The IS 13920 : 1993¹ covers the requirements for design and detailing of monolithic special reinforced concrete (RC) moment resisting frames (SMRF) so as to give them adequate toughness and ductility to resist severe earthquake shaking without collapse and moderate shaking with some non-structural damage and some non-structural damage.

Prior to 1993, the IS 4326 : 1976² (Code of practice for earthquake resistant design and construction of buildings) laid down requirements for ductile detailing in seismic areas of moderate to high hazard. The IS 13920 : 1993 differs from the IS 4326 : 1976 in the following.

(i) Material specifications have been introduced for the lateral force-resisting elements

(ii) Geometric constraints have been introduced for the lateral force-resisting elements as also detailing and location of splices, provisions of minimum and maximum reinforcement

(iii) Requirements for the transverse reinforcement in beams and columns and their detailing have been expanded

(iv) Provisions for reinforced concrete shear walls are included

The IS 13920 : 1993 specifies the same level of ductility for all buildings regardless of the level of seismic hazard the building is subjected to and makes no distinction between zones of moderate, high and very high seismic hazard in the energy dissipation requirements. Thus, seismic zones III to V require the same ductile detailing.

Need for varying toughness requirements in moderate versus high seismic zones

The level of ductile detailing in concrete structures directly affects its energy dissipation capacity (toughness). It is fairly apparent that structures in higher seismic zones or those assigned to higher seismic performance or design categories should possess a higher degree of toughness. The degree of energy dissipation, and therefore the detailing, should logically increase for structures progressing from ordinary through intermediate to special categories, based on the seismic zone they are located in as well as the level of seismic performance that is required of them.

¹ The IS 13920 : 1993
² The IS 4326 : 1976
The Bhuj earthquake of 2001 demonstrated that ordinary RC buildings (with well defined frames) in seismic zone III performed badly when they were marginally designed and poorly detailed even for gravity loads or had a soft storey, stiffness discontinuities, torsion, plan or vertical mass irregularities. Most buildings in zone III performed reasonably well as long as they did not possess any major irregularities, even though many of them were not specifically detailed as per with the ductility provisions of IS 13920. One of the reasons for this behaviour was the contribution of the infill panel walls to the stiffness and strength of the building. The intensity of shaking in zone III towns and cities was also much lower.

Based on lessons learnt from past earthquakes, for ordinary buildings (with importance factor = 1), a case may be made for a varying level of required energy dissipation capacity (toughness) the structure is called upon to demonstrate, depending on the seismic zone it is located in and which is assumed while computing the design seismic loads. By reducing the response reduction factor and thus designing for a higher seismic force, the detailing requirements may be relaxed in zone III.

Thus, a separate type of frame, say the intermediate moment resisting frame (IMRF) whose performance would be between that of the ductile moment resisting frame (detailed as per IS 13920 : 1993) and the ordinary moment resisting frame could be considered for application in moderate seismic zone. The seismic detailing requirements of this type of frame would be less stringent than that required as per IS 13920 : 1993 for special RC moment resisting frames. To compensate for the reduction in the toughness due to a relaxation of the ductility criteria, the response reduction factor \( R \) may be less than the value of 5 for (ductile) special RC moment resisting frame but may be more than 3.0 which is the value of \( R \) for ordinary RC moment resisting frame. The factor could be considered to be between 3.5 to 4. Such a relaxation in energy dissipation requirement is only for the ordinary, regular buildings in zone III which do not fall in the category of irregular buildings.

ACI 318-02 (Building Code Requirements for Structural Concrete) also has a similar provision and allows for the use of "Intermediate moment frames" in regions of moderate seismic hazard. For such intermediate frames, the detailing requirements are greatly relaxed in ACI 318. The requirement of toughness is reduced by reducing the response modification coefficient \( R \) from 8 in special moment resisting concrete frames to 5 in intermediate concrete moment frames in the International Building Code (IBC 2003), thus increasing the seismic load by about 1.6 times. The International Building Code (2003), like the ACI 318, allows the use of intermediate moment frames for buildings in seismic design category C.

The suggestions for revised requirements of ductile detailing for zone III made herein are based on those of ACI 318-02 for intermediate frames.

**Requirements of intermediate moment resisting frame**

As distinct from the requirements of special RC moment resisting frames spelt out in IS 13920, the intermediate (reinforced concrete) moment resisting frames (IMRF) will perform at a lower level of toughness with an appropriate compensating modification in the response reduction factor.

The suggested relaxations in the various ductility requirements of IS 13920 : 1993 for intermediate frames are discussed herein.

**Flexural members**

**Longitudinal reinforcement**

It is necessary to provide flexural members with a threshold level of toughness. To achieve this, the IS 13920 requires that minimum positive strength at a joint face should be equal to at least half the negative strength at the joint face. It further requires that minimum steel at any face should not be less than 25 percent of the maximum negative steel at any joint face.

This criteria may be relaxed for intermediate frames such that the positive moment strength at the face of the joint is not less than one third the negative moment strength provided at that face of the joint. The positive or the negative moment strength at any section along the length of the member is not less than one fifth the maximum moment strength provided at the face of either joint.

**Transverse reinforcement**

IS 13920 requires the web reinforcement in flexural members to have a 135 degree hook and an additional 10 diameter length of the hoop reinforcement beyond the hook. The 135 degree hook is rather difficult to execute and in the case of a 200 mm wide flexural members with 50 mm clear cover, the 10 diameter additional length of the hoop bar beyond the hook practically touches the vertical leg of the hoop on the other side (for an 8 mm or higher diameter bar), Fig 1(a). This causes various construction difficulties such as difficulty in the placement of these hoops, in the placing of concrete and in the vibration of the concrete. This requirement should be eliminated for intermediate moment resisting frames (IMRFs) in view of the reduced requirement of toughness and a 90 degree hook with a 8d extension instead may be allowed, Fig 1(b).

**Design shear strength**

It is necessary in all seismic zones to avoid a shear failure in frame members. Hence, the shear capacity of any frame member should be greater than the sum of actual shear on the member due to vertical loads and that associated with the development of the full moment capacity of the member.

Presently, in IS 13920, the shear capacity required in flexural members is given as:

\[
V_{as} = V^a_{dL} + 1.4 \left( \frac{M^a_{u,lim} + M^b_{u,lim}}{L_{as}} \right)
\]

\[
V_{sb} = V^b_{dL} + 1.4 \left( \frac{M^a_{u,lim} + M^b_{u,lim}}{L_{as}} \right)
\]
Fig 1 Transverse reinforcement in flexural members 
(a) 135° hook is difficult to execute (b) A 90° hook with a 8d extension would be better

\[ V_{as} = V_s^{dl} + 1.4 \left( \frac{M_{as,lim}^{th} + M_{as,lim}^{ho}}{L_{AB}} \right) \]

\[ V_{ab} = V_s^{dl} - 1.4 \left( \frac{M_{ab,lim}^{th} + M_{ab,lim}^{ho}}{L_{AB}} \right) \]

where,

- \( V_{as}, V_{ab} \) = the design shear force,
- \( V_s, V_s \) = the shear due to vertical loads,
- \( M_{as,lim}^{th}, M_{as,lim}^{ho} \) = the sagging and hogging moment capacities of the beam,
- \( M_{ab,lim}^{th}, M_{ab,lim}^{ho} \) = the sagging and hogging moment capacities of the beam,
- \( L_{AB} \) = the clear span of the beam.

The factor of 1.4 for the moment capacity of the flexural member is meant to take care of the design steel stress of 0.87\( f_y \) and the fact that in reality steel can take up to 1.25\( f_y \) due to strain hardening. Thus, moment capacity of the member is taken as 1.25/0.87 = 1.44 say 1.4 times the calculated capacity.

For IMRF, the required shear capacity of flexural members may be reduced to following:

\[ V_{as} = V_s^{dl} + \left( \frac{M_{as,lim}^{th} + M_{as,lim}^{ho}}{L_{AB}} \right) \]

\[ V_{ab} = V_s^{dl} - \left( \frac{M_{ab,lim}^{th} + M_{ab,lim}^{ho}}{L_{AB}} \right) \]

Note that the 1.4 factor for the moment capacity of the beams as given in IS 13920 is proposed to be eliminated in IMRF. The rationale behind this proposed change is that the structure is not likely to be called upon to demonstrate as high a level of toughness as in high and very high seismic zones.

### Spacing of transverse reinforcement

The maximum spacing of the hoop reinforcement as specified in IS 13920: 1993, may be retained for IMRFs. That is, maximum hoop spacing over a length of 2d at either end of a beam shall not exceed the smallest of:

1. \( d/4 \)
2. Eight times the diameter of the smallest longitudinal bar enclosed
3. 100 mm.

Stirrups shall be placed at not more than \( d/2 \) throughout the length of the member.

### Columns

#### Longitudinal reinforcement lap splicing

IS 13920 requires that the vertical column bars should be spliced only in the central half of the member length and proportioned as a tension splice. Further, not more than 50 percent of the bars may be spliced at a section. The latter requirement in conjunction with the former is extremely difficult to follow especially for short floor heights where the column bars are perforce required to be of at least two and sometimes even three floor heights to ensure compliance of the above requirements. Maintaining the plumbness of such long bars then becomes a challenge.

The requirement of not more than 50 percent of the bars to be spliced at a section also does not take into account the actual construction systems and practice. In recent times with increased mechanisation at sites, column cages are often fabricated at the ground level and placed at the final location by means of cranes or other devices. In such a case, the laps of all vertical bars are at one location. The requirement also does not account for future provision of a floor where all the bars may be lapped at one location.

While ACI 318 requires that the laps of column bars in high and very high seismic zones should be located within the central half of the member length, it does not have a requirement that maximum of 50 percent of bars may be lapped at one location.
A more practical approach would be to eliminate the requirement of maximum 50 percent of bars to be lapped at one location in IMRF and require a higher, punitive lap length, say 1.5 times that required presently, when more than 50 percent of the bars are to be lap spliced at one location. The same may in fact be extended for the SMRFs also.

Transverse reinforcement

IS 13920 has rather stringent requirements for the required area of confining steel. As per IS 13920:1993, for circular hoops,

\[ A_{sh} = 0.09 S D_k \frac{f_{ck}}{f_y} \left( \frac{A_k - 1.0}{A_k} \right) \]

while for rectangular hoops steel,

\[ A_{sh} = 0.18 S h D_k \frac{f_{ck}}{f_y} \left( \frac{A_k - 1.0}{A_k} \right) \]

where,

- \( A_{sh} \) = area of the bar cross section
- \( D_k \) = diameter of core measured to the outside of the hoop
- \( S \) = spacing of hoops
- \( A_k \) = area of gross section of column
- \( A_c \) = area of concrete core
- \( f_{ck} \) = characteristic compressive strength of concrete cube
- \( f_y \) = yield stress of steel.

The formula yields unrealistically high diameter of hoop reinforcement steel for small columns. As per the above formula, the diameter for hoop reinforcement of confining steel works out to 16 mm for a column of 200 mm x 200 mm. Similarly, for very large columns (for instance, in case of bridge piers), the equation gives very low transverse steel. This needs to be addressed in the code appropriately.

The above clauses were formulated with the intent that the column would have the same axial strength after spalling of the cover concrete as before spalling.

In zones with moderate seismic hazard, such a situation is not expected or envisaged for ordinary buildings and the above requirements for area requirement of hoop steel should be eliminated as long as the detailing requirements mentioned below are adhered to, in order to ensure that the concrete is properly confined.

Spacing of transverse reinforcement

To ensure the minimum level of toughness and ensure that concrete is well-confined, the spacing criteria for hoop steel in IS 13920 may be maintained, that is, at both ends of the (column) member hoops shall be provided at spacing, \( s_o \), over a length, \( l_o \), measured from the joint face.

Shear capacity of transverse reinforcement

As with flexural members, it is very important to prevent shear failure in columns. Hence the shear capacity of the column should exceed that shear associated with the development of the moment capacity of the column at both ends.

IS 13920 requires this to be as follows:

\[ V_u = 1.4 \left( \frac{M_{b,lim} + M_{d,lim}}{h} \right) \]

For IMRF, the above equation may be revised to:

\[ V_u = \left( \frac{M_{b,lim} + M_{d,lim}}{h} \right) \]

\( V_u \) = the shear force to be resisted

\( M_{b,lim}, M_{d,lim} \) = the top and bottom moment capacities of the column and

\( h \) = the height of the column.

Note that the 1.4 factor for design shear force for columns as per IS 13920 is missing. The rationale for this change is the same as for beams mentioned earlier.

Structural walls

Properly designed and detailed RC shear walls have consistently performed well in moderate seismic zones in the past earthquakes and these should be encouraged. It is suggested that in IMRF, the ductility requirements of Section 9 of IS 13920 for boundary elements and coupling beams may be eliminated.

Flat slabs

Flat slabs have become extremely popular structural systems for office buildings in the past few years. While flat slab structures have not demonstrated very good behaviour in...
Table 1: Recommendations for new proposed IMRF

<table>
<thead>
<tr>
<th>Clause of IS 13920</th>
<th>Pertaining to</th>
<th>Present requirement for SMRF in IS 13920</th>
<th>Suggested recommendation for new proposed IMRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.3</td>
<td>Flexural members – Longitudinal reinforcement</td>
<td>Minimum positive strength at a joint face should be equal to at least half the negative strength at the joint face</td>
<td>Minimum positive strength at a joint face should be equal to at least one-third the negative strength at the joint face</td>
</tr>
<tr>
<td>6.2.4</td>
<td>Flexural members – Longitudinal reinforcement</td>
<td>Minimum steel at any face should not be less than 25 percent of the maximum negative steel at any joint face</td>
<td>Minimum steel at any face should not be less than 20 percent of the maximum negative steel at any joint face</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Web reinforcement –</td>
<td>135° hook + 10d extension of hoop bar</td>
<td>90° hook + 4d extension of hoop bar</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Web reinforcement – Shear capacity</td>
<td>Minimum steel at any face should not be less than 25 percent of the maximum negative steel at any joint face</td>
<td>Minimum steel at any face should not be less than 20 percent of the maximum negative steel at any joint face</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Columns lap splices</td>
<td>Maximum 50 percent of bars to be lapped at one location</td>
<td>This requirement to be relaxed</td>
</tr>
<tr>
<td>7.3.4</td>
<td>Transverse reinforcement Shear capacity in columns</td>
<td>( V_c = 1.4 \left( \frac{M^\text{min} + M^\text{max}}{h_s} \right) )</td>
<td>( V_c = \left( \frac{M^\text{min} + M^\text{max}}{h_s} \right) )</td>
</tr>
<tr>
<td>7.4.7</td>
<td>Area of special confining steel in columns for circular hoops,</td>
<td>( A_s = 0.09 S D_s \left( \frac{f_{c'} - 1.0}{f_{c'}} \right) )</td>
<td>This requirement to be eliminated</td>
</tr>
<tr>
<td>7.4.8</td>
<td>Area of special confining steel in columns for rectangular hoops,</td>
<td>( A_s = 0.18 S h D_s \left( \frac{f_{c'} - 1.0}{f_{c'}} \right) )</td>
<td>This requirement to be eliminated</td>
</tr>
<tr>
<td>9.4-9.5</td>
<td>Shear walls</td>
<td>Boundary elements, coupling beams</td>
<td>Detailing clauses for flat slabs (for example, provisions of integrity steel) required</td>
</tr>
</tbody>
</table>

Table 1 summarises the suggested changes required in IS 13920 for IMRF for use in zone III or lower.

References
3. Building code requirements for structural concrete, ACI318-02, American Concrete Institute, USA.

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past earthquakes and are not very desirable in high and very high seismic zones, they may be used with caution in moderate seismic zones. However there are no requirements for the placement, location and detailing of reinforcement in flat slabs in IS 13920. This needs to be rectified immediately and some minimum requirement of provision of integrity steel needs to be included on priority basis for seismic zone III.

Conclusion

There appears to be a need to differentiate between the ductility criteria in zones of moderate seismic hazard from those in zones of high and very high seismic hazard as provided for in ACI 318-02. In zones II and III, buildings may be designed with less stringent ductility detailing but with an increase in the design seismic force.

Thus for zone III, there should be a choice of using either

(i) SMRF as per the existing IS 13920 with corresponding response reduction factor R value as 5.0 as spelt out in IS 1893 : 2003

or

(ii) IMRF zone III with a corresponding reduced R say 4

Similarly, in zone II, an engineer may detail as per IS 456 only (OMRF with R value of 3.0, as IMRF (with R value of 4.0), or as SMRF (with R value of 5.0)).