Finite Element Modeling of Axial Compressive Behaviour of Ultra High Strength Concrete Filled Square and Rectangular GFRP Tubes

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Abstract

Objective: An exploratory research on developing finite element model for studying the axial compressive behaviour of square and rectangular UHSC filled GFRP tubes was conducted. Methods/Statistical Analysis: The well-known fact of deviation in uniformity of confinement in square and rectangular concrete filled GFRP tubes was focused in the nonlinear finite element model. A square and rectangular cross section having same thickness 3mm was chosen keeping two different corner radii 30, and 40mm. The unconfined concrete strength was limited to 120 MPa. The simulation of UHSC filled GFRP tubes were done using ANSYS using elements SOLID 65 for concrete and MEMBRANE 41 for GFRP tube. Findings: The research findings from this investigation on verification by ACI code (ACI committee 440, 2002) revealed that the square CFFTs offer better confinement when compared with rectangular CFFTs and the corner radii significantly affected the ultimate load capacity of the square and rectangular CFFTs. Applications / Improvements: The study has come up with newer method of simulation of GFRP tubes using shell elements assuming perfect bonding between concrete and the tubes. This is the first kind of study in existing FEA database using shell elements. The results agreed with those predicted by the code.

Keywords: Behaviour, Compressive, GFRP, Rectangular, Square, Ultra High Strength Concrete

1. Introduction

The country like India which is seismic prone and vulnerable to inevitable destructions due to earthquake activities, demands alternate and innovative construction methodologies and design procedures to prevent structural collapse. One of the reliable alternate could be using composite materials for construction and developing composite structures in areas prone to seismic activity. An extensive literature survey in this area suggests many innovative techniques for improving the ductility of the structures during the earthquakes and one among them is to use high strength concrete and with better confinement capabilities like Fibre / Fiber Reinforced Polymer (FRP) materials. The history of this material has gained popularity over the past two decades and enormous research works have been carried out in predicting the compressive and flexural behavior of FRP confined concrete in and around the world. The researchers have concluded that the High Strength Concrete (HSC), Ultra High Strength Concrete when used with FRP confinement offers superior structural performance in seismic prone areas. There are two different kinds of methodologies adopted in this research area: Pre Jacketing Method and Post Jacketing Method. In the former methodology, the FRP tube acts as a permanent formwork and concrete is filled into the FRP tube. In the later technique, the FRP wrapping is done on the cast concrete.
Structural element and often this kind of methodology are adopted for retrofitting technique and rehabilitation of structures. The researchers have concluded that there is no much difference in the structural behavior of Pre jacketing methodology and Post jacketing methodologies. However each methodology has its own advantages. There has been lot of research works done in both the areas. There has been majority of studies done on Concrete filled circular FRP tubes. But, the research works on concrete filled square and rectangular FRP tubes is limited. Also it has been observed by the researchers that the confinement provided by circular CFTs is uniform and that provided by square and rectangular CFTs (Concrete Filled FRP tubes) is non uniform. This investigation focused on finite element modeling of Ultra High Strength Concrete (UHSC) filled GFRP (Glass Fibre Reinforced Polymer) tubes under axial compression.

2. Finite Element Modeling

The ultra-high strength concrete filled GFRP tubes were modeled by simulating the GFRP tubes using shell elements and specifying the corresponding thickness for the element. Thus the GFRP tube was modeled using 2D element. The concrete was modeled using solid element (3D solid model). Although previous studies have used 3D solid elements for both concrete and FRP tubes, this research is the first of its kind in the finite element study to use this type of shell element. The study revealed the possibilities of using shell elements for GFRP tubes. The load was applied in all the nodes available at the surface. In the previous studies, the load has been applied as pressure over the area subjected to compression as shown in Figure 1. The formation of cracks has been shown in Figure 2. The element types used are narrated.

2.1 Concrete

The concrete used in this study was modeled using SOLID65 element as shown in Figure 3 which has all the capabilities and properties needed to accurately predict the behavior of all grades of concrete i.e., NSC, HSC and UHSC as the case may be. The eight node - solid element SOLID65 has three degrees of freedom at each node i.e., translation in x, y and z directions was used to model concrete. The element is capable of plastic deformation, cracking in three orthogonal directions and crushing. The unconfined concrete strength was adopted as 120 MPa corresponding to UHSC. The nonlinearity of the concrete was modeled as per IS 456: 2000 and the elastic modulus was defined as

$$E_c = 5000 \sqrt{f_{ck}}$$

and the Poisson’s ratio was taken to be 0.20. The Open Shear Transfer Coefficient and Closed Shear Transfer Coefficient were taken to be...
0.2 and 0.30 respectively and the tensile strength of the concrete element was given as $0.70 \sqrt{f_{ck}}$. The concrete element SOLID 65 was adopted from the FEA software ANSYS 15.0. This study was confined to FEA modeling only and hence the short stocky column having GFRP tube confinement was assumed to be unreinforced.

2.2 Glass Fibre / Fibre Reinforced Polymer Tubes

The GFRP tubes were simulated using MEMBRANE4 element shown in Figure 4. This shell element has membrane (in-plane) stiffness but no bending (out-of-plane) stiffness. It is intended for shell structures where bending of the elements is of secondary importance. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.

3. Conclusions

1. The Table 1 shows the values of stress tensor for both the specimens of dimensions 150 X 120 mm and 133 X 133 of two corner radii 30mm and 40mm. The tabulation shows a steady increase in the stress tensor with increase in the corner radius. This shows the effective confinement behavior of the UHSC filled GFRP tube. It could be noted that the both the specimens don't have much variation in the area except that the shape of the GFRP tubes which are rectangle and square.

2. The Square tube offers better confinement when compared with the rectangular GFRP tube thus showing an increase in the peak strength ($f'_{cu}$) of the UHSC confined GFRP tubes.

3. Even though the area of the rectangular specimen is greater than that of the square one, the confinement of the square tube is uniform whereas the confinement provided by the rectangular specimen is not uniform.

4. The strain reduction factor $K_{\varepsilon}$ as shown in Table 2 is constant as the unconfined concrete strength is 120 MPa for both the specimens.

5. There is no much variation in the ultimate strain $\varepsilon_{cu}$ recorded in the FEA model and a constant range is seen for both the specimens.

6. The corner radius has significant influence in the ultimate strength values of the UHSC filled GFRP tubes as observed in Table 1 showing good increment in the observed values of $f'_{cu}$.
Table 1. Stress values obtained from FEA model

<table>
<thead>
<tr>
<th>SPECIMEN</th>
<th>$f'_c$ (MPa)</th>
<th>$s_x$ (MPa)</th>
<th>$s_y$ (MPa)</th>
<th>$s_z$ (MPa)</th>
<th>$t_{xy}$ (MPa)</th>
<th>$t_{yz}$ (MPa)</th>
<th>$t_{zx}$ (MPa)</th>
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</thead>
<tbody>
<tr>
<td>150A120R30</td>
<td>120</td>
<td>157</td>
<td>-157</td>
<td>8.6</td>
<td>12.6</td>
<td>-9.24</td>
<td>-22.9</td>
</tr>
<tr>
<td>150A120R40</td>
<td>120</td>
<td>-48.6</td>
<td>-31.6</td>
<td>-8.6</td>
<td>15.2</td>
<td>-28.8</td>
<td>33</td>
</tr>
<tr>
<td>133B133R30</td>
<td>120</td>
<td>33</td>
<td>-208</td>
<td>-13.4</td>
<td>12.6</td>
<td>-22.8</td>
<td>31</td>
</tr>
<tr>
<td>133B133R40</td>
<td>120</td>
<td>24</td>
<td>-502</td>
<td>-31.4</td>
<td>14.7</td>
<td>-107</td>
<td>76</td>
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</table>

Table 2. Strain reduction factor

<table>
<thead>
<tr>
<th>SPECIMEN</th>
<th>$f'_c$ (MPa)</th>
<th>$f'_c$ (MPa)</th>
<th>$\varepsilon_{c,0}$ (%)</th>
<th>$\varepsilon_{c,0}$ (%)</th>
<th>$\varepsilon_{h,up}$ (%)</th>
<th>$k_s$</th>
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<tbody>
<tr>
<td>150A120R30</td>
<td>120</td>
<td>157</td>
<td>1.1</td>
<td>0.368</td>
<td>0.00852</td>
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<td>1.27</td>
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<td>0.00852</td>
<td>3.45</td>
</tr>
<tr>
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<td>120</td>
<td>208</td>
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<td>0.368</td>
<td>0.00852</td>
<td>3.26</td>
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<tr>
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<td>502</td>
<td>1.3</td>
<td>0.368</td>
<td>0.00852</td>
<td>3.532</td>
</tr>
</tbody>
</table>

4. Closure

The predicted results are based on FEA modeling and have to be substantiated by experimental studies. In this investigation, after simulating the concrete model and the GFRP tubes, the nodes of close tolerance were merged and thus the delamination behavior of the UHSC filled GFRP tubes have been neglected. Hence further study may focus on simulation adopting solid elements for GFRP tubes as well taking into account the orthotropic nature of the GFRP tubes. Also the study was confined to concrete of strength 120 MPa keeping the thickness of the tube 3mm. The ultimate observation in this FEA study revealed the strain enhancement factor is almost equal for square and rectangular sections. Further studies can be conducted by varying the thickness of GFRP tube and the unconfined concrete strength of the concrete.
5. References