Performance of Reinforced Bottle Shaped Struts in Glass Fiber Reinforced Concrete

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Abstract— The present experimental investigation has been carried out to comparatively evaluate the transverse reinforcement requirement for bottle-shaped struts in glass fiber reinforced concrete and quantify the improved performance of bottle shaped strut for different amounts of transverse reinforcement. The influence of parameters related to transverse reinforcement on the strength and serviceability behavior of bottle-shaped struts also studied. The results of this investigation reveal that the minimum web reinforcement content specified in codes is sufficient for satisfying the serviceability requirements with respect to cracking for M25 grade concrete for fiber reinforced concrete also. As the grade of concrete increases, transverse reinforcement content can be increased for increase in load carrying capacity. Provision of transverse reinforcement with 1\% of glass fibers increases the load carrying capacity by as high as 70\% for M25 and 90\% for M40 grade concrete. Also observed that, performance of reinforced bottle shaped struts depends not only on the amount of reinforcement but also on size and spacing of transverse steel. For the same amount of transverse steel, better to provide less dia bars with close spacing to improve ductility. 

Key words: Reinforced Bottle, Glass Fiber, Reinforced Concrete

I. INTRODUCTION

Reinforced concrete beam theory is based on the Bernoulli’s assumption that strain varies linearly across the depth of the member, as a result of which plane sections remain plane before and after bending. This assumption is validated by St. Venant's principle, which states that the stresses due to axial load and bending approach a linear distribution at a distance approximately equal to the overall depth of the member, \( h \), away from a discontinuity. Therefore, St. Venant's principle does not apply to sections located closer than distance ‘\( h \)’ from a discontinuity in the applied load or geometry. This leads to the identification of the so called Discontinuous or Disturbed or D-region within reinforced concrete members. Thus, reinforced concrete structures may be divided into regions where beam theory is valid, often referred to as 'Beam' or 'Bernoulli' or simply 'B-regions', and regions where discontinuities affect member behavior, known as 'Disturbed' or 'D-regions'.

D-regions occur at statical discontinuities in a member, e.g., in the vicinity of concentrated loads such as supports and applied forces or at geometrical discontinuities marked my abrupt change in the cross sectional dimensions of the structural member.

In general any region outside the D-region is called a 'B-region'. The mechanics and behaviour of B (Bernoulli or Beam) region are well understood and the entire flexural behaviour can be predicted by simple calculations. Members containing significant extents of D-regions are called non-flexural or shear critical members. Some examples of non-flexural members are deep beams, corbels, articulations, spandrel beams, pile caps, transfer girders and dapped-end beams etc.

As the strain profile in non-flexural members is highly non-linear, they cannot be designed using normal elastic theory. Strut-and-tie modeling is currently the most rational and simple method for designing non-flexural members, i.e., members containing significant extent of D-regions. The Strut-and-tie modeling is based on the lower-bound theorem of the theory of plasticity. In this method, the complex D-region is modeled as a truss carrying the applied loads to the supports. This truss is known as the strut-and-tie model and is a statically admissible stress field in lower-bound (static) solutions. Like a real truss, a strut-and-tie model consists of compression members (struts) and tension members (ties) interconnected at nodes.

Struts are the compression components of a strut-and-tie model that carry compressive forces and represent compressive stress fields whose principal compressive stresses are predominantly along the axis of the strut. The geometry of a strut varies widely and depends on the force path that each individual strut is intended to model. Strut can be prismatic ‘(Fig.-1a)’, bottle-shaped ‘(Fig.1b)’, or fan-shaped ‘(Fig.-1c)’.

Fig. 1: Different types of struts in Strut and Tie modeling

Fig. 2: Prismatic and bottle-shaped struts in a deep beam

Among those three struts, the behavior of a bottle-shaped strut is relatively complex due to the presence of transverse tension, \( T \), which is induced by the outwardly dispersing compressive stress trajectories as shown in Fig. 3. The transverse tension is primarily resisted by concrete until the formation of a splitting crack. Even after cracking, a bottle-shaped strut can continue to remain serviceable and carry significantly higher load provided sufficient and
properly detailed transverse reinforcement is available to ensure equilibrium of forces in the strut.

Fig. 3: Transverse tension in bottle-shaped strut

As per the STM provisions in ACI 318-11, the nominal strength of a bottle shaped strut without axial reinforcement, \( F_{ns} \), is calculated from the expression

\[
F_{ns} = \frac{f_{ce}}{A_{cs}}
\]

Where \( A_{cs} \) is the lesser of the cross-sectional areas of the node-strut interfaces at the two ends of a bottle-shaped strut and \( f_{ce} \) is the smaller of the effective compressive strength values of concrete in the strut obtained from Eqs. (2) and (3) below.

\[
f_{ce} = 0.85\beta_s f_{c}^{'}
\]

\[
f_{ce} = 0.85\beta_n f_{c}^{'}
\]

where \( f_{ce} \) is the specified cylinder crushing strength of concrete, \( \beta_s \) and \( \beta_n \) are the strut efficiency and nodal efficiency factors as per Secs. A.3.2 and A.5.2 of ACI 318-11 respectively.

The ACI Code identifies two types of bottle-shaped struts namely reinforced and unreinforced struts and the efficiency factors specified for these two types of struts for normal concrete are 0.75 and 0.60 respectively for cylinder compressive strengths up to 40 MPa. The larger \( \beta_s \) factor of 0.75 can be used for bottle-shaped struts when the web reinforcement in the strut satisfies the following requirement (Clause A3.3.1 of ACI 318-11)

\[
\sum \frac{A_{si}}{b_{si}} \sin \alpha_i \geq 0.003
\]

Where \( A_{si} \) is the total area of surface reinforcement at spacing \( S_i \) in the i-th layer of reinforcement crossing a strut at an angle \( \alpha_i \) to the axis of strut as shown in fig 4

Fig. 4: Detailing of reinforcement in a bottle-shaped strut

II. RESEARCH SIGNIFICANCE

From the literature, it is found that, by providing provisions to resist transverse tension, load carrying capacity, ductility and cracking behavior of the bottle shaped strut will be significantly improved. The transverse tension can be resisted by providing some reinforcement or by increasing tensile strength of concrete. As it is known that addition of fibers increase tensile strength of concrete, an attempt was made to study the performance of bottle shaped strut with transverse reinforcement in glass fiber reinforced concrete.

III. EXPERIMENTAL PROGRAM

The experimental program carried out for two different grades of concrete in two phases. In phase 1, optimum fiber content in concrete, for maximum compressive and tensile strength is found by testing standard cubes and cylinders as per IS 5816(1999) & IS 516 (1959) respectively for different amounts glass fiber volume fractions in concrete. In phase II, concrete panels of size 400mm X 400mm X 100 mm are casted with optimum fiber concrete obtained in phase I and for different amounts of transverse reinforcement in the strut, and tested to failure by applying in plane loading as shown in Fig.5.

IV. INSTRUMENTATION AND TEST PROCEDURE

Cubes and Cylinders are tested for ultimate load under axial compression in CTM. Panels are tested under compression in plane loading using 200kN capacity UTM as shown in Fig.5. Peak load is measured for every panel.

V. PHASE – I RESULTS

<table>
<thead>
<tr>
<th>Grade</th>
<th>% fiber</th>
<th>Comp. Strength (fck)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M25</td>
<td>0</td>
<td>26.73</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>27.70</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>28.80</td>
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<tr>
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<td>27.03</td>
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<tr>
<td></td>
<td>2.0</td>
<td>22.97</td>
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<td></td>
<td>2.5</td>
<td>19.53</td>
</tr>
<tr>
<td>M40</td>
<td>0</td>
<td>42.10</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>43.20</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
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<td>35.30</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>32.10</td>
</tr>
</tbody>
</table>

Table 1: Compressive Strength Results
Table 2: Split Tensile Strength Results

<table>
<thead>
<tr>
<th>% of fiber</th>
<th>Split Tensile Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.8</td>
</tr>
<tr>
<td>1</td>
<td>3.3</td>
</tr>
<tr>
<td>1.5</td>
<td>3.1</td>
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<tr>
<td>2</td>
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<tr>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>0</td>
<td>6.2</td>
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<tr>
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</tr>
<tr>
<td>1</td>
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</tr>
<tr>
<td>1.5</td>
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<td>5.4</td>
</tr>
<tr>
<td>2.5</td>
<td>5.2</td>
</tr>
</tbody>
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Table 3: Specimen Details

Comparison of increase in load carrying capacity of the strut with different amounts of transverse reinforcement ratio, with respect to unreinforced normal concrete is shown below “Fig. 8,9” for M25 and M40 grades of concrete.

Table 4: Details of Panels

<table>
<thead>
<tr>
<th>S.No</th>
<th>Grade of Concrete</th>
<th>% of steel</th>
<th>Dia of bar</th>
<th>Spacing of bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M25</td>
<td>0.1</td>
<td>4mm</td>
<td>105mm</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.1</td>
<td>3mm</td>
<td>59mm</td>
</tr>
<tr>
<td>3</td>
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<td>0.3</td>
<td>4mm</td>
<td>35mm</td>
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<tr>
<td>4</td>
<td></td>
<td>0.3</td>
<td>3mm</td>
<td>20mm</td>
</tr>
</tbody>
</table>

VI. PHASE – II RESULTS

Specimen details and test results of panels shown in Table 3 below

**Table 2: Split Tensile Strength Results**

- From the “Fig. 6,7” it can be observed that, both compressive strength and split tensile strength were maximum at 1% volume fraction of glass fibers in concrete. Therefore for Phase II, panels were cast for different transverse reinforcement at 1% fiber volume fraction.

**Table 3: Specimen Details**

ACI 318-11 spoke only about area of transverse reinforcement in bottle shaped strut but not on the effect of spacing and size of reinforcement. Therefore effect of spacing of reinforcement is studied by providing same amount of area with different spacing using different diameters of bars. Details of the panels studied for this parameters is given in Table 4.
Fig. 10: Load Vs Deflection of 1% fiber at 0.3 % steel

From the “Fig.10” it can be observed that, spacing of reinforcement play an important role in improving the ductility and performance from serviceability point of view.

VIII. CONCLUSIONS

From the results shown above, the following conclusions can be drawn

Addition of glass fibers to the concrete improves the performance of concrete (compressive strength and split tensile strength) for fiber content up to 1% of cement weight, beyond which the performance is degraded. Therefore 1% volume fraction of glass fibers is optimum for concretes up to M40 grade.

By providing transverse reinforcement to bottle shaped strut, load carrying capacity is increased to as high as 70% for M25 grade concrete and 90% for M40 grade concrete compared to unreinforced bottle shaped strut in normal concrete.

Load carrying capacity of bottle shaped strut is increased up to transverse reinforcement of 0.3% of gross cross section area beyond which it is constant for M25 grade concrete, whereas for M40 grade concrete, load carrying capacity is increased up to 0.4% transverse reinforcement. Therefore amount of transverse reinforcement can be increased as the concrete grade increases.

In addition to the amount of transverse reinforcement, spacing of reinforcement also plays a very important role in improving the performance of the bottle shaped strut in terms of ductility. Providing smaller dia bars with less spacing is a better option.

Load deformation behavior is significantly improved with addition of transverse reinforcement to bottle shaped strut. Therefore addition of transverse reinforcement increases not only the strength but also the ductility characteristics of the bottle shaped struts.

ACKNOWLEDGEMENT

I would like to thank Department of Civil Engineering staff and management of MVGR College of Engineering for their support in doing this work.

REFERENCES


