Critical Structural Design Aspects for Tall Buildings

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Key points to consider

- How tall is considered to be tall?
- BIS Code for Tall Buildings 10639 is being finalised and Draft has been circulated for comments.
- Comments received till 31st October will be reviewed and it’s much overdue copy may come out soon.
- Current BIS Codes donot recommend Performance Based Analysis and Designs.
- BIS 1893 conforms to COLLAPSE PREVENTION.
Important to understand What is a Collapse Prevention design ??

World over the Earthquake Safety of buildings is of four categories:

- Fully Operational
- Immediate occupancy
- Life Safety
- Collapse Prevention
Earthquake Resistant buildings are of 4 types, Most buildings in India follow the minimum code standards and therefore will be classified as Category-D buildings for Earthquake Safety.
Category-A: Fully Operational: The building, its contents and utilities are shaken by an earthquake, but no damage occurs in either of the above; the function of the building is not disrupted due to the occurrence of the earthquake.

Category-B: Immediate Occupancy: The building, its contents and utilities are shaken predominantly in their linear range of behavior and only minor damage may occur in them; the use of prevailing functions of the building and facilities is not restricted after the earthquake so that its functioning can be resumed immediately after the earthquake.
Category-C: Life Safety: The building, its contents and utilities are shaken severely in their non linear range of behavior. Significant damage occurs in them, but the building remains within its reserve capacity and does not reach the state of imminent collapse. The use of the facility is restricted after the earthquake until detailed structural safety assessment is performed to ascertain the suitability of the building for retrofitting. If found suitable for retrofitting, the building maybe retrofitted.

Category-D: Collapse Prevention: The building, its contents and utilities are shaken severely in their non linear range of behavior. Major damage occurs in them. The building does not have any additional reserve capacity and is in the state of imminent collapse. The building cannot be used after the earthquake.
Why are BIS Codes still based on Collapse Prevention??

- It is Least Cost amongst all options, and Ease of Analysis and design must have prompted our Code makers to follow Collapse Prevention post Independence.

- Performance Based designs coupled with Energy dissipating devices are a must to upgrade Building safety to other categories.

- A revision to BIS 1893 is highly overdue—it’s draft has been circulated and Final Code likely to be released later this year.

- A BIS Code for Tall structures is also due for release anytime soon and it’s contents must be discussed, debated and understood in detail for implementation across India.
how does Draft 10639 define a Tall building?

- It defines any building 45m to 250 m in height as a Tall Building
- Recommends that the provisions be followed for less than 45m buildings as well, for better performance and higher safety
- Recommends Performance Based analysis and Design for Code exceeding and Irregular structures
What exactly is an Irregular building and why?

LET’S GO BACK TO BIS 1893-PART-I FOR A MINUTE AND REFER TABLE NO 5, CL 7.1, WHICH IDENTIFIES IRREGULAR BUILDING SHAPES AND ALSO HOW MUCH OF IRREGULARITY IS UNACCEPTABLE.
So what are the types of Irregularity? Why is it significant to know if the building is irregular?

An Irregular Building, even if less than 250m, becomes a Code exceeding building, requiring specialised design, review and Structural Health Monitoring.

Irregularities maybe of two types:

I. Plan Irregularities

II. Vertical Irregularities
Indian Code Specifies Five Types of Plan Irregularities

1. **Torsion Irregularities (Should be avoided in zone III, IV and V)**

   Torsion Irregularities can be avoided
   
   1. Plan aspect ratio < 3
   
   2. Distribution of vertical element resisting lateral load should be balanced according to mass in plan

\[ \Delta_2 < 1.5 \Delta_1 \]
2. Re-entrant Corners

Plan has a projection in direction of size < 15% of it overall plan dimension in that direction.
PLAN IRREGULARITIES

3. Diaphragm Discontinuity

Floor slab cutout/openings <50% of total floor area
PLAN IRREGULARITIES

4. Out of Plan offset

In zone III, IV and five should be avoided.
5. Non-Parallel Lateral Load Resisting System
1. Stiffness Irregularities

a. Soft Storey

Lateral Stiffness of the storey is less than 70% of the lateral stiffness of storey above or less that 80% of the average lateral stiffness of three stories above

b. Extreme Soft Storey

Lateral Stiffness of the story is less than 60% of the lateral stiffness of story above or less that 70% of the average lateral stiffness of three stories above

Building on Stilts are Fall Under These Categories
VERTICAL IRREGULARITIES

Stiffness Stiffness for the Building

 Yas Stiffness Which

Mass Irregularity

4. Mass Irregularity

Fig. 4 Vertical Irregularities — Continued
Effect of weak Storey

Figure 4.25: Weak storey in a building: collapse of open storey in the five-storey residential building during 2001 Bhuj earthquake (India) in Bhuj town
2. Mass Irregularities

The Seismic Weight of any Story is more than the 150 Percent of that of the adjacent Storey
3. Vertical Geometric Irregularity

The Horizontal Dimension of lateral force resisting in any story is more than 125% of that in adjacent story

Vertical geometric irregularity when $L_2 > 1.25 \ L_1$
4. In-Plane Discontinuity in Vertical Element Resisting Lateral Force

In-Plane Offset of the Lateral Force Resisting Element Greater Than the Length of Those Elements (b>a)
5. Discontinuity in Capacity—Weak Storey

Earlier code: Story Lateral Strength is Less Than 80% of That in The Story Above, are the Weak Storey. When Lateral Strength of F1 < 0.8 F2 then F1 is the weak Storey.

Revised code: Story Lateral Strength is Less Than of That in The Story Above, are the Weak Storey. When Lateral Strength of F1 < F2 then F1 is the weak Storey.
BUILDING CONFIGURATIONS

- SHOULD HAVE SIMPLE RECTANGULAR PLAN AND BE SYMMETRICAL BOTH WITH RESPECT TO MASS AND RIGIDITY SO THAT THE CENTRES OF THE MASS AND RIGIDITY OF THE BUILDING COINCIDE WITH EACH OTHER

- BUILDINGS HAVING PLANS WITH SHAPES LIKE L, T, Y, E SHOULD BE SEPARATED INTO RECTANGULAR PARTS BY PROVIDING SEPARATION GAPS AT APPROPRIATE LOCATIONS.
# Earth Quake prone Indian Cities with Geographical Area

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Seismic Zone</th>
<th>Percentage Geographical Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>II</td>
<td>41.40</td>
</tr>
<tr>
<td>2</td>
<td>III</td>
<td>30.40</td>
</tr>
<tr>
<td>3</td>
<td>IV</td>
<td>17.35</td>
</tr>
<tr>
<td>4</td>
<td>V</td>
<td>10.90</td>
</tr>
</tbody>
</table>

*Source: Delhi Government – Paper on Vulnerability Assessment and Risk Analysis [Link](http://delhi.gov.in/wps/wcm/connect/32a302004869a2e9de0fd14d7cd9d11/chapter+2.pdf?MOD=AJPERES&Imod=1682716207)*

### Major Indian Cities in High Seismic Zones

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Town</th>
<th>Seismic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Guwahati</td>
<td>V</td>
</tr>
<tr>
<td>2</td>
<td>Imphal</td>
<td>V</td>
</tr>
<tr>
<td>3</td>
<td>Jorhat</td>
<td>V</td>
</tr>
<tr>
<td>4</td>
<td>Shillong</td>
<td>V</td>
</tr>
<tr>
<td>5</td>
<td>Srinagar</td>
<td>V</td>
</tr>
<tr>
<td>6</td>
<td>Amritsar</td>
<td>IV</td>
</tr>
<tr>
<td>7</td>
<td>Chandigarh</td>
<td>IV</td>
</tr>
<tr>
<td>8</td>
<td>Dehradun</td>
<td>IV</td>
</tr>
<tr>
<td>9</td>
<td>Delhi</td>
<td>IV</td>
</tr>
<tr>
<td>10</td>
<td>Patna</td>
<td>IV</td>
</tr>
<tr>
<td>11</td>
<td>Shimla</td>
<td>IV</td>
</tr>
<tr>
<td>12</td>
<td>Agra</td>
<td>III</td>
</tr>
<tr>
<td>13</td>
<td>Ahmedabad</td>
<td>III</td>
</tr>
<tr>
<td>14</td>
<td>Bhubaneswar</td>
<td>III</td>
</tr>
<tr>
<td>15</td>
<td>Chennai</td>
<td>III</td>
</tr>
<tr>
<td>16</td>
<td>Goa</td>
<td>III</td>
</tr>
<tr>
<td>17</td>
<td>Kolkata</td>
<td>III</td>
</tr>
<tr>
<td>18</td>
<td>Lucknow</td>
<td>III</td>
</tr>
<tr>
<td>19</td>
<td>Mumbai</td>
<td>III</td>
</tr>
<tr>
<td>20</td>
<td>Pune</td>
<td>III</td>
</tr>
</tbody>
</table>

*Source: Bureau of Indian Standards Code IS-1893*
This standard is a *prescriptive code* covering design aspects of tall buildings. These aspects include:

(a) Selection of appropriate structural system;
(b) Geometric proportioning of the building;
(c) Integrity of Structural System;
(d) Resistance to Wind and Earthquake effects; and
(e) Other special considerations related to high-rise buildings.
Only for buildings for 20,000 or fewer persons.

This standard following structural systems of Tall Buildings:

a) Structural Wall Systems;

b) Moment Frame Systems;

c) Moment Frame – Structural Wall Systems;

d) Structural Wall – Flat Slab Floor Systems with perimeter Moment Frame;

e) Structural Wall – Tube Frame Systems; and

f) Any of the above with additional framing systems, e.g., Outrigger Trusses, Belt Trusses and Braced Frames.

In case of conflict with other relevant BIS Codes, clauses given in this code shall govern.
The maximum building height (in m) shall not exceed values given in Table 1 for buildings with different structural systems.

<table>
<thead>
<tr>
<th>Seismic Zone</th>
<th>Structural Wall System + Flat Slab Floor System with perimeter Moment Frame</th>
<th>Structural System</th>
<th>Moment Frame System</th>
<th>Moment Frame + Structural Wall System</th>
<th>Structural Wall System</th>
<th>Structural Wall + Tube Frame System</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Not Allowed</td>
<td>Not Allowed</td>
<td>100 m</td>
<td>100 m</td>
<td>150 m</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Not Allowed</td>
<td>Not Allowed</td>
<td>100 m</td>
<td>100 m</td>
<td>150 m</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>70 m</td>
<td>60 m</td>
<td>160 m</td>
<td>160 m</td>
<td>220 m</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>100 m</td>
<td>80 m</td>
<td>180 m</td>
<td>180 m</td>
<td>250 m</td>
<td></td>
</tr>
</tbody>
</table>
Slenderness Ratio

The maximum values of the ratio of height $h$ to minimum Base Width shall exceed values given in Table 2. B

<table>
<thead>
<tr>
<th>Seismic Zone</th>
<th>Structural Wall System + Flat Slab Floor System with perimeter Moment Frame</th>
<th>Moment Frame System</th>
<th>Moment Frame + Structural Wall System</th>
<th>Structural Wall System</th>
<th>Structural Wall System + Tube Frame System</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Not Allowed</td>
<td>Not Allowed</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>IV</td>
<td>Not Allowed</td>
<td>Not Allowed</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>
Plan Geometry

The plan shall generally be rectangular (including square) or elliptical (including circular). In buildings with said plan geometries, structural members participate efficiently in resisting lateral loads without causing additional effects arising out of re-entrant corners and others.

Plan Aspect Ratio

- The maximum plan aspect ratio (L/B) of the overall building shall not exceed 5.0.
- Lateral translational stiffness of any storey shall not be less than that of the storey above.
- Lateral translational strength of any storey shall not be less than that of the storey above.
- The natural period of fundamental torsional mode of vibration shall not exceed 0.9 times the smaller of the natural periods of the fundamental translational modes of vibration in each of the orthogonal directions in plan.
The fundamental translational lateral natural period in any of the two horizontal plan directions, shall not exceed 8 seconds.

**Material**

All floor slabs shall be cast-in-situ. Precast floor systems without a minimum screed of 75 mm concrete shall not be used in Seismic Zones III, IV and V, but can be used in Seismic Zone II.

**Openings**

Openings in floor diaphragm shall not be permitted along any floor diaphragm edge, unless perimeter members are shown to have stability and adequate strength.

The maximum area of openings in any floor diaphragm shall not exceed 30% of the plan area of diaphragm.

At any storey, the minimum width of floor slab along any section after deduction of openings shall not be less than 5 m. And, the minimum width of the slab beyond an opening to edge of slab shall not be less than 2 m. Further, the cumulative width of the slab at any location shall not be less than 50% of the floor width.
Natural Frequency of Floor System

The natural vertical vibration frequency of any floor system shall not exceed 3 Hz without demonstration of acceptability using rational procedures.

Vertical Accelerations

Under gravity loads, the peak vertical acceleration at any vibration frequency of any floor shall not exceed values given in Table 3.

<table>
<thead>
<tr>
<th>Use</th>
<th>Peak acceleration (m/s²) at any excitation frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>0.05</td>
</tr>
<tr>
<td>Office</td>
<td>0.05</td>
</tr>
<tr>
<td>Commercial</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Concrete

The minimum grade of concrete shall be M30.
The maximum grade of concrete shall be M70.

- The grades of concretes used in slabs and beams shall not be less than 70% of that used in columns and walls in contact.
- Column concrete shall be placed in the beam/slab at column location for a minimum of 0.6 m from face of column. This concrete shall be well integrated with the beam/slab concrete.

Reinforcing Steel

The characteristic yield strength of the steel reinforcement bars used in construction shall not exceed 1.2 times the value used in design.
The ultimate strength of reinforcement bars shall not exceed 1.25 times the characteristic yield strength.

No lapping of bars shall be allowed in RC beams, columns and walls, when diameter of bars is 16mm of higher; mechanical couplers shall be used to extend bars.
The damping ratio considered shall not be greater than 2% of critical for concrete buildings, 1.5% for composite buildings, and 1% for steel buildings.

**Lateral Acceleration**

From serviceability considerations, under standard wind loads with return period of 10 years, the maximum structural peak combined lateral acceleration $a_{max}$ in the building for along and across wind actions at any floor level shall not exceed values given in Table 4, without or with the use of wind dampers in the building.

<table>
<thead>
<tr>
<th>Building Use</th>
<th>Maximum Peak Combined Acceleration $a_{max}$ ($m/s^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>0.15</td>
</tr>
<tr>
<td>Office / Commercial</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Seismic Effects

For buildings in Seismic Zones IV and V, deterministic site-specific design spectra shall be estimated and used in design. When site-specific investigations result in higher hazard estimation, the same shall be used.

Design Base Shear Coefficient of a building under design lateral forces, shall not be taken less than that given in Table 5.

<table>
<thead>
<tr>
<th>Building height, $H$</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \leq 120m$</td>
<td>0.7%</td>
<td>1.6%</td>
<td>2.4%</td>
</tr>
<tr>
<td>$H \geq 200m$</td>
<td>0.5%</td>
<td>1.25%</td>
<td>1.75%</td>
</tr>
</tbody>
</table>

Note: For buildings of intermediate heights in the range 120m – 200m, linear interpolation shall be used.
Considerations

Computer modeling shall consider following:

(1) Rigid end offsets of linear members in the joint region, when centerline modeling is adopted;

(2) Floor diaphragm flexibility, as applicable;

(3) Cracked cross sectional area properties as per Table 6; and

(4) P-Δ effects.

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Un-factored Loads</th>
<th>Factored Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td>Moment of Inertia</td>
</tr>
<tr>
<td>Slabs</td>
<td>1.0 A&lt;sub&gt;g&lt;/sub&gt;</td>
<td>0.36 l&lt;sub&gt;g&lt;/sub&gt;</td>
</tr>
<tr>
<td>Beams</td>
<td>1.0 A&lt;sub&gt;g&lt;/sub&gt;</td>
<td>0.7 l&lt;sub&gt;g&lt;/sub&gt;</td>
</tr>
<tr>
<td>Columns</td>
<td>1.0 A&lt;sub&gt;g&lt;/sub&gt;</td>
<td>0.9 l&lt;sub&gt;g&lt;/sub&gt;</td>
</tr>
<tr>
<td>Walls</td>
<td>1.0 A&lt;sub&gt;g&lt;/sub&gt;</td>
<td>0.9 l&lt;sub&gt;g&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
In-plane stiffness of floor slabs shall be modeled, unless it is demonstrated that it is extremely stiff and sufficiently strong to remain elastic under seismic actions. Refer IS 1893 to identify when a floor slab may be considered to be extremely stiff in its own plane.

When buildings with unreinforced masonry infill panels contribute to storey lateral stiffness, their effect shall be modeled as equivalent diagonal struts as per provisions of relevant clause IS 1893.

The analytical model for performing dynamic analysis of buildings with irregular configuration shall adequately represent irregularities in the configuration of the building.

Cracked sectional properties shall be used when representing concrete elements as per Table 6 of this standard.
- Second order deformation effects (P-Δ effects) shall always be considered.
- Stiffness of flat slab frames (i.e., slab-column frames) shall be ignored in lateral load resistance, in all seismic regions, and especially in Seismic Zones III, IV and V.
- Eccentricity shall be considered in analysis of loads applied by beams on columns or applied by offset columns above, if not dealt explicitly within the model.
- Multiple towers connected by a single podium shall be modeled separately and integrally. When modeled separately, if the part of podium attached to the tower is with more than two spans, at least two spans to be modeled with the tower; the design of the podium shall be based on the worst effect from the two cases.
Staircase

Staircases built integrally with the structural system of the building and not confined by structural walls shall be included in the 3D structural model, and its elements designed as per forces induced in them under various load combinations.

Multiple Tall Buildings connected with a Common Podium

This section deals with requirements for the following Tall Buildings with Podium:

(a) Tall Building with Single Tower and Podium (Figure 3a); and

(b) Tall Building with Multiple Towers and common Podium (Figure 3b).
Modeling

Sensitivity Analyses

(a) As part of collapse prevention evaluation, two sets of Sensitivity Analyses shall be carried out using upper-bound and lower-bound cracked section properties of floor diaphragms, given in Table 7. These analyses shall be in addition to those required to be carried out using other cracked section properties described in 7.2 of this standard.

Besides that of the floor diaphragms, flexibility shall be considered of following structural elements also in the structural analysis with appropriate modification to their stiffness:

(i) Perimeter walls and their foundation supports; and

(ii) Foundation supports under the tower lateral load resisting system.
Backstay

Backstay transfer forces from lateral load resisting elements in the tower to additional structural elements provided within the podium and basement, typically through one or more floor diaphragms. Lateral load resistance in the podium levels with assured force transfer path through floor diaphragms at these levels, helps the tall building to resist lateral overturning forces. This component of overturning resistance, referred as the Backstay Effect (also called as Shear Reversal), is critical, because shear force changes direction within the podium levels, and the same lateral load resisting element helps resist the changing shear force.

The following shall be considered:

(a) In estimating backstay effects, two lateral loads paths shall be considered (Figure 2), namely:

(i) Direct Load Path, where overturning resistance is provided by the tower elements and foundation directly beneath the tower; and

(ii) Backstay Load Path, where overturning resistance provided by in-plane forces in the backstay elements (lower floor diaphragm and perimeter walls).

40
Backstay floor diaphragms shall be modeled considering their in-plane and out-of-plane floor flexibility. Any large discontinuity present in the slab shall be modeled.

In Backstay Load Path case, relative stiffness shall be considered of floor diaphragms and perimeter walls, along with vertical in-plane rocking stiffness of soil below the walls. Also, horizontal pressure imposed by soil on retaining walls shall be considered. Axial stiffness of elements (representing backstay) along load path shall be reduced to account for cracking, bond slip, interface slip and other such effects.

The backstay diaphragms shall be designed in accordance with the following:

(i) They shall be designed for the maximum of forces derived from sensitivity analysis.

(ii) When the lateral force resisting system of a Tall Building has plan irregularity as per Table 5 of IS 1893 (Part 1) of Type I (torsion irregularity), Type II (re-entrant corners) and Type IV (out of plane offsets), and vertical irregularity as per Table 6 of IS 1893 (Part 1) of Type IV (in-plane discontinuity of vertical elements resisting lateral forces), seismic forces shall be amplified by a factor of 1.5 in the design of:
1) Connections of diaphragms to vertical elements and to collectors; and

2) Collectors and their connections, including connections to vertical elements, of the seismic forces resisting system.

(iii) When the lateral force resisting system of a Tall Building has plan irregularity of Type iii (diaphragm discontinuity) as per Table 5 of IS 1893 (Part 1) at the backstay diaphragm levels, collector elements and their connections to vertical elements shall be designed to resist seismic forces amplified by an over-strength factor of 2.5.
Structural walls

(a) Structural walls shown in Fig. 2 can sustain plastic hinges at the level of the backstay diaphragm also. Such walls shall be designed and detailed for plastic hinge development at that level also.
(b) All peripheral columns of the tower (irrespective of whether they are gravity columns or not) shall be provided with confinement reinforcements throughout the storeys adjoining (above and below) the backstay diaphragm level, as per the requirements of IS 13920.

FIG. 2 Load paths in Lateral Overturning Resistance of Tall Buildings with Podiums
Towers connected by common podium

When buildings have two or more towers, they shall be designed considering the following:

(a) Such buildings shall be modeled as separate towers as well as integral towers. The podium shall be designed based on the worst of the two results.

(b) The estimation of natural period (for calculation of base shear) shall be based on INDIVIDUAL building model.

(c) In the integral tower modeling,

(i) Directional effects for all worst possibilities (i.e. tower shaking in the same and in the opposite directions) should be considered in the design load combinations; and

(ii) Equivalent static seismic forces can be used, provided they are scaled to match base overturning moments obtained from response spectrum analysis.
(d) Where significant changes occur to mass or stiffness between the floors, the floor diaphragms of upper and lower levels shall be modelled to capture

(i) Diaphragm forces. Equivalent beam approach, finite element approach or strut and tie approach may be adopted to model the diaphragms.

(ii) Potential cracking in the diaphragm by considering an upper bound and a lower bound axial stiffness. The lower and upper bound values of axial and flexural stiffnesses given in Table 5 for sensitivity analysis, may be considered for the cracked section properties, to arrive at the design level earthquake demand on the RC diaphragms.

(d) Plan irregularities shall not be present of Type I (torsion irregularity) and Type iii (diaphragm discontinuity) as per Table 5 of IS 1893 (Part 1), in the first connected floor and the first tower floor above the connected floor.

(e) Vertical irregularities shall not be present of Type I (soft story) as per Table 6 of IS 1893 (Part 1), in the first connected level and the level above it.
(f) All floor slabs between the towers of connected podium shall be at least 150mm thick with double mesh reinforcements not less than 0.25% of cross section area in each direction.

(g) Peripheral columns of the tower shall be provided with confinement reinforcements as per IS 13920 at the first connected level and a level above.

(h) Structural walls of the tower shall be provided with boundary elements as per IS 13920 at the first connected level and a level above.

(i) A transfer structure shall not be provided at the first connected floor.

Ductility

Notwithstanding any of the clauses of this standard, the designer shall take all measures to ensure that the building has:

a) Sufficient ductility capacity;

b) Acceptable energy dissipation mechanism; and

c) Desirable sequence of initiation of ductile behaviour in members.
The minimum dimension of a column shall not be less than:

(a) 15 times the largest beam bar diameter of the longitudinal reinforcement in the beam passing through or anchoring into the column joint, and

(b) 300 mm.

In a moment frame – structural wall system, the moment frame shall comply with the requirements of Clause 8.3 of this standard, and the structural wall with the requirements of Clause 8.5. In addition, the moment frames and structural walls shall comply with the requirements of IS 13920.

Special moment frame and shear walls shall not be discontinued in lower storeys and supported on less stiff and brittle elements.

Structural Wall Systems

The thickness of structural wall shall not be less than 160mm or Hw/20, whichever is larger.
Concentrated gravity loads applied on the wall above the design flexural section shall be assumed to be distributed over a width equal to the bearing width, plus a width on each side that increases at a slope of 2 vertical to 1 horizontal down to the design section, but

(a) Not greater than the spacing of the concentrated loads; and

(b) Not extending beyond the edges of the wall panel.

Design of coupling beam shall comply with requirements of IS 13920, unless it can be shown that loss of stiffness and strength of the coupling beams will not impair the vertical load carrying ability of the structure, the egress from the structure, or the integrity of non-structural components and their connections to the structure.

The nominal design shear stress shall be limited to $\tau_{\text{max}}$, in structural walls and coupling beams in structural walls under factored design loads, where $\tau_{\text{max}}$ is as per Table 20 in IS 456.
The amount and distribution of the minimum reinforcement in structural walls shall be as per IS 13920.

At locations where yielding of longitudinal reinforcements is likely to occur as a result of lateral displacement, development length of longitudinal reinforcement shall be 1.25 times the values calculated for the bar yielded in tension, i.e., at a stress level of $f_y$.

The maximum longitudinal reinforcement ratio in coupling beam shall be as given in Table 8.

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**Table 8 Cracked RC Section Properties**

<table>
<thead>
<tr>
<th>Span – Depth Ratio</th>
<th>Maximum reinforcement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_y/D \leq 1.0$</td>
<td>0.6</td>
</tr>
<tr>
<td>$1.0 \leq L_y/D &lt; 2.0$</td>
<td>1.2</td>
</tr>
<tr>
<td>$2.0 \leq L_y/D$</td>
<td>1.5</td>
</tr>
</tbody>
</table>
At each storey of the moment frame - structural wall interactive dual system, the structural walls shall be designed to resist at least 75% of the design storey shear, and the moment frame at least 25% of the design storey shear.

Requirements for each storey resisting more than 35% of Design Base Shear

Removal of a structural wall or wall pier with a height-to-length ratio greater than 1.0 within any storey, or collector connections thereto, shall not result in more than 33% reduction in storey strength, nor shall the resulting structural system have a torsional irregularity as per IS1893 (Part 1).

Special requirements for Seismic Zone IV and Zone V

(a) Structural walls shall be continuous to the base without being transferred in plane or out of plane at any level;

(b) The thickness of structural wall shall not be less than 200 mm;
(c) The minimum longitudinal and transverse reinforcements shall not be less than 0.4% of gross cross sectional area in each direction;

(d) The reinforcements shall be distributed in two curtains in each direction;

(e) Structural walls shall be fully embedded and anchored at their base in adequate basements or foundations, so that the wall does not rock. In this respect, walls supported by slabs or beams are not permitted; and

(f) All openings in structural walls shall be aligned preferably vertically. Random openings, arranged irregularly, shall not be permitted in coupled walls, unless their influence is either insignificant.
Flat Slab – Structural Wall Systems

- Structural Wall shall carry all loads on the building, and column strips of the flat slab system shall not be included in the lateral load resisting system.
- Columns and structural walls built integrally with a slab system shall resist moments caused by factored loads on the slab system.

Frame Tube – Structural and Tube-In-Tube Wall System

The minimum requirements for reinforcement bar diameters in beams of moment frames and tubes are given in Table 9.

### Table 9 Reinforcement requirements in beams

<table>
<thead>
<tr>
<th>Reinforcement type</th>
<th>Seismic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone II</td>
</tr>
<tr>
<td>(1) Stirrup diameter</td>
<td>&gt; 8 mm</td>
</tr>
<tr>
<td>(2) Stirrup spacing</td>
<td>&lt; 150 mm</td>
</tr>
<tr>
<td>(3) Main reinforcements</td>
<td>&gt; 16 mm</td>
</tr>
</tbody>
</table>
FOUNDATIONS

- A Factor of Safety of 1.5 shall be provided against overturning and sliding under factored design loads.

Geotechnical Investigations

- For geotechnical investigation, boreholes shall:
  - (a) Be spaced at ~30m within the plan area of the building,
  - (b) Be a minimum of 2 boreholes per tower, and
  - (c) Have a depth of at least 1.5 times estimated width of foundation.

Depth of Foundation

- The embedded depth of the building shall be at least 1/15 of height of building for raft foundation and 1/20 of the height of building for pile and piled raft foundation (excluding pile length). But, when the foundation rests on hard rock, this requirement may be relaxed.

- Expansion Joints are prohibited in basements of tall buildings.
Modeling of Soil

- When spring constant or modulus of sub-grade reaction approach is used for modelling raft foundations, then zoned spring constants or zoned modulus of sub-grade reaction shall be utilized for design, at least for the case of (Dead Load + Live Load) condition.

Settlements of Foundations

- Maximum vertical settlement of raft or piled raft foundations under gravity loads shall be limited to

- (a) on Soil: 50 mm for raft/pile-raft foundations and to 25 mm for isolated foundations; and

- (b) on Rock: 50 mm for raft/pile-raft foundations and to 12 mm for isolated foundations.
RECOMMENDATIONS FOR SEISMIC MONITORING

Earthquake Shaking: All tall buildings in zone V & tall buildings exceeding 150 m in Seismic Zone IV & III shall be instrumented with tri-axial accelerometers to capture translational and twisting behavior of buildings during strong earthquake shaking.

Wind Oscillations: Buildings over 150 height may be instrumented with anemometers and accelerometers to measure wind speed, acceleration and direction on top of the buildings.

Foundation Settlement and Pressure Measurement

Raft or Piled-raft shall be instrumented for monitoring long-term pressure imposed by soil on the raft, at appropriate number (at least 5) pressure pads below the raft. Alternatively, piles can be instrumented with strain gauges at their top to measure the load on them.
SEISMIC UPGRADEATION OF BUILDING

SEISMIC UPGRADEATION COST DIFFERENCE

1. From Collapse Prevention to Life Safety 250/-
2. From Collapse Prevention to Immediate Occupancy 350/-
3. From Collapse Prevention to Fully Operational 700/-
4. From Life Safety to Immediate Occupancy 250/-
Thank You