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Seismic Analysis of Beam Column Joints in Reinforced Concrete Moment Resisting Frames

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Abstract—*The beam column joint is the crucial zone in a reinforced concrete moment resisting frame. It is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. During earthquake, the beam column joints may fail due to the bond and shear failure mechanisms which are brittle in nature. Therefore, a code should be developed to provide adequate anchorage to longitudinal bars and confinement of core concrete in resisting shear, so that the joint can bear the extensive inelastic deformations in a stable manner. In Indian practice the joints are generally assumed to be rigid which fails to consider the effect of high shear forces developed within the joint. Thus the behavior of the joints must be understood properly for safe design of the joints. Design and detailing of beam column joints in reinforced concrete structures are given in IS 13920. But, considering the earthquake effects followed after the release of the IS 13920: 1993, a need to improve the code for more safety was considered. Many deficiencies were identified and a revised version was proposed. In this paper, a three bay five storey reinforced concrete moment resisting frame for a general building located in zone V has been designed in SAP as per code procedures (IS 456:2000 and IS 1893:2002) and the beam column joints are designed and detailed as per the recommendations of proposed draft of IS 13920 and analyzed in ANSYS.*

1. INTRODUCTION

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint. Beam column joints are crucial connecting elements of a moment resisting frame which are critical in assuring the safety of a structure during earthquakes. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members especially under seismic loading. The pattern of forces acting on a joint depends upon the configuration of the joint and the type of loads acting on it. The stress resultants from the framing members are transferred into the joint through bond forces along the longitudinal reinforcement bars passing through the joint and through flexural compression forces acting on the joint face. The joints should have enough strength to resist the induced stresses and sufficient stiffness to control undue deformations. However it is of particular importance to ensure that joint deformations, associated with shear and particularly bond mechanisms, do not contribute excessively to overall storey drifts [1].

Extensive research has been carried out on studying the behavior of joints under seismic conditions through experimental and analytical studies. Since their constituent materials have limited strengths, the joints have limited force carrying capacity which develop complex mechanisms involving bond and shear within the joint. When forces larger than these are applied during earthquakes, joints are severely damaged. If not designed properly the joint region may jeopardize the entire structure, even if other structural members conform to the design requirements [2]. Repairing damaged joints is difficult, and so beam column joints must be designed primarily to resist damage in earthquake prone regions. Jain et al. [3] studied the design and detailing code provisions on beam-column joints in IS 13920 : 1993 [4]. It is reported that these do not adequately address the prevention of anchorage and shear failure in this region during severe earthquakes.

Also after the release of the code, the earthquakes viz. (the 1997 Jabalpur, 2001 Bhuj, 2004 Sumatra, 2006 Sikkim, and 2011 Sikkim earthquakes) had disastrous effects. Thus it was felt that the IS 13920 needs further improvement, and a revised version was proposed. The revised version is assisted by ACI 318[5], IBC 2003[6], EN 1998-1:2003[7], NZS 3102: Part 1:1995[8].

2. ANALYSIS MODELS AND METHODS

A five storey RC frame having plan dimensions of 12m x 9m located in seismic zone V on medium soil is considered. The building details are shown in fig. Since the height of the regular building is 13.5m, dynamic analysis is not mandatory. The frame is designed based on IS codes. Using SAP [9] the frame model is checked for its capability to withstand loads. Then a particular joint is modeled and analyzed in ANSYS [10] to understand the joint strength more accurately.

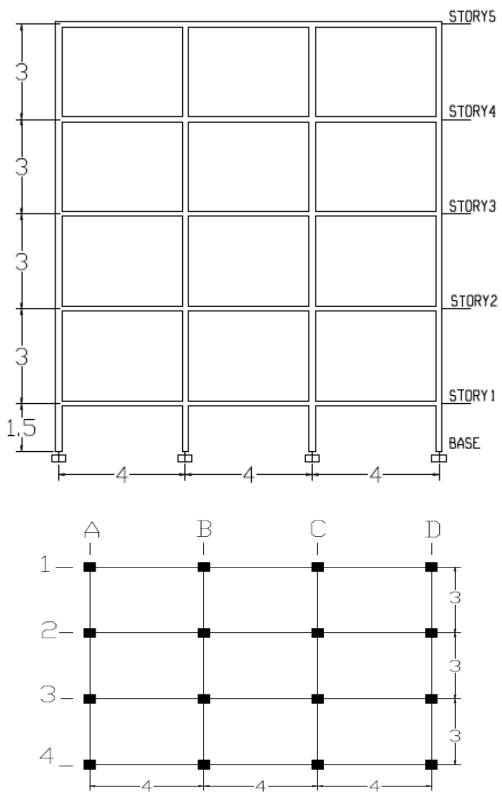

Fig. 1: Elevation and plan of building (All dimensions in m)

3. METHODOLOGY

Using the proposed draft of IS 13920 [11], the following checks are done for beam column joint

1. Check for joint shear: the following are calculated-
   a. Column shear, $V_{col} = 1.4(M_h + M_s)/h_s$
   b. Force developed in top (T_1) and bottom bars(T_2), T = 1.25 A_{st} x f_y
   c. Joint shear, $V_{joint} = T_1 + T_2 - V_{col}$
   d. The effective width of the joint ,
      i. $b_j = b_b + 0.5 \times h$
      ii. $b_j = b_c$, whichever less, h= full depth of column
   e. Shear strength of joint = $1.2\sqrt{f_{ck}}\, A_g$

If joint shear is less than the shear strength of the joint, the design is safe. If not the section needs to be redesigned.

2. Check for flexural ratio

   SM_u/SM_b must be greater than 1.1, else redesign the section

   Mu is obtained from SP 16 using the values of $P_u/f_{ck}bD(=0)$, d'/D and p/f_{ck}

Mb is the total hogging and sagging moment in the beam.

The procedure is followed for check for earthquake in X and Y direction.

3. Confining links:
   a. This special confining reinforcement shall not be more than
      i. 1/4th of minimum member dimension of beam or column,
      ii. 6 times diameter of the smallest longitudinal reinforcement bars,
      iii. 100 mm,

      But not less than 75 mm.
   b. The special reinforcement shall have an area of cross section not less than

$$A_{sh} = \frac{0.18 \times S\, h\, f_{ck}}{f_y}\left(\frac{A_g}{A_k} - 1\right)$$

Where h = longer dimension of rectangular stirrup measured to its outer face, which does not exceed 300 mm

A_k= area of confined concrete core in rectangular stirrup measured to its outer dimensions.

A_g = Gross area of column cross section.

4. RESULTS AND DISCUSSIONS

Following the code provisions [12,13] the beam column joint is designed and detailed.

The beam size is of 300 mm x 400 mm and has 4 nos of 20ø HYSD bars on the top and 3 nos of 16ø bars at the bottom. The placement of the stirrup is shown in Fig. 2.

The columns have a size of 400 mm x 400 mm with 8 nos of 20ø HYSD bars and 8ø mild steel stirrups.

The reinforcement details are shown below.

Fig. 2: Reinforcement details of beam and column respevtively.

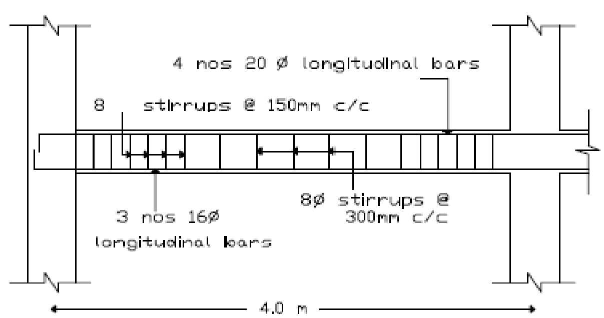

Fig. 3: Reinforcement details for an intermediate beam.

Confinement links of 8ø dia @ 100mm c/c is provided for a distance of l_o (450mm) on either side of the joint and nominal reinforcement of 8ø dia @ 200mm c/c is provided at mid height. Along the beam stirrups of 8ø dia is provided for a length of $2d_e$ (=800mm).

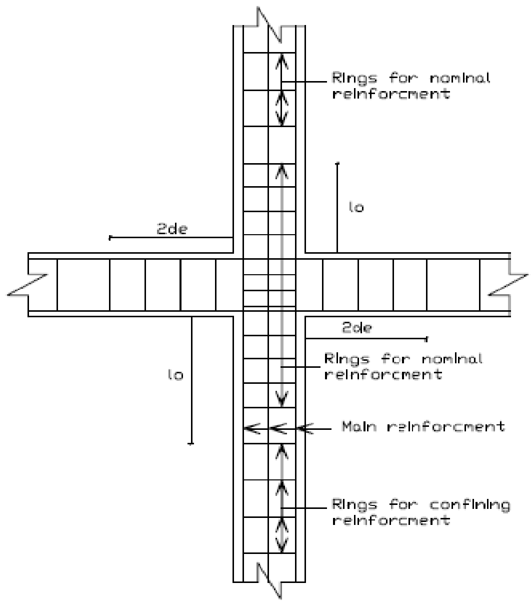

Fig. 4: Reinforcement detailing for the beam column joint.

The ANSYS model, after application of loads, plots the supposed cracks that will occur in the structure. The crack plot is shown in Fig. 5. It shows that certain cracks develop in the beam joint region but no major harm is caused to the joint.

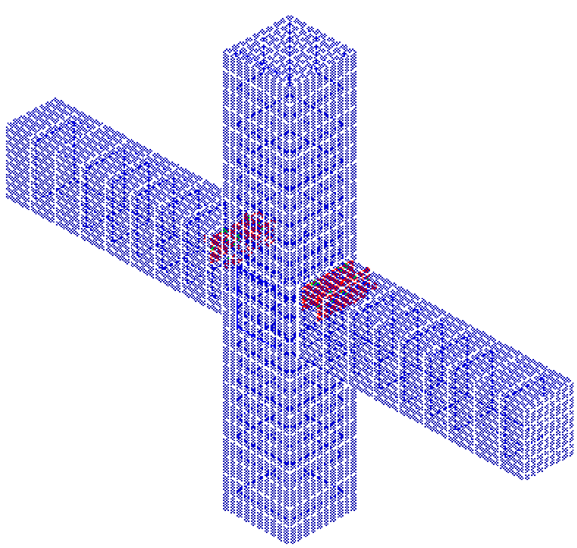

Fig. 5: Cracks in the interior joint

It is also seen that as the load increases the dispacement and stress also increases (Fig. 6) and it reaches a point when cracks start to develop in the joint region.

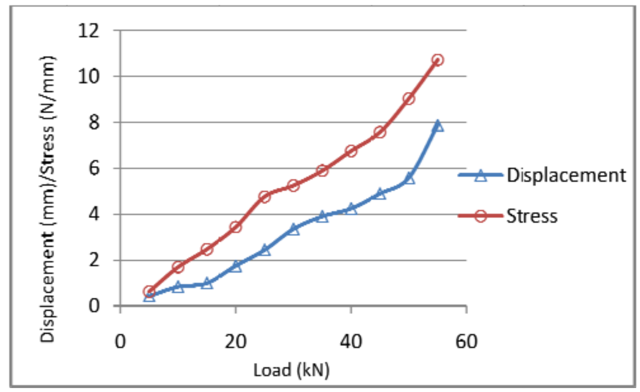

Fig. 6: Load vs Displacement, stress graph for an interior joint.

5. CONCLUSION

The present analysis of the joint section shows that the revised draft of IS 13920 has given emphasis on the following considerations which were not prominent in the code earlier.

1. The detailing patterns of longitudinal reinforcements significantly affect joint efficiency.
2. The provision of tension steel ratio prevents the possibility of a sudden failure in members having large cross section.
3. The provision of minimum reinforcement avoids congestion of reinforcement, which may cause insufficient or a poor bond between reinforcement and concrete.
4. Column-to-beam strength ratio provision in the strong column – weak beam design philosophy for moment resisting frames will allow the building to fail in beam-hinge mechanism, but not in storey mechanism.
5. Shear design of beam-column joints ensures that brittle shear failure does not precede the actual yielding of the beam in flexure

Thus it can be said that members designed with the new draft will be able to withstand dynamic loading efficiently and the structure will be safe.

6. ACKNOWLEDGEMENTS

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