OF STEEL FIBERS WITH SHEAR REINFORCEMENT.**

<table>
<thead>
<tr>
<th>Type of bar</th>
<th>% of steel fibre</th>
<th>Load (N)</th>
<th>% increase in load</th>
<th>Deflection (mm)</th>
<th>% decrease in deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bar</td>
<td>0%</td>
<td>153680</td>
<td>11.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>163080</td>
<td>10.18</td>
<td></td>
<td>9.03</td>
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<tr>
<td></td>
<td>2%</td>
<td>174210</td>
<td>9.67</td>
<td></td>
<td>13.58</td>
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<tr>
<td></td>
<td>3%</td>
<td>185520</td>
<td>8.86</td>
<td></td>
<td>20.83</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>193450</td>
<td>7.24</td>
<td></td>
<td>35.30</td>
</tr>
<tr>
<td>BFRP bar</td>
<td>0%</td>
<td>136800</td>
<td>19.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>167550</td>
<td>17.58</td>
<td></td>
<td>10.49</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>178500</td>
<td>16.79</td>
<td></td>
<td>14.51</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>188580</td>
<td>11.89</td>
<td></td>
<td>39.46</td>
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<tr>
<td></td>
<td>4%</td>
<td>199160</td>
<td>9.63</td>
<td></td>
<td>50.97</td>
</tr>
<tr>
<td>CFRP bar</td>
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<td>234320</td>
<td>7.89</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1%</td>
<td>244260</td>
<td>7.56</td>
<td></td>
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<tr>
<td></td>
<td>2%</td>
<td>256750</td>
<td>7.35</td>
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<td>6.84</td>
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<tr>
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<td>267130</td>
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<td></td>
<td>8.62</td>
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<tr>
<td></td>
<td>4%</td>
<td>278960</td>
<td>6.51</td>
<td></td>
<td>17.49</td>
</tr>
</tbody>
</table>

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Load deflection curve is plotted for beams reinforced with CFRP bar and different percentage of steel fibers with shear reinforcement is shown in fig.11.

Fig.10 Load-deflection curve of beams reinforced with CFRP bar and different percentages of steel fibers without shear reinforcement.

From figure 10, it is clear that beam reinforced with CFRP bar and 4% steel fibre has the highest load carrying capacity and lowest deflection.

From figure 11, it is clear that beam reinforced with CFRP bar and 4% steel fibre has the highest load carrying capacity and lowest deflection.
Deflection of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers without shear reinforcement is shown in fig.12.

Fig.12 Deflection comparison chart of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers without shear reinforcement.

From figure 12, it is clear that beam reinforced with CFRP bar and 4% steel fibre has less deflection.

Ultimate load of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers without shear reinforcement is shown in fig.13.

Fig.13 Ultimate load comparison chart of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers without shear reinforcement.

From figure 13, it is clear that beam reinforced with CFRP bar and 4% steel fibre has high load carrying capacity.

Deflection of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers with shear reinforcement is shown in fig.14.

Fig.14 Deflection comparison chart of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers with shear reinforcement.

From figure 14, it is clear that beam reinforced with CFRP bar and 4% steel fibre has less deflection.

Ultimate load of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers with shear reinforcement is shown in fig.15.

Fig.15 Ultimate load comparison chart of beams reinforced with steel bar, BFRP bar, CFRP bar and different percentage of steel fibers with shear reinforcement.

From figure 15, it is clear that beam reinforced with CFRP bar and 4% steel fibre has high load carrying capacity.
The following conclusions are obtained.

1. As the percentage of steel fibers increases from 0 to 4%, load carrying capacity increases and deflection decreases.

2. Without shear reinforcement, ultimate load carrying capacity of beam reinforced with CFRP bar and 4% steel fibers is increased about 21.53% when compared to beam reinforced with CFRP bar and 0% steel fibers.

3. Deflection of beam reinforced with CFRP bar and 4% steel fibers without shear reinforcement is decreased about 20.93% when compared to beam reinforced with CFRP bar and 0% steel fibers without shear reinforcement.

4. Ultimate load bearing capacity of beam reinforced with CFRP bar and 4% steel fibers with shear reinforcement is increased about 19.05% when compared to beam reinforced with CFRP bar and 0% steel fibers with shear reinforcement.

5. Deflection of beam reinforced with CFRP bar and 4% steel fibers with shear reinforcement is decreased about 17.49% when compared to beam reinforced with CFRP bar and 0% steel fibers with shear reinforcement.

6. Maximum load carrying capacity is for beams having 4% steel fibers for all beams with and without shear reinforcement. This may be due to the fact that concrete is weak in tension and it requires some reinforcement to cope with tensile forces.

7. From the results, beam reinforced with CFRP bar and 4% steel fibers which has highest load bearing capacity and lowest deflection compared to all beams.

REFERENCES


