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REVISION OF IS: 13920 – A REVIEW (PART 2)

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Abstract: *The seismic response of reinforced concrete (RC) structures, to a great extent, depends upon the ductile detailing of the reinforcement. The Indian Standard IS: 13920 pertains to the ductile detailing aspect of reinforcement in RC structures. The code IS: 13920 has been recently revised. The modifications in the provisions of this standard have been reviewed and discussed in this study in two parts. The part 1 included the modifications in the scope, terminology, general specifications, adjunct standards and the provisions related to beams and columns. This part 2 of the study includes the details of modifications in the provisions related to special confining reinforcement, beam column joints, special shear walls and gravity columns.*

Index terms- *RC structures, ductile design and detailing, seismic resistance, IS: 13920, gravity columns.*

I. INTRODUCTION

The Indian standard IS: 13920 for Ductile Detailing of Reinforced Concrete structures subjected to seismic forces, was first adopted by the Bureau of Indian Standards in the year 1993 to surpass the limitations of the then existing standard IS: 4326- 1976 [1]. The unsatisfactory performance of RC structures in the earthquakes after 1993 led to further research in field. As a result IS: 13920 has been revised. Revision in codes is a periodic process. IS: 13920-2016 [2] is the first revision of the code IS: 13920-1993 [3]. IS: 13920-2016 has been referred as the new code in this study, while IS: 13920 – 1993 has been referred as the old code or earlier or older version of the code. This paper is part 2 of a series of two papers. The Part 1 incorporated the changes if any in the scope, terminology, the related list of standards, general specifications, beams and column. This part 2 incorporates the modifications in the provisions for special confining reinforcement, beam column joints, special shear walls and gravity columns.

II. REVISION IN PROVISIONS RELATED TO SPECIAL CONFINING REINFORCEMENT

A confinement zone in a structural member is that region where a greater amount of ductility requirement is satisfied by providing a smaller spacing of transverse reinforcement. The greater ductility requirement is created during the event of an earthquake or during deformation of the member in transverse direction because of any reason. The concrete of the RC member undergoes maximum non linearity in its stress-strain response during earthquake so the increased transverse reinforcement helps in dissipation of earthquake energy. Such locations are usually column ends, beam ends, beam column joints etc. Thus special confining reinforcement is provided in these locations mostly in the form of more closely spaced ties. Now as per the code IS 13920, if a larger amount of transverse reinforcement is needed from the provisions of shear strength requirements for beams and for columns, then that required transverse reinforcement shall be provided and special confining reinforcement is not needed in such a case.

The provisions for the zone length in which special confining reinforcement is required to be provided are the same as those given in the old code.

As per the new code the spacing of the links providing the special confining reinforcement shall not exceed the least of the following:

- One fourth of the minimum member dimension of the beam or column.
- 6 times the diameter of the smallest reinforcement bar provided in the longitudinal direction of the member.
- 100 mm.

The second requirement mentioned above, that is 6 times the diameter of the smallest longitudinal reinforcement bar, has been added in the new code. This clause was not mentioned in the earlier version of the code. The old code required the minimum spacing of these links as 75 mm. This provision has been discontinued in the new code.

There was a provision in the old code for minimum area of circular hoops or spirals that were to be used as special confining reinforcement. The new code has extended this clause with some modifications. The area of the circular links or spirals should be the maximum of the following:

- $0.09\, s_v\, D_k \frac{f_{ck}}{f_y} \left[\frac{A_g}{A_k} - 1\right]$
- $0.024\, s_v\, D_k \frac{f_{ck}}{f_y}$

Where
s_v = pitch of spiral or spacing of links,
D_k = diameter of core of circular column measured to the outside of spiral / link,
f_{ck} = characteristic compressive strength of concrete cube,
f_y = 0.2 percent proof strength of transverse steel reinforcement bars,
A_g = gross area of column cross-section, and
A_k = area of concrete core of column = $[\pi . D_k^2 / 4]$.

Provision has also been provided for area of rectangular links. The area of bars forming rectangular links should be the maximum of the following:

- $0.18\ s_v\ h \frac{f_{ck}}{f_y}\left[\frac{A_g}{A_k} - 1\right]$
- $0.05\ s_v\ h \frac{f_{ck}}{f_y}$

Where
h = longer dimension of rectangular link measured to its outer face,
A_h = area of confined concrete core in rectangular link measured to its outer dimensions.

The code has also restricted the maximum value of h as 300 mm. If h is greater than this value then it can be reduced by providing cross ties. For such a case, A_k shall be taken as overall core area for any type of link arrangement. The hooks of cross ties shall enclose the longitudinal bars on the periphery. The restriction for value of h was mentioned in the earlier version of the code also. There were also numerical examples present in the old code showing the calculation of requirement of hoops and their spacing for circular and rectangular columns which have been removed in the new code. However, such examples are useful so it should have been retained in the new code.

The provisions related to the locations where the special confining reinforcement is required, are obviously same in the new code as mentioned in the old code.

III. REVISION IN PROVISIONS RELATED TO BEAM COLUMN JOINTS OF MOMENT RESISTING FRAMES

There have been substantial modifications and additions in the provisions related to beam column joints of moment resisting frames in the new code. The main focus is on the shear strength of concrete in the joint as well as the shear stress demand of the joint. The concept and values of nominal shear strength specified in the new code have been adopted from International standard of American concrete Institute ACI 318 M 02 [4].

Shear Strength of Concrete in a Joint

The nominal shear strength of concrete in a beam column joint is calculated as a function of the effective shear area of joint and square root of characteristic compressive strength of concrete as given below:
$\tau_{jc} = 1.5\ A_{ej} \sqrt{f_{ck}}$ for joints confined by beams on all four faces
$\tau_{jc} = 1.2\ A_{ej} \sqrt{f_{ck}}$ for joints confined by beams on three faces
$\tau_{jc} = 1.0\ A_{ej} \sqrt{f_{ck}}$ for other joints.

Here the effective shear area of joint A_{ej} is taken as the product of effective breadth of joint perpendicular to the direction of shear force (b_j) and effective width of joint along the direction of shear force (w_j).

The effective width of joint is further calculated as the minimum of the width of beam b_b and $(b_c + 0.5h_c)$ i.e. the sum of the width of column (b_c) and 0.5 times the depth of column (h_c) in the direction considered. This is applicable if width of column is less than the width of beam.

Design Shear Stress Demand on a Joint

The new code suggests that the design shear stress demand (τ_{jd}) acting horizontally along each of the two principal plan directions of the joint can be calculated from the earthquake shaking considered along each of these directions by dividing the design shear force demand (V_{dj}) by the product of effective breadth of joint perpendicular to the direction of shear force (b_j) and effective width of joint along the direction of shear force (w_j). The shear force demand shall be calculated in both the principal plan directions X and Y also considering that the longitudinal beam bars in tension attain a stress of 1.25 f_y when over strength plastic moment hinges are formed at the ends of beams.

It has been re-specified here that when the beam reinforcement extends through the beam column joint, the minimum width of column parallel to beam shall be at least 20 times the diameter of the largest longitudinal beam bar.

Transverse Reinforcement

The provisions related to transverse reinforcement requirements in beam column joints are retained as such in the new code with one addition that all 135 degree hooks of cross ties should be along the outer face of columns in the exterior and corner joints. Since the interior face of an exterior beam column joint is confined by beams, it is better to place the cross ties with all 90 degree hooks on the inner side and 135 degree hooks at the exterior side of the joint.

IV. PROVISIONS GOVERNING SPECIAL SHEAR WALLS

Special shear walls hold the same meaning as held by the term 'Shear walls' in the old version of code. These walls are a part of the lateral load resisting system of an earthquake resistant RC building.

In the general requirements for special shear walls, the minimum thickness of wall specified as 150 mm in the earlier code has been retained in the new code to avoid lateral instability in higher seismic zones. The requirement of minimum thickness of 300 mm has been added for buildings coupled with shear wall. This has been done to avoid constructional difficulties in placement of diagonal bars with the reinforcement in the coupling beam. It is also required now to check that the minimum thickness provided conforms to the fire resistance requirements based on occupancy as per IS 456 [5].

The minimum ratio of length of wall to its thickness has also been specified as 4 in the new code.

The new code also classifies the shear walls into three categories depending on the ratio of overall height (h_w) to the length of wall (L_w) in the following way:

If $(h_w/L_w) < 1$, Squat walls
If $1 \leq (h_w/L_w) \leq 2$, Intermediate walls
If $(h_w/L_w) > 2$, Slender walls.

In the design of flanged wall sections, the effective flange width requirements are the same as those mentioned in the old code with an addition that the effective flange width should not exceed the actual width available.

The minimum reinforcement requirements along vertical and horizontal directions have been extensively classified for the three categories of walls i.e. squat walls, intermediate walls and slender walls. The requirement of reinforcement in two layers is same as in the old code with an addition that the vertical steel bars should be contained within the horizontal steel bars which should form a closed core concrete area with closed loops and cross ties. The provisions for maximum spacing of bars have also not been changed in the new code. They are similar to those provided for RC slabs in IS 456.

The new code mentions clearly that special shear walls should have properly designed foundations and they should not be discontinued to rest on beams, columns or inclined members.

Design for Shear Force

The design for shear for special shear walls is same as for RC beams with the provisions as per IS 456. The effective depth of wall section required for calculation of nominal shear stress demand should be calculated along the length of the wall and it can be taken as 0.8 times the length of wall for rectangular sections. In flanged sections, the flanges will not be taken for calculating the shear capacity. Also vertical reinforcement of wall shall be used to calculate the permissible shear strength of concrete.

Design for Axial Force and Bending Moment

The design for combined axial force and bending moment for special shear walls is as per IS 456 and the provisions are the same as mentioned in the old code.

The design for flexure of slender rectangular structural wall section with uniformly distributed vertical reinforcement will be calculated as per Annexure A of the standard. The same was mentioned in the old code as well but according to the new code, the Annexure A is not applicable for structural walls with boundary elements.

Boundary Elements

Most of the provisions for boundary elements are same as in the old code. The old code included a formula to calculate the additional compressive load induced by the seismic forces. This calculation is still required but the formula has been dropped in the new code.

The requirements of special confining reinforcement for boundary elements have been modified as detailed below:
The special confining reinforcement has to be provided throughout the height of boundary elements.
The area of reinforcement is given by

$$A_{sh} = 0.05\, s_v\ h\, \frac{f_{ck}}{f_y}$$

The maximum spacing of reinforcement should not exceed

- one third of minimum member dimension boundary element
- 6 times the diameter of smallest longitudinal reinforcement bars and
- 100 mm. If the maximum distance between cross ties or parallel legs of links is up to 200 mm, the maximum spacing requirement of 100 mm maybe relaxed to 150 mm.

Coupling Beams

The coplanar special structural walls are required to be connected by providing coupling beams. The design provisions are the same in the new code as mentioned in the old code; only the heading has been changed from 'Coupled shear walls' to 'Coupling beams'.

Openings in Walls

Openings in shear walls cause high shear stresses in the adjoining areas. Thus such areas need to be checked for adequate horizontal shear reinforcement to prevent diagonal tension failure due to shear. [6]

The design provisions for opening in walls in the new code are the same as mentioned in the old code with one addition that the area of vertical and horizontal steel should be provided half on either side of the wall in each direction respectively. Design provisions related to discontinuous walls have been dropped in the new code. The provisions for construction joints in the new code are the same as mentioned in the old code.

Development, Splice and Anchorage Requirement

The provision for anchoring of horizontal reinforcement is the same as mentioned in the old code. The provisions for splicing of vertical reinforcement have been modified in the new code as detailed below:

For Slender walls [$(h_w/L_w) > 2$], the splicing of vertical reinforcement should be avoided in zones of possible flexural yielding, extending for the distance greater of the length of wall above the base of wall and one sixth of the wall height but in either case, not greater than 2 times the length of wall. Splicing zones should be provided with closed links with spacing not exceeding 150 mm.

The lap length of splices should at least be equal to the development length of the largest longitudinal reinforcement bar in tension. The lap splices should be provided only within the central half of clear wall height. They should not be provided within a joint or within a distance of 2 times the effective depth from a location of possible yielding of reinforcement. The code also mentions that not greater than 50% of the area of steel bars should be placed at any one section. This percentage was 33.33% in the earlier code.

The new code permits the provision of mechanical couplers conforming to IS 16172 [7] within a distance of 2 times the depth of the member from the beam column joint or in any location of possible yielding of reinforcement.

The new code suggests avoiding the weld splices as far as possible. They cannot be provided in any case within a distance of 2 times the depth of the member from the face of the member or in any location of possible yielding of reinforcement. Also the new code has prohibited the welding of links, ties, inserts or other similar elements to vertical reinforcement bars in any seismic zone.

For buildings located in seismic zones 2 and 3 the new code suggests to provide closed loop transverse links around lapped spliced bars of diameter greater than 16 mm. Such links should have a minimum diameter of one fourth the diameter of spliced bar but not less than 8 mm with the maximum spacing of 150 mm centre to centre.

V. PROVISIONS FOR GRAVITY COLUMNS IN BUILDINGS

The term 'Gravity columns' has been introduced in the new code to differentiate between the columns which are a part of the lateral load resisting system and the columns which are not gravity columns have been defined in the new code as those columns which are not a part of the lateral load resisting system and so are designed only for forces due to gravity loads. The code also requires that such columns should be able to resist the gravity loads while undergoing lateral displacements during the event of an earthquake. Hence suitable provisions have been mentioned for ductile detailing of these columns.

When the Gravity columns are subjected to 'R' times (i.e. Response reduction factor times) the design lateral displacement under the factored equivalent static design seismic load calculated by IS 1893 (Part 1) [8], then they will be detailed for bending moment as mentioned below:

For a Gravity column with small gravity loads i.e. when the bending moment and horizontal shear forces induced in the gravity column under the said lateral displacement combined with factored gravity bending moment and shear force does not exceed the design moment of resistance and design lateral shear capacity of the column, the gravity column shall satisfy all the requirements of splicing of longitudinal bars and of transverse reinforcement as mentioned for columns and inclined members in the new code. Here the maximum spacing of links along the full column height has been relaxed to 6 times the diameter of smallest longitudinal bar or 150 mm, whichever is less. If such a gravity column has factored gravity axial stress greater than $0.4f_{ck}$ then it will satisfy the above mentioned clauses and shall have transverse reinforcement at least one half of the requirement of special confining reinforcement mentioned in this standard.

For Gravity columns with higher gravity load that is when the bending moment and shear force is developed under the said lateral displacement plus the factored gravity bending moment and shear force are greater than the design moment and shear strength of the frame, the gravity column shall be designed for the requirements of transverse reinforcement as mentioned for columns and inclined members in this standard. They will also need to comply the provisions for special confining reinforcement as per this new code. The mechanical and welded splices for these columns will be provided as per the provisions mentioned for columns and inclined members in this new code.

VI. CONCLUSIONS

IS: 13920-2016 is the first revision of the code on ductile detailing of RC structures subject to seismic forces. There have been substantial modifications and additions in the provisions related to beam column joints of moment resisting frames in the new code. The main focus is on the shear strength of concrete in the joint as well as the shear stress demand of the joint. The new code also classifies the shear walls into squat walls, intermediate walls and slender walls depending on the ratio of overall height to the length of wall and then mentions different reinforcement requirements for the different categories of walls, which is more appropriate. The term 'Gravity columns' has been introduced in the new code for columns which are not a part of the lateral load resisting system and the code also provides suitable provisions for ductile detailing of these columns. The first revision has made substantial modifications in many of its provisions stressing upon enhanced shear strength for better energy dissipation during an earthquake. The new code has suggested complying all the ductile design and detailing provisions for all lateral load resisting systems in seismic zones III, IV and V and optionally for structures in seismic zone II. This makes design and detailing provisions of IS: 456 useful for only seismic zone II. Bureau of Indian standards can merge the two codes for better understanding and application of the design and detailing provisions for RC structures.

VII. REFERENCES

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