Influence of Square and Triangular Shape Stirrups in a Square Column

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Abstract: The design of transverse reinforcement is an important aspect in the design of a concrete column. However, it is concrete which plays the major role in bearing axial load upon column, but it always the reinforcement which takes care of the column after of yielding of concrete began and not much importance is given to the transverse reinforcement in IS code, only minimum requirement of cross sectional area and spacing is specified. For small cross-sectional columns only square stirrups specified. This paper presented a study of RCC column with square stirrups replaced by triangular stirrups. For the study, 3-D finite element model is developed using the commercial software ABAQUS (ver. 6.13). Two columns one with square stirrups and another with triangular stirrups have been modeled and analyzed under same loading condition, each column possessed same material properties. Obtained result shows the improvement in deformation and plastic strain generated in concrete post yielding, in column with triangular stirrups with respect to column with square stirrups.

1. Introduction

In general, designing and construction of structures like small residential buildings are not done strictly according to standard codes of practice. Even if care of designing is taken properly then their execution are not done properly. It is observed that various small structures like residential buildings, shopping complexes initially constructed to single or double storey but later on more stories added to them without doing proper up-gradation of columns and foundation of the structure. In almost every structure, columns are more abused with compared to any other structural elements. Provisions of minimum size and concrete cover are mostly neglected, making it under size resulting narrow gaps in formworks and contact of reinforcement with formworks, which makes concreting difficult. So, to make concreting easier concrete are made porous and rebars are kinked to get better alignment. Transverse reinforcements are often kept to minimum.

Columns transfer the loads from beams and slabs to the foundation which means beams and slabs are supported on columns. In many cases the failure of whole structure was triggered by failure of columns. Hence their designing is very important keeping in mind various kind of loads acting on them.

1.1. Behaviour of Reinforced Concrete

It is well known that, concrete when confined with reinforcement shows significant improvement in strength and ductility under compression. Under high axial compression, due to internal cracking concrete tends to develop transverse strain. But if reinforcements are provided then the concrete exerts pressure on them, which in turn exerts reaction pressure on concrete (Subramanian [9]). This limits further cracking in the concrete and improving its ability to sustain higher stress and strain. So in the case of column transverse reinforcement's role is as crucial as of longitudinal reinforcement and in fact without proper transverse reinforcement, longitudinal reinforcement will not perform to its full potential. As discussed above effective confinement of reinforced concrete columns is very important aspect in its designing. However initially being neglected, confining reinforcement was given importance in later researches (Sakai [6]).

1.2. Purpose of Transverse Reinforcement

Transverse reinforcement has an important role in the design of a RCC column and also having many functions for which they are suggested in the design of beams and columns. Transverse reinforcement prevents buckling of longitudinal reinforcement bars. It resists shear force and avoids shear failure. It confines the concrete core to provide sufficient ductility (deformability). It clamp together lap splices. But it should be noted that, all of the above functions are effective only when concrete cracks or spalls. All of the above functions are critical for the column to maintain vertical or lateral capacities and post-yield range.

2. Finite Element Modeling

Experimental based methods are widely used as a mean to analyze individual elements of concrete structure such as column and the effect of concrete strength under static or dynamic loading are
evaluates. While analysis with experimental methods we get real life response, but it is extremely time consuming, and the use of materials can be quite costly. With the development of several numerical tools, there are advanced techniques employed for analyzing the behavior of concrete structure.

The finite element method is a special form of matrix analysis, where the whole continuum is discretized into a finite number of elements connected at different nodal points. The general principles and use of the finite element method are well documented (e.g. Desai and Abel [2], Zienkiewicz et al. [10]).

In structural analysis, nonlinear modeling using finite element analysis has evolved to address complex issues of various structural forms (Claeson [1]). In fact, due to the universal nature of the finite element method in modeling real-life complex conditions including geometric and material nonlinearity in the response, this numerical technique has been widely used in design and assessment of complex structures (Rombach [5]).

Numerical analysis, typically using the finite element or finite difference method, is currently the most advanced tool available to analyze reinforced concrete structures.

Finite element modeling of concrete column with longitudinal and stirrups reinforcement is developed using ABAQUS, ver. 6.13 (Simulia [7, 8]) commercial software. The step by step modeling procedure is used in the analysis. From the geometry to the job creation in the software, the step-by-step model is prepared for the analysis. The meshing, boundary condition and interaction is also included in the given model. The material property of concrete is represented in Table 1 (Jankowiak [3], Oliver [4]).

Table 1 Concrete material properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2.43E-009</td>
</tr>
<tr>
<td>Elastic</td>
<td></td>
</tr>
<tr>
<td>Young’s Modulus (N/mm²)</td>
<td>20000</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.18</td>
</tr>
<tr>
<td>Concrete Damaged Plasticity</td>
<td></td>
</tr>
<tr>
<td>Dilation Angle (Degree)</td>
<td>31</td>
</tr>
<tr>
<td>Eccentricity (mm)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The density, elastic and plastic properties of steel material for RRC column for both the cases of stirrups (square and triangular) used in the finite element analysis model are given in Table 2 (Jankowiak [3], Oliver [4]).

Table 2. Steel properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
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<td>Density</td>
<td>7.85E-009</td>
</tr>
<tr>
<td>Elastic</td>
<td></td>
</tr>
<tr>
<td>Young’s Modulus (N/mm²)</td>
<td>210000</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
</tr>
<tr>
<td>Yield Stress (N/mm²)</td>
<td>350</td>
</tr>
<tr>
<td>Plastic Strain</td>
<td>0</td>
</tr>
</tbody>
</table>

The design pattern of proposed model for triangular stirrups are represented in Fig. 1a (plan view) and Fig. 1b (perspective view) respectively. Rest of the design of rebars and concrete parts of column are kept as per standard practice. Arrangement of transverse reinforcement is given in Figure 2a,b (a: square, b: triangular). The spacing of square stirrups is 200 mm while spacing of triangular stirrups is 100 mm.
3. Results

Concrete columns of 3.1 m height with square stirrups and triangular stirrups are analyzed separately in this research work. Finite element of concrete column finite element models with square and triangular stirrups are developed with the help of ABQUS (ver. 6.13). After the analysis of these models, vertical deformations and plastic strain in concrete are presented in the following subsections.

3.1. Vertical deformation

The results obtained from the finite element analysis of square and triangular shapes of stirrups in square column, the initial vertical displacement of the column with square and triangular shapes before yield range of failure of concrete are 6.7 mm and 6.5 mm respectively. The final vertical displacement estimated under plastic failure limit of concrete for column with square and triangular shapes of stirrups model is 571.37 mm and 407.26 mm respectively which is comparable with the results and also indicates that stirrups are influencing the deformation behavior of the column particularly in post-yield range. The static general force of unit 30 MPa is applied at the top of the column for the analysis. The results obtained from the finite element analysis for vertical displacement for these models with square stirrups and triangular stirrups are in the Figure 3 and Figure 4 respectively. The results are comparable with the performance of concrete column for the arrangements of the shapes of stirrups.

3.2. Plastic Strain in concrete

The results from the analysis of the finite element models with square stirrups and triangular stirrups are obtained and the estimated plastic strains for these two cases are presented in the Figure 5 and Figure 6 respectively. The plastic strain estimated for column with square stirrups model is 0.302 and the plastic strain estimated for column with triangular stirrups is 0.216 which is comparable with the results and also indicates that stirrups are influencing the plastic behavior of concrete in the
column. The static general force of unit 30 MPa is applied at the top of the column for the analysis.

![Plastic strain in column with square stirrups](image)

**Figure 5.** Plastic strain in column with square stirrups

![Plastic strain in column with triangular stirrups](image)

**Figure 6.** Plastic strain in column with triangular stirrups

4. Conclusions

The performance of concrete columns with square and triangular stirrups are assessed by developing models with the help of finite element based commercial software ABAQUS (ver. 6.13). The vertical displacements and plastic strain in concrete are estimated after the static analysis of the model. The static general force of unit 30 MPa is applied at the top of the column. The estimated vertical displacements and plastic strains are clearly indicating that transverse reinforcement influence the vertical deformation behavior of the column in post-yield range as well as the plastic behavior of concrete.

5. References


