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Indian Standard

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(पहला पुनरीक्षण)

Criteria for Structural Safety of Tall Concrete Buildings

(First Revision)

ICS 91.080.40

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FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Special Structures Sectional Committee had been approved by the Civil Engineering Division Council.

The large scale urbanization in the country and shortage of land in urban areas for accommodating the vast population migrating thereto, is being addressed through vertical developments in the form of tall buildings. This standard has been formulated to comprehensively address the special issues associated with the design of reinforced concrete tall buildings, whose design is governed not just by structural safety aspects, but also by serviceability aspects, especially under the conditions of wind effects. This standard has therefore been formulated to cover these aspects relating to reinforced concrete buildings of height greater than 50 m, but less than or equal to 250 m.

This standard provides prescriptive requirements for design of reinforced concrete tall buildings. The following salient aspects, which are based on the prescriptive approach, are addressed in this standard:

a) Structural systems that can be adopted in tall building;
b) General requirements including;(1) height limitations of different structural systems, (2) elevation and plan aspect ratios, (3) lateral drift, (4) storey stiffness and strength, (5) density of buildings, (6) modes of vibration, (7) floor systems, (8) materials, and (9) progressive collapse mechanism;
c) Wind and seismic effects:(1) load combinations, and (2) acceptable serviceability criteria for lateral accelerations;
d) Methods of structural analysis to be adopted, and section properties (in cracked and uncracked states) of reinforced concrete member to be considered in analysis;
e) Structural design aspects for various applicable structural systems;
f) Issues to be considered in design of foundations; and
g) Systems needed for structural health monitoring.

This standard provides procedure for approval of buildings that do not conform to the prescriptive requirements of this standard.

The committee responsible for the formulation of this standard has taken into consideration the views of users, engineers, architects, builders and technologists, and has related the standard to the practices followed in the country in this field. Also, due consideration has been given to the coordination of this standard with the corresponding international standards prevailing in different regions of the world.

In this revision, the following changes have been incorporated:

a) Systems with structural walls at core have been dropped. All structural wall systems should have well distributed walls;
b) The wind return period of wind for natural drift under wind conditions has been revised;
c) Requirements for maximum vertical acceleration of floors have been dropped;
d) Maximum horizontal acceleration requirement has been revised for residential buildings;
e) A new expression for estimating the approximate fundamental natural period of buildings over 50 m has been provided;
f) Load combination has been specified considering P-Δ effects;
g) An expression for interstorey drift stability coefficient θ has been introduced;
h) The minimum requirement for transverse reinforcement in structural walls has been revised; and
j) The procedure for approval of buildings that do not conform to the prescriptive requirements of this standard has been revised in Annex B.

(*Continued on third cover*)

Indian Standard

CRITERIA FOR STRUCTURAL SAFETY OF TALL CONCRETE BUILDINGS

(First Revision)

1 SCOPE

1.1 This standard covers the following design aspects of reinforced concrete (RC) buildings of height greater than 50 m, but less than or equal to 250 m. Generally, this standard is based on prescriptive approach and covers the following design aspects of tall buildings:

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 tall buildings.

1.2 This standard is not applicable for tall buildings located in the near-field of seismogenic faults. For the purposes of this standard, near-field is taken as 10 km (shortest distance) from a seismogenic fault.

For buildings located within 10 km (shortest distance) of seismogenic faults, more rigorous approach is needed to proportion, analyze, design, detail and construct such buildings. The prescriptive requirements mentioned in this standard shall be used for proportioning such buildings, but more stringent specifications may be specified by the client/owner of the building or by the tall building committee appointed by the local authority administering the building project.

1.3 This standard is applicable only for buildings that house 20 000 or fewer persons.

1.4 This standard may also be used for design of buildings of height equal to or less than 50 m. The provisions of this standard will add value to the design of such buildings. However, this standard is not applicable for design of buildings of height more than 250 m.

1.5 This standard addresses the following typical structural systems of tall concrete 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 – Framed tube systems;
f) Framed-tube system;
g) Tube-in-tube system;
h) Multiple tube system;
j) Hybrid system; and
k) Any of the above with additional framing systems, for example, outrigger trusses, belt trusses and braced frames.

1.6 This standard shall be read along with all Indian Standards relevant to design and construction of buildings and structures. In case of conflict, clauses given in this standard shall be applicable.

1.7 For buildings that do not conform to the prescriptive requirements of this standard, a more rigorous procedure is necessary for design and review. The general procedure to be adopted is given in Annex B to proportion, analyze, design, detail, gain approval and construct such buildings. Performance objectives or procedures more stringent than those specified in Annex B may be specified by the client and/or owner of the building or by the tall building committee appointed by the local authority administering the building project.

2 REFERENCES

The standards listed in Annex A contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the edition indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of these standards.

3 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

3.1 Building Height — The difference in levels between the base level of a building, at which inertia forces generated in the structure are transferred to the foundation, which then transfers these forces to the ground, and the highest level of a building, which is the roof of the topmost level which is structurally integral and continuous with the floor below (*see also* **4**).

3.2 Connecting Structure — A structure that links two or more towers, except at the podium levels.

NOTE — There are two distinctive types of connecting structures with each one requiring a different structural treatment, namely, (a) the connecting structure having the role of transferring gravity loads only and with no participation in the role of resisting the lateral loads on either of the towers; and (b) the connecting structure participating in the lateral load resisting structural system, where the two towers act together when one or both towers is subjected to lateral loads due to the interaction provided by the connecting tower.

3.3 Core — An assembly of Structural walls coupled with link elements and offering lateral stiffness in two orthogonal directions.

3.4 Coupled Structural Wall Building — A building comprising of structural walls linked by in-plane beam elements, wherein the vertical and lateral loads are resisted by these structural walls, through axial load, in-plane bending moment and shear force, and the coupling action created by push-pull in the wall elements by framing action provided by link beams.

3.5 Frame Building — A building comprising beams and columns, wherein the vertical and lateral loads are resisted by these elements through moment-frame action.

3.6 Gravity Columns — Vertical members that are intended to carry primarily the vertical loads arising out of the dead and imposed loads on the building, and do not participate in the lateral load resisting system. Such columns shall be capable primarily of carrying the gravity loads and additional induced loads while complying with the relative lateral deformation effects imposed on them during lateral earthquake shaking.

3.7 Key Elements — The element such that its failure would cause the collapse of more than a limited area close to it. The limited area may be taken equal to 70 m^2 or 15 percent of the area of the storey, whichever is lesser. If key elements exist, it is preferable to modify the layout so that the key element is avoided.

3.8 Linking Beams (also called Coupling Beams) — Horizontal members spanning two (vertical) structural walls.

3.9 Mixed Building or Hybrid Building — A building in which select primary elements resisting vertical and/or lateral loads comprise more than one material; composite elements comprising structural steel and reinforced concrete are common examples.

3.10 Multi-Tower Structures Linked by Podium — Two or more towers above a common podium structure that are not separated by a movement joint at the podium level.

3.11 Natural Period — The time taken (in seconds) by the structure to complete one cycle of oscillation in its natural mode of oscillation.

3.12 Structural Systems and Sub-Systems

3.12.1 *Structural Wall System* — A structural system comprising of inter-connected structural walls, wherein the vertical and lateral loads are resisted by the walls through axial load, in-plane bending moment and shear force. The wall elements are configured by a combination of structural wall elements connected integrally to a floor diaphragm. The wall elements form the primary lateral load resisting structural system for the building, and resist the loads imposed on them through axial, shear and flexural actions, and through coupling actions offered by the connecting link elements if provided.

3.12.2 *Moment Frame System* — A structural system comprising (beam-column) frames and resisting the vertical and lateral loads.

3.12.3 *Moment Frame-Structural Wall System* — A structural system comprising (beam-column) frames and structural walls resisting the vertical and lateral loads. The relative share of the lateral load resisted between these systems is dependent on their relative lateral stiffnesses.

3.12.4 *Structural Wall System with Flat Slab Floor System* — A structural system comprising structural walls, a beam-less floor system, and columns resisting the vertical and lateral loads. The relative share of the lateral load resisted between these systems is dependent on their relative lateral stiffnesses.

3.12.5 *Core and Outrigger Structural System* — A structural system comprising wall element(s) and perimeter columns, resisting the vertical and lateral loads. Essentially, the perimeter columns are for resisting gravity loads only. The core structure is connected to select perimeter column element(s) (often termed outrigger columns) by beam elements, known as outriggers, at discrete floor locations along the height of the building. This type of structure is an extension of the core structure, to enhance the lateral stiffness for taller structures, which mobilizes the perimeter columns, and offers increased leverage for push pull-action through the framing action offered by the deep beam(s) connecting the core to the outrigger columns. The global lateral stiffness is sensitive to: flexural stiffness of the core element, the flexural stiffness of the outrigger element(s) and the axial stiffness of the outrigger column(s).

3.12.6 *Core, Outrigger and Belt Wall System* — A structural system, which is an extension to the core and outrigger structure to enhance the lateral stiffness further, where the outrigger column(s) is linked to the adjacent columns by deep beam elements (often known as belt truss), typically at the same level as the outrigger elements. The sharing of loads between multiple columns has the dual function of enhancing the axial stiffness and mobilizing greater number of gravity columns to counteract the induced tension loads generated by the overall lateral loads.

3.12.7 *Framed-Tube System* — A structural system comprising closely spaced columns and deep beams in the perimeter frame for efficient tube action. The internal vertical elements, comprising core or columns are primarily utilized to resist gravity loads only. Effective utilization of the perimeter of the building maximizes the overall stiffness for a given building plan shape; this system is effective for very tall buildings.

3.12.8 *Tube-in-Tube System* — A structural system, which is an extension of the tube structure, where there is an internal tube, often a core element, supplementing the external perimeter described as the tube structure above, to enhance the overall lateral global stiffness. Just as the tube structure, typically, even this system is suited for very tall buildings.

3.12.9 *Multiple-Tube System* — A structural system, which is an extension of the tube structure and/or the tube-in-tube structure, where the architectural plan of the tower facilitates multiple tubes to be connected together, to enhance the lateral stiffness of the structure. Just as the tube structure and the tube-in-tube structure, typically, this suited is reserved for very tall buildings.

3.13 Super Tall Building — A building of height greater than 250 m.

3.14 Tall Building — A building of height greater than 50 m, but less than or equal to 250 m.

3.15 Transfer Structure — A structure, comprising of horizontal deep beams, trusses or thick slabs that transfers load actions and supports vertical elements above to vertical elements below that are not aligned with each other, through flexural and shear actions. Alternatively, it can be a trussed structure that fulfils the task through axial actions in the truss members.

4 SYMBOLS

For the purpose of this standard, the following letter symbols shall have the meaning indicated against each; where other symbols are used, they are explained at appropriate places. All dimensions are in metres (m), loads in Newton (N), stresses in mega Pascal (MPa) and time in second (s), unless otherwise specified.

a – Major axis of elliptic plan shape of the building

A_{cr} – Cracked area of section

A_g – Gross area of section

b – Minor axis of elliptic plan shape of the building

h_i – Inter-storey height of i^{th} floor in the building

l_s – Clear span of coupling beam

B – Smaller plan dimension of the building at its base

B_t – Width of tower above podium level

D – Dimension of the building in plan along the considered direction of earthquake shaking

d – Overall depth of coupling beam

H – Building height from its base to roof level,

a) excluding the height of basement storeys, if basement walls are connected with the ground floor slab or basement walls are fitted between the building columns, but

b) including the height of basement storeys, if basement walls are not connected with the ground floor slab and basement walls are not fitted between the building columns

H_t – Height of tower above podium level

h_w – Unsupported height of structural wall

I_{eff} – Effective or cracked moment of inertia of section

I_g – Gross moment of inertia of section

L – Larger plan dimension of the building at its base

L_t – Length of the tower above podium level

M_u – Factored bending moment at a cross-section in a vertical member of the building

P_u – Factored axial load at a cross-section in the vertical member of the building

P_{uz} – Factored pure axial load capacity (at M_u = 0) of a vertical member of the building

T_a – Approximate fundamental translational lateral natural period

$\Delta_{Ma.}$ – Maximum relative lateral displacement within the storey

5 GENERAL REQUIREMENTS

5.1 Elevation

5.1.1 *Height Limit for Structural Systems*

The maximum building height (in m) shall not exceed values given in Table 1 for buildings with different structural systems.

5.1.2 *Slenderness Ratio*

The maximum values of the ratio of height to minimum base width *B* shall not exceed values given in Table 2.

5.1.3 *Aerodynamic Effects*

Elevation profile, façade features of the building, and plan shape of the building shall be such as to attract minimum wind drag effects. Effects of features such as sharp corners, projected balconies, etc, shall be considered in design.

Table 1 Maximum Values of Height *H* above Top of Base Level of Buildings with Different Structural Systems, in metres

(*Clause* 5.1.1)

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed[1)]	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube[2)]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	120	150	150	180
ii)	IV	NA	150	200	200	225
iii)	III	60	200	225	225	250
iv)	II	80	250	250	250	250

[1)] Structural walls are considered to be well-distributed when structural walls that are outside of the core are capable of carrying at least 25 percent of the lateral loads.

[2)] This includes systems covered under **1.5** (g), **1.5** (h) and **1.5** (k).

Table 2 Maximum Slenderness Ratio (H_t/B_t)

(*Clause* 5.1.2)

Sl No.	Seismic Zones	Structural System				
		Moment Frame	Structural Wall Well Distributed	Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube[1)] *
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	V	NA	8	8	9	9
ii)	IV	NA	8	8	9	9
iii)	III	4	8	8	9	10
iv)	II	5	9	9	10	10

[1)] This includes systems covered under **1.5** (g), **1.5** (h) and **1.5** (k).

5.2 Plan

5.2.1 *Plan Geometry*

5.2.1.1 The plan shall preferably 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.

5.2.2 *Plan Aspect Ratio*

The maximum plan aspect ratio (L_t/B_t) of the overall building shall not exceed 5.0. In case of an *L* shaped building, L_t and B_t shall refer to the respective length and width of each leg of the building.

5.3 Storey Stiffness and Strength

Parameters influencing stiffness and strength of the building should be so proportioned, that the following are maintained:

a) Lateral stiffness of any storey shall not be less than 70 percent of that of the storey above.

b) Lateral strength of any storey shall not be less than 90 percent that of the storey above.

5.4 Deformations

5.4.1 *Lateral Drift*

When design lateral forces are applied on the building, the maximum inter-storey lateral drift ratio (Δ_{Max}/h_i) under serviceability loads (including wind load with return period of 20 years), which is estimated based on the sectional properties for serviceability loads mentioned in **7.2**, shall be limited to 1/500. Total drift at the topmost usable floor shall be limited to *H*/500. For a single storey the drift limit may be relaxed to h_i/400. For design earthquake force, the maximum inter-story drift shall be h_i/250.

5.5 Natural Modes of Vibration

5.5.1 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.

5.5.2 The fundamental translational natural periodin any of the two horizontal plan directions, shall not exceed 8s, considering sectional properties as per Table 5 corresponding to serviceability loads.

5.6 Floor Systems

5.6.1 *Material*

All floor slabs shall be cast *in-situ*. For precast floor systems a minimum structural topping of 75 mm concrete with reinforcing mesh shall be used in seismic zones III, IV and V, but can be reduced to 50 mm in seismic zone II.

5.6.2 *Openings*

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

5.6.2.2 The maximum area of openings in any floor diaphragm shall not exceed 30 percent of the plan area of diaphragm. Transfer of lateral forces from diaphragm to lateral load resisting vertical elements shall be ensured using collector elements, if required.

5.6.2.3 At any storey, the minimum width of floor slab along any section after deduction of openings shall not be less than 5 m, if there is no perimeter beam. Further, the cumulative width of the slab at any location shall preferably not be less than 50 percent of the floor width.

5.6.3 *Natural Frequency of Floor System*

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

5.7 Materials

5.7.1 *Concrete*

5.7.1.1 The minimum grade of concrete shall be M 30.

5.7.1.2 The maximum grade of concrete shall be M 70. When higher grades are required, the designer shall ensure through experimentation that such concretes shall have at least a minimum crushing strain in compression of 0.002. *See* Annex C for detailed specifications of higher grades of concrete

5.7.2 *Reinforcing Steel*

5.7.2.1 Reinforcing Steel shall conform to provisions of IS 13920.

5.7.2.3 Lapping of longitudinal bars shall be avoided in RC columns and walls that form a part of the lateral load resisting system; when diameter of bars is 20 mm or higher; mechanical couplers as per IS 16172 shall be used to extend bars.

5.8 Progressive Collapse

Following are general guidelines to avoid progressive collapse of structure.

5.8.1 Possibilities of progressive collapse shall be precluded by:

a) selecting structural systems that are appropriate for ensuring structural integrity;
b) adopting rigorous structural investigations that verify acceptable structural behaviour, even when select critical members do not play their intended role; and
c) providing adequate redundancy and integrity to the structure.

5.8.2 *Requirements of Key Elements*

5.8.2.1 Key elements are members, joints or other components, whose failure would result in a disproportionate deterioration of the building and whose presence is vital to ensure ductile behaviour of the building. Vertical and lateral resistance of key elements shall be improved in many ways, including by the use of higher partial safety factors for loads and materials, to ensure that they do not yield before the designated ductile elements.

5.8.2.2 Elements adjoining key elements and capable of providing an alternative load transfer path, shall be suitably designed and detailed.

6 LOADS AND LOAD COMBINATIONS

6.1 The loads and load combinations specified in IS 875 (Parts 1 to 5), IS 456, IS1893 (Part 1) and IS 13920 shall be applicable for tall buildings also. In addition, requirements given in subsequent clauses shall be applicable.

6.2 Wind Effects

6.2.1 For buildings (a) with height greater than 150 m, or (b) with complexities in plan or elevation geometry, or (c) sited on complex topography with group effect or interference effect (existing and future potential), or (d) whose natural period is greater than 5 s, wind effects shall be determined by site-specific wind tunnel studies.

6.2.2 *Site-Specific Wind Tunnel Studies*

6.2.2.1 When wind tunnels studies result in higher storey shears and overturning moments than those calculated at based on IS 875 (Part 3), the results of wind tunnel studies may be used in design.

6.2.2.2 When wind tunnel studies result in lower story shears and moments than those calculated based on IS 875 (Part 3).

a) The minimum design wind base shear shall be at least 70 percent of that derived based on IS 875 (Part 3), and
b) The relative distribution of storey shears shall be as obtained from wind tunnel studies.

6.2.2.3 When wind tunnel studies indicate torsional motion, structural system of the building should be modified suitably to mitigate the torsional effects, so as to bring the torsional velocity below 0.003 rad/s for 10 year return period.

6.2.2.4 The damping ratio considered shall not be greater than 2 percent of critical for concrete buildings.

6.2.3 *Lateral Acceleration*

From serviceability considerations, under standard wind loads with return period of 10 years, the maximum structural peak combined horizontal acceleration a_{Max} in the building for along and across wind actions at any floor level shall not exceed values given in Table 3, without or with the use of wind dampers in the building.

Table 3 Permissible Peak Combined Acceleration

(*Clause* 6.2.3)

Sl No.	Building Use	Maximum Peak Combined Acceleration, a_{Max} m/s^2
(1)	(2)	(3)
i)	Residential	0.18
ii)	Mercantile	0.25

6.3 Seismic Effects

6.3.1 Vertical shaking shall be considered simultaneously with horizontal shaking for tall buildings in seismic zone V.

6.3.2 For buildings in seismic zone V, deterministic site-specific design spectra may preferably be estimated and used in design. When site-specific investigations result in higher hazard estimation, site-specific investigation results shall be used.

6.3.3 Design base shear coefficient of a building under design lateral forces, shall not be taken less than that given in Table 4.

6.3.4 Approximate Fundamental Natural Period

For buildings of height 50 m and more, the fundamental period, T (in sec) for a structure shall be determined by accounting for all structural properties and inherent stiffness of the building through rigorously validated structural analysis procedures. The fundamental period shall however not exceed the value obtained from the approximate fundamental translational natural period T_a (in s) of oscillation, estimated by following expression:

$T_a = 0.0644\,H^{0.9}$ for concrete moment resisting frame systems; and

$T_a = 0.0672\,H^{0.75}$ for all other concrete structural systems

7 STRUCTURAL ANALYSIS

7.1 Software

Structural analysis shall be carried out using standard 3-D computer model using well-established structural analysis software.

7.2 Considerations

Computer modelling shall consider the following:

a) Rigid end offsets of linear members in the joint region, when centerline modelling is adopted;
b) Floor diaphragm flexibility, as applicable;
c) Cracked cross sectional area properties as per Table 6; and
d) The load combination for the initial analysis considering *P*-Δ effects shall be taken as: 1.2 *DL* + 0.5 *IL* ±1.5 *EL/WL.*

Table 4 Minimum Design Base Shear Coefficient (Percent of Seismic Weight)

(*Clause* 6.3.3)

Sl No.	**Building height, *H***	**Seismic Zone**			
		II	III	IV	V
(1)	(2)	(3)	(4)	(5)	(6)
i)	$H \le 120$m	0.7	1.1	1.6	2.4
ii)	$H \ge 200$m	0.5	0.75	1.25	1.75

NOTE — For buildings of intermediate height in the range 120 m to 200 m, linear interpolation shall be used.

Table 5 Cracked Section Properties of RC members

(*Clauses* 5.5.2,7.3.6, 8.1.3.2.1 *and* 7.2)

Sl No.	**Structural Element**	**Serviceability Design**		**Strength Design**	
		Cross-Sectional Area	Moment of Inertia	Cross-Sectional Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	$1.0A_g$	$0.35I_g$	$1.00A_g$	$0.25\ I_g$
ii)	Beams	$1.0\ A_g$	$0.7\ I_g$	$1.00\ A_g$	$0.35\ I_g$
iii)	Columns	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$
iv)	Walls	$1.0\ A_g$	$0.9\ I_g$	$1.00\ A_g$	$0.70\ I_g$

7.3 Modelling

7.3.1 Modelling of buildings shall follow a simple approach, which reflects the distribution of mass and stiffness properties to properly account for all significant inertial forces under seismic actions and deformation shapes.

7.3.2 Analytical model of a building shall reflect the true behaviour of its members as well of the whole structure. One can adopt lumped modelling that is frame element modelling, distributed modelling that is finite element modelling or a combination of the two.

7.3.3 In-plane stiffness of floor slabs shall be modelled, unless it is demonstrated that it is extremely stiff and sufficiently strong to remain elastic under seismic actions. *See* IS 1893 (Part 1) to identify when a floor slab may be considered to be extremely stiff in its own plane.

7.3.4 In moment frame buildings, when buildings with unreinforced masonry infill panels contribute to storey lateral stiffness, their effect shall be modelled as equivalent diagonal struts as per relevant provisions of IS 1893 (Part 1).

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

7.3.6 Cracked sectional properties shall be used when representing concrete elements as per Table 5.

7.3.7 In reinforced concrete buildings, lateral deflections resulting from unfactored lateral loads shall be estimated using section properties intended for use with unfactored lateral loads, and lateral deflections resulting from factored lateral loads using section properties intended for use with factored lateral loads.

7.3.8 Buildings may be considered to be fixed at their bases for determining lateral effects on buildings. When modelling flexibility of foundations, reference shall be made to **8** and **9.**

When foundation flexibility is included in linear analysis, load-deformation characteristics of foundation-soil system shall be accounted for by equivalent linear stiffness, using soil properties that are consistent with soil strain levels associated with the design forces. A 50 percent increase and decrease in stiffness shall be incorporated in dynamic analysis, unless smaller variation can be justified; the largest value of response shall be used in the raft design.

7.3.9 Second order deformation effects (P-Δ effects) shall be considered.

7.3.10 The flexibility of the building shall be such that the inter-storey drift stability coefficient satisfies:

$$\theta = \frac{P_i \Delta_i}{V_i h_{i-1} R} \leq 0.2$$

where

P_i = total design vertical load at level i;
Δ_i = design storey drift at level i;
V_i = design shear force at level i;
h_{i-1} = storey height below level i; and
R = response reduction factor.

7.3.11 Stiffness of frames with flat slabs as horizontal members (that is, slab-column frames) shall be ignored in lateral load resistance, in all Seismic zones. These shall be designed as gravity elements for deformation compatibility.

7.3.12 The model used in structural analysis of solid, coupled, perforated or punched structural walls shall represent stiffness, strength and deformation capacities of structural wall, structural wall segments and coupling beams or spandrel connections between structural walls. Stiffness of coupling beams and spandrel connections shall capture aspect ratio of these coupling beam and spandrel connections, extent of cracking anticipated, and reinforcement provided in them.

7.3.13 Effects shall be considered of construction sequence in buildings taller than 150 m.

7.3.14 Tower(s) connected by a podium shall be modelled separately and integrally.

7.4 Building Movements

For buildings taller than 150 m, and for buildings taller than 100 m with mass asymmetry, analysis shall be carried out for both vertical and horizontal long-term building movements.

7.4.1 Measures shall be taken in concrete and composite buildings to minimize adverse effects of shrinkage, creep, temperature variation and foundation settlement during the design life of the building (not less than 30 years).

7.4.2 Non-structural elements, such as curtain walls, cladding, partitions and finishes and service installations (for example, elevators, vertical pipes, ducts and cables), shall be required to withstand long-term movements of the building and associated differential effects.

7.4.3 Details of connections of non-structural elements with the structural elements of the building shall be planned, such that their relative movements are allowed without causing distress to both structural and non-structural elements.

7.4.4 Appropriate vertical compensation and sway compensation shall be accounted for during construction to minimize long term building movements for concrete and composite structures.

7.4.5 In gravity load analysis, internal forces shall be considered, which are developed due to differential vertical movement of vertical structural elements, due to shrinkage, creep, temperature, foundation settlement and construction compensation. In any case the total shrinkage strain of concrete shall not exceed 0.04 percent.

7.4.6 To calculate the effect of creep and shrinkage, selected strain prediction models of concrete shall be based on established principles of mechanics elaborated in specialist literature.

8 STRUCTURAL DESIGN

8.1 General Requirements

8.1.1 *Method of Design*

Limit state design method (as given in IS 456) shall be used in the design of RC members.

8.1.2 *Staircase*

Staircases built integrally with the structural system of the building and not confined by structural walls, shall be included in the three-dimensional structural model, and its elements designed as per forces induced in them under various load combinations. Alternately, a sliding joint may be provided.

8.1.3 *Multiple Tall Buildings connected with a Common Podium*

8.1.3.1 This section deals with requirements for the following tall buildings with podium:

a) Tall building with single tower and podium (*see* Fig. 1A); and
b) Tall building with multiple towers and common podium (*see* Fig. 1B).

8.1.3.2 *Modelling*

8.1.3.2.1 *Sensitivity analyses*

a) As part of collapse prevention evaluation, two sets of backstay sensitivity analyses shall be carried out using upper-bound and lower-bound cracked section properties of floor diaphragms and the stiffness parameters for those diaphragms and perimeter walls of podium and below the level of the backstay are given in Table 6. These analyses shall be in addition to those required to be carried out using other cracked section properties described in **7.2**.

Table 6 Stiffness Parameters

[*Clause* 8.1.3.2.1]

Sl No.	Stiffness Parameter	Values to be Adopted	
		Upper-Bound	Lower-Bound
(1)	(2)	(3)	(4)
i)	I_{eff}/I_g	0.5	0.15
ii)	A_{cr}/A_g	0.5	0.15

b) Besides that of the floor diaphragms, flexibility of following structural elements in the structural analysis with appropriate modification to their stiffness:

1) Perimeter walls and their foundation supports; and

2) Foundation supports under the tower lateral load resisting system.

8.1.3.3 *Buildings with multiple towers*

8.1.3.3.1 *Backstay*

Backstay transfers the forces from lateral load-resisting elements in the tower to additional structural elements provided within the podium and the 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 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 load paths shall be considered (*see* Fig. 2), namely:

1) *Direct load path* — where overturning resistance is provided by the tower core elements and foundation directly beneath the tower; and

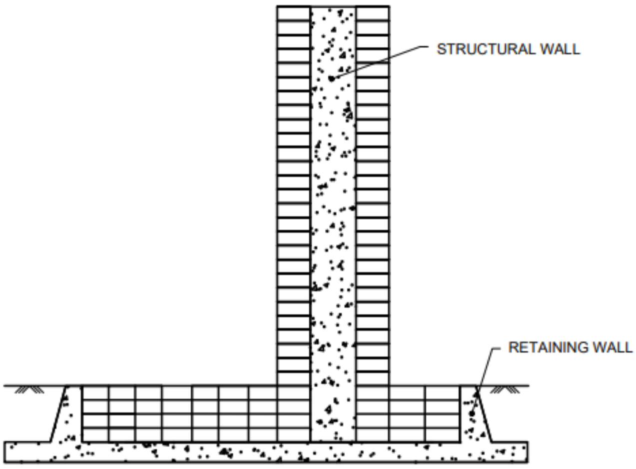
2) *Backstay load path* — where overturning resistance provided by in-plane forces in the backstay elements (lower floor diaphragm and perimeter walls).

In some tall buildings, backstay effects may not be considered. These include the following configurations:

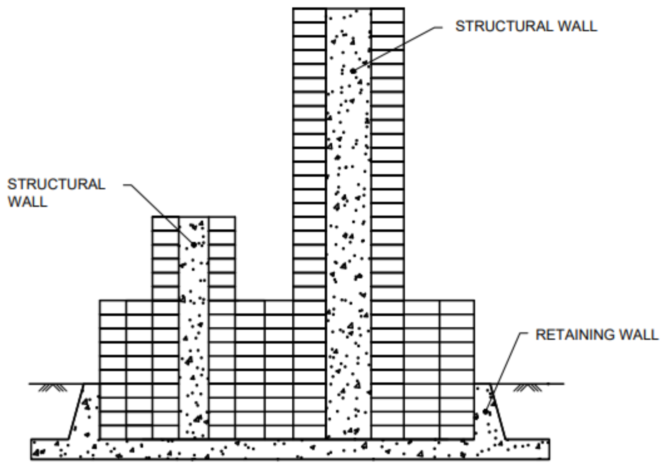
1) Buildings without below grade levels or buildings without significantly increased lateral load resisting systems at the base;

2) Buildings that extend below grade, but have structural separations between the superstructure and the podium portions of the building, and that accommodate lateral load deformations without transfer of lateral forces from superstructure portion to podium portion; and

3) Buildings with perimeter basement walls, where the walls are located directly below the lateral load resisting elements of the superstructure above. Here, there may be a marked change in lateral strength and stiffness at this level, but lateral forces will not be transferred through the floor diaphragms.



1A SINGLE TOWER



1B MULTIPLE TOWER

FIG. 1 TALL BUILDINGS WITH PODIUMS, CORE STRUCTURAL WALL AND BELOW-GRADE PERIMETER RETAINING WALL

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

c) In direct load path case, vertical stiffness shall be considered of the piles, foundation and supporting soil.

d) 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.

e) In tall buildings with backstay diaphragms, collector elements shall be provided (*see* Fig. 2), which are capable of transferring forces from the lateral load-resisting system of the tower to the additional elements providing the resistance and in turn to those forces of the podium. Such collector elements shall be provided for transferring lateral forces originating in the other portions of the structure.

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

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

   2) 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:

      i) Connections of diaphragms to vertical elements and to collectors; and

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

g) 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.

h) Backstay diaphragm floor shall be at least 150 mm thick, with double mesh reinforcement not less than 0.25 percent of cross section area in each direction (including both layers of reinforcement steel).

j) Adequate measures shall be taken to prevent shear sliding failure at connections of diaphragm to structural walls; here, the inclination of the strut shall be taken as 45°. Additional reinforcements shall be provided to resist the shear force at the interface between diaphragm and structural walls.

8.1.3.3.2 *Structural walls*

a) Structural walls shown in Fig. 2 can sustain plastic hinges at the level of the backstay diaphragm also. Such walls shall also be designed and detailed for plastic hinge development at that level.

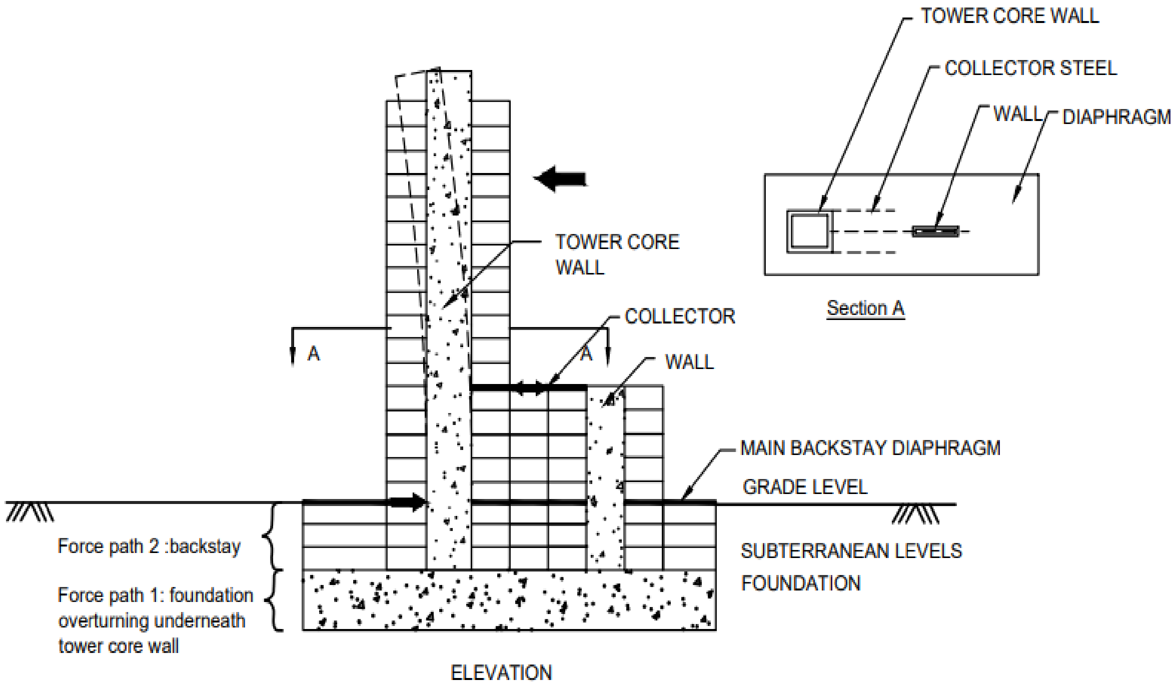
b) All peripheral columns of the tower (irrespective of whether they are gravity columns or not) shall be provided with confinement reinforcements throughout the storeys adjoining (above and below) the backstay diaphragm level, as per the requirements of IS 13920.

8.1.3.3.3 *Towers connected by common podium*

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

a) Such buildings shall be modelled 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.



a) Path 1: Direct load path through tower elements, and
b) Path 2: Indirect load path through backstay elements

FIG. 2 LOAD PATHS IN LATERAL OVERTURNING RESISTANCE OF TALL BUILDINGS WITH PODIUMS

c) In the integral tower modelling:

1) Directional effects for all worst possibilities (that is, tower shaking in the same and in the opposite directions) should be considered in the design load combinations; and

2) 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:

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

2) 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 6 for sensitivity analysis, may be considered for the cracked section properties, to arrive at the design level earthquake demand on the RC diaphragms.

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

f) Vertical irregularities of Type I (soft story) as per Table 6 of IS 1893 (Part 1) shall not be present in the first connected level and the level above it.

g) Topmost slab between the towers of connected podium shall be at least 150 mm thick with double mesh reinforcements not less than 0.25 percent of cross-sectional area in each direction.

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

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

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

8.2 Ductility

Not-withstanding 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.

8.3 Frame Buildings

Frame structure for seismic design shall have at least two planar frames with minimum 3 bays in the direction where the lateral load resistance is provided by the moment frames.

8.4 Moment Frame — Structural Wall Systems

8.4.1 Frame structural wall systems shall be designed as dual systems as per IS 1893 (Part 1).

8.4.2 In a moment frame-structural wall system, the moment frame shall comply with the requirements of **8.3**, and the structural wall with the requirements of **8.5**. In addition, the moment frames and structural walls shall comply with the requirements of IS 13920.

8.4.3 *Special requirements for Seismic Zone* IV *and Seismic Zone V*

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

8.5 Structural Wall Systems

8.5.1 The thickness of structural wall shall not be less than 160 mm or $h_i/20$, whichever is larger.

8.5.2 Opening in structural walls and the associated coupling beams shall meet the following requirements:

a) For walls, when the opening size is less than 800 mm or one-third length of wall, whichever is lesser, in height or length, the influence of the opening may not be taken into account in the overall stiffness of the building.

b) For beams, the opening size shall be less than one-third of the height or length of beam and location of the opening shall be such that the top and bottom one-third of height of the coupling beam is not disturbed.

c) In either case, all four sides of the opening shall be strengthened with additional reinforcements, and shall comply with requirements of IS 13920. Diameter of reinforcement bars used in this reinforcement shall not be less than 12 mm.

8.5.3 Gravity columns in structural wall buildings shall be designed as per requirements of deformation compatibility on non-seismic members given in IS 1893 (Part 1).

8.5.4 Beams carrying predominant vertical load shall not be supported on coupling beams. Also, columns or structural walls carrying predominant vertical load shall not be supported on coupling beam.

8.5.5 In a structural wall system, the structural wall shall comply with the requirements of IS 13920.

8.5.6 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.

8.5.7 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.

8.5.8 The nominal design shear stress shall be limited to $\tau_{c,max}$ in structural walls that do not sustain tensile axial stress under any load combination, while the nominal design shear stress shall be limited to 0.5 $\tau_{c,max}$ in structural walls under tension in any load combination and coupling beams in structural walls under factored design loads, where $\tau_{c,max}$ is as per Table 20 in IS 456.

8.5.9 The amount and distribution of the minimum reinforcement in structural walls shall be as per IS 13920.

8.5.10 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, that is at a stress level of f_y.

8.5.11 The maximum longitudinal reinforcement ratio in coupling beam shall be as given in Table 7.

Table 7 Maximum Longitudinal Reinforcement in Coupling Beams

(Each at top and bottom surface)

(*Clause* 8.5.11)

Sl No. (1)	Span to Depth Ratio (2)	Maximum Reinforcement Percent (3)
i)	$L_s/D \leq 1.0$	0.6
ii)	$1.0 \leq L_s/D < 2.0$	1.2
iii)	$2.0 \leq L_s/D$	1.5

8.5.12 *Requirements for Each Storey Resisting more than* 35 *percent of Design Base Shear*

Structural wall with a height-to-length ratio greater than 1.0 may be removed in any storey above, if it accounts for less than one-third of the storey shear strength. Further, the resulting structural system must not have any torsional irregularity as per IS 1893 (Part 1).

8.5.13 *Special Requirements for Seismic Zones* IV *and* V

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

b) The minimum longitudinal reinforcement in structural walls shall not be less than 0.4 percent of gross cross-sectional area;

c) The minimum transverse reinforcement in Structural walls shall not be less than 0.25 percent of gross cross-sectional area;

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 preferably be aligned vertically. Random openings, arranged irregularly, shall not be permitted in coupled walls, unless their influence is insignificant.

8.6 Flat Slab — Structural Wall Systems

8.6.1 In structures with flat slab system as gravity load carrying system, structural walls shall carry all lateral loads on the building, and column strips of the flat slab system shall not be included in the lateral load resisting system. All requirements related to structures with flat slabs mentioned in IS 1893 (Part 1) shall be met with.

8.7 Framed Tube System, Tube-in-Tube System and Multiple Tube System

8.7.1 The plan shape of a tube-in-tube system shall be regular with a length to width ratio not more than 2 and, the inner tube shall be centered with the outer tube.

8.7.2 Reentrant corners and sharp changes to tubular form should be avoided.

8.7.3 Column spacing of framed tube shall preferably be not more than 5 m.

8.7.4 In a framed-tube system:

a) Area of corner column shall be 1 to 2 times that of internal column; and

b) Height to width ratio of the opening shall be similar to ratio of storey height to column spacing.

8.7.5 Due consideration shall be given to shear lag effects in the design of tube structures.

8.7.6 In seismic zones III, IV and V:

a) Single span frame shall not be adopted; and

b) Axial compression ratio of columns shall be as per IS 13920.

8.7.7 Beams carrying predominantly gravity load shall be directly supported on columns or on walls and not on frame beams.

8.7.8 The minimum requirements for reinforcement bar diameters in beams of moment frames of framed-tube structures are given in Table 8.

Table 8 Reinforcement Requirements in Beams

(*Clause* 8.7.8)

All dimensions in millimetres.

Sl No.	Reinforcement Type	Seismic Zone	
		II	III, IV and V
(1)	(2)	(3)	(4)
i)	Stirrup diameter	≥ 8	≥ 10
ii)	Stirrup spacing	≤ 150	≤ 100
iii)	Main (longitudinal) reinforcements	≥ 16	≥ 16

9 FOUNDATIONS

9.1 Load paths and mechanisms shall be ensured explicitly for transferring vertical and lateral loads between structure and soil system underneath.

9.2 A factor of safety of 1.5 shall be provided against overturning and sliding under, (a) unfactored design wind load, gravity load and other permanent imposed load; and (b) 2.5 times design earthquake load, unfactored gravity load and other permanent imposed load.

9.3 Geotechnical Investigations

All geotechnical investigations needed to establish the safety of the building shall be conducted including for liquefaction potential analysis, and estimation of soil spring constants and modulus of subgrade reaction.

9.3.1 For geotechnical investigations, IS 1892 shall be referred.

9.4 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, this requirement may be relaxed,

a) when the foundation rests on hard rock; or
b) when there is no uplift under any portion of the raft in any service load combination, and provided the minimum competent founding strata requirement is fulfilled.

9.5 Podium and basement roof slab shall be capable of transferring in-plane shear from the tower to the foundation.

9.6 Expansion Joints shall preferably be avoided in basements of tall buildings. If provided such joints shall be suitably detailed for water tightness.

9.7 Modelling of Soil

9.7.1 While modelling raft foundations through spring constant or modulus of sub-grade reaction, 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. For design of rafts for buildings taller than 150 m, a soil-structure interaction study shall be conducted, using actual column loads and column locations to obtain the zoned spring constants.

9.7.2 For piled raft foundations designed with settlement reducing piles, soil-structure interaction study shall be conducted with actual column loads and column locations. This analysis shall be conducted at a minimum for combinations of following loads:

a) Dead,
b) Live,
c) Wind in X-direction,
d) Wind in Y-direction,
e) Seismic in X-direction, and
f) Seismic in Y-direction.

where

X and Y are orthogonal axes in plan.

9.8 Settlements of Foundations

9.8.1 Maximum vertical settlement of raft or piled raft foundations under gravity loads shall comply with requirements of IS 1904 and IS 12070. The maximum vertical settlement is limited to 125 mm in raft or raft-pile foundation subject to maximum angular distortion of raft not exceeding 1/500, and 50 mm in rock.

10 RECOMMENDATIONS FOR NON-STRUCTURAL ELEMENTS

The non-structural elements (NSEs) of tall buildings shall comply with all relevant existing national standards and guidelines as laid down by the various statutory and non-statutory bodies as well as the client/owner of the building. In addition, specifications laid down in **10.1, 10.2** and **10.3** shall be applicable for:

a) Planning, design and construction of NSEs of new tall buildings; and
b) Re-planning, assessment and retrofitting of NSEs of existing tall buildings.

The specifications laid down in **10.1, 10.2** and **10.3** shall govern over similar clauses given in the prevalent relevant Indian standards.

10.1 Design Strategy

NSEs shall be classified into three types depending on their earthquake behaviour, namely:

a) Acceleration-sensitive NSEs;
b) Deformation-sensitive NSEs; and
c) Acceleration-and-deformation-sensitive NSEs.

NSEs in tall buildings shall be protected against the effects mentioned above. Major NSEs shall be protected based on engineered calculations as per clauses given in this section.

10.2 Design Guidelines — Acceleration-Sensitive NSEs

The design lateral force F_p for the design of acceleration-sensitive NSEs shall be calculated as:

$$F_p = Z\left(1+\frac{x}{h}\right)\frac{a_p}{R_p} I_p W_p$$

where

= Seismic zone factor [as defined in IS 1893 (Part 1)];

I = importance factor of the NSE (*see* Table 9);

R = component response modification factor (*see* Table 10);

a = component amplification factor (*see* Table 10);

W = weight of the NSE;

= height of point of attachment of the NSE above top; and

h = overall height of the building.

Table 9 Proposed Importance Factors

(*Clause* 10.2)

Sl No. (1)	NSE (2)	*I*p (3)
i)	Component containing hazardous contents	
ii)	Life safety component required to function after an earthquake (for example, fire protection sprinklers system)	2.5
iii)	Storage racks in structures open to the public	
iv)	All other components	2.0

Table 10 Coefficients a_p and R_p of Architectural, Mechanical and Electrical NSEs

(*Clause* 10.2)

Sl No. (1)	NSE (2)	p (3)	p (4)
i)	**Architectural Component or Element:**		
a)	Interior non-structural walls and partitions:		
	1) Plain (unreinforced) masonry walls	1.0	1.5
	2) All other walls and partitions	1.0	1.5
b)	Cantilever elements (unbraced or braced to structural frame below its center of mass)		
	1) Parapets and cantilever interior non-structural walls	2.5	2.5
	2) Chimneys and stacks where laterally supported by structures	2.5	2.5
c)	Cantilever elements (braced to structural frame above its center of mass):		
	1) Parapets	1.0	2.5
	2) Chimneys and stacks	1.0	2.5
	3) Exterior non-structural walls	1.0	2.5
d)	Exterior non-structural wall elements and connections:		
	1) Wall element	1.0	2.5
	2) Body of wall panel connection	1.0	2.5
	3) Fasteners of the connecting system	1.25	1.0

Table 10 (*Continued*)

Sl No. (1)	**NSE** (2)	p (3)	p (4)
e)	Veneer:		
	1) High deformability elements and attachments	1.0	2.5
	2) Low deformability and attachments	1.0	1.5
f)	Penthouses (except when framed by and extension of the building frame)	2.5	3.5
g)	All ceilings	1.0	2.5
h)	Storage cabinets and laboratory equipment	1.0	2.5
j)	Access floors:		
	1) Special access floors	1.0	2.5
	2) All other	1.0	1.5
k)	Appendages and ornamentations	2.5	2.5
m)	Signs and billboards	2.5	2.5
n)	Other rigid components:		
	1) High deformability elements and attachments	1.0	3.5
	2) Limited deformability elements and attachments	1.0	2.5
	3) Low deformability elements and attachments	1.0	1.5
p)	Other flexible components:		
	1) High deformability elements and attachments	2.5	3.5
	2) Limited deformability elements and attachments	2.5	2.5
	3) Low deformability elements and attachments	2.5	1.5
ii) Mechanical and Electrical Component/Element:			
a)	General mechanical:		
	1) Boilers and furnaces	1.0	2.5
	2) Pressure vessels on skirts and free-standing	2.5	2.5
	3) Stacks	2.5	2.5
	4) Cantilevered chimneys	2.5	2.5
	5) Others	1.0	2.5
b)	Manufacturing and process machinery:		
	1) General	1.0	2.5
	2) Conveyors (non-personnel)	2.5	2.5
c)	Piping systems:		
	1) High deformability elements and attachments	1.0	2.5
	2) Limited deformability elements and attachments	1.0	2.5
	3) Low deformability elements and attachments	1.0	1.5
d)	HVAC system equipment:		
	1) Vibration isolated	2.5	2.5
	2) Non-vibration isolated	1.0	2.5
	3) Mounted in-line with ductwork	1.0	2.5
	4) Other	1.0	2.5
e)	Elevator components	1.0	2.5
f)	Escalator components	1.0	2.5
g)	Trussed towers (free-standing or guyed)	2.5	2.5

Table 10 (*Concluded*)

Sl No. (1)	**NSE** (2)	p (3)	p (4)
h)	General electrical:		
	1) Distributed systems (bus ducts, conduit, cable tray)	2.5	1.0
	2) Equipment	5.0	1.5
j)	Lighting fixtures	1.0	1.5

10.3 Design Guidelines — Displacement-Sensitive NSEs

a) Displacement-sensitive NSEs connected to buildings at multiple levels of the same building or of adjacent buildings, and their supports on the structural elements (SE), shall be designed to allow the relative displacements imposed at the ends by the load effects imposed on the NSE.

b) This imposed relative displacement can arise out of strong earthquake shaking, thermal conditions in the SE and NSE, creep of materials, imposed live loads, etc. In such cases, the relative displacement imposed by each of these effects shall be cumulated to arrive at the design relative displacement, Δ. The effects of earthquake shaking shall be estimated using earthquake demand given by equation given in **10.2**.

c) NSE shall be designed to accommodate design relative displacement, Δ determined by linear static or linear equivalent static analysis of the building structure subjected to load effects mentioned above.

d) Flexibility or clearance of at least the design relative displacement shall be provided:

1) within the NSE, if both supports on the SE offer restraints against relative translation between the SE and the NSE; or
2) at the unrestrained support, if one of the supports on the SE offers no restraint against relative translation between the SE and the NSE, and the other does.

e) For NSE supported between two levels of the same building, or between two different buildings or between a building and the ground, or between building and another system (like an electric pole or communication antenna tower), the design relative displacement, Δ shall be estimated as below:

1) Design horizontal and vertical relative displacements Δ_X and Δ_Y, respectively, between two levels of the same building (building A), one at height h_{z1} and other at height h_{z2} from base of the building at which the NSE is supported consecutively, shall be estimated as:

$$\Delta_X = 1.2\left(\delta_{Z1}^{AX} - \delta_{Z2}^{AX}\right)$$

$$\Delta_Y = 1.2\left(\delta_{Z1}^{AY} - \delta_{Z2}^{AY}\right)$$

where δ_{Z1}^{AX} and δ_{Z2}^{AX}, and δ_{Z1}^{AY} and δ_{Z2}^{AY}, are the design horizontal and vertical displacements, respectively, at levels z_1 and z_2 of the building A (at height h_{z1} and h_{z2} from the base of the building) under the application of the load effects mentioned in this standard; and

2) Design horizontal and vertical relative displacements Δ_X and Δ_Y, respectively, between two levels on two adjoining buildings or two adjoining parts of the same building, one on the first building (Building A) at height h_{z1} from its base and other on the second building (Building B) at height h_{z2} from its base, at which the NSE is supported consecutively, shall be estimated as:

$$\Delta_X = |\delta_{Z1}^{AX}| + |\delta_{Z2}^{BX}|$$
$$\Delta_Y = |\delta_{Z1}^{AY}| + |\delta_{Z2}^{BY}|$$

where δ_{Z1}^{AX} and δ_{Z2}^{BX}, and δ_{Z1}^{AY} and δ_{Z2}^{BY}, are the design horizontal and vertical displacements, respectively, at level z_1 (at height h_{z1}) of building A and at level z_2 (at height h_{z2}) of building B, respectively, at which the two ends of the NSE are supported.

11 MONITORING DEFORMATIONS IN BUILDINGS

11.1 Earthquake Shaking

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

11.2 Wind Oscillations

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

11.3 Foundation Settlement and Pressure Measurement

11.3.1 Permanent settlement markers (at corners and center) shall be provided at raft top level and referenced to a permanent benchmark. Records of settlement shall be maintained till completion of the building and preferably even after completion.

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

ANNEX A

(*Clause* 2)

LIST OF REFERRED STANDARDS

IS No.	*Title*
IS 456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
IS 875	Code of practice for design loads (other than earthquake) for buildings and structures:
(Part 1) : 1987	Dead loads — Unit weights of building material and stored materials (*second revision*)
(Part 2) : 1987	Imposed loads (*second revision*)
(Part 3) : 2015	Wind loads (*third revision*)
(Part 4) : 2021	Snow loads (*third revision*)
(Part 5) : 1987	Special loads and load combinations (*second revision*)
IS 1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
IS 1893 (Part 1) : 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
IS 1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*fourth revision*)
IS 4926 : 2003	Ready-mixed concrete — Code of practice (*second revision*)
IS 9103 : 1999	Concrete admixtures — Specification (*first revision*)
IS 12070 : 1987	Design and construction of shallow foundations on rocks — Code of practice
IS 13920 : 2016	Ductile design and detailing of reinforced concrete structures subjected to seismic forces (*first revision*)
IS 16172 : 2014	Reinforcement couplers for mechanical splices of bars in concrete — Specification

ANNEX B

(*Foreword and Clause* 1.7)

GUIDELINES FOR BUILDING AUTHORITY HAVING JURISDICTION FOR APPROVAL PROCESS FOR DESIGN OF CONCRETE TALL BUILDINGS NOT CONFORMING TO THE PRESCRIPTIVE REQUIREMENTS OF THIS STANDARD

B-1 GENERAL

B-1.1 This Annex provides a process for the design and approval of concrete tall buildings that are not in conformance of the prescriptive requirements of this standard, to ensure acceptable performance of such buildings under gravity, wind, seismic and other pertinent load conditions.

Every concrete tall building not conforming to the prescriptive requirements shall go through the process of being reviewed by a structural design review (SDR) panel as described in this Annex.

The process described in this Annex may also be used for concrete buildings that are not categorized as tall, at the discretion of the Building Authority Having Jurisdiction (BAHJ) over the project.

B-1.2 Concrete tall buildings that are not in conformance of the prescriptive requirements of this standard and are addressed by this Annex include:

a) Buildings with heights exceeding the maximum prescribed limits in this standard in general and for the respective structural system;
b) Buildings taller than 50 m with heights not exceeding the maximum prescribed limits in this standard but which have structural irregularities as defined in IS 1893 (Part 1) or in this standard;
c) Complex buildings with structural features such as coupled towers, split-levels, significant gravity transfers, and structural systems not addressed by this standard;
d) Base-isolated structures and structures with energy dissipating systems; and
e) Buildings not meeting the requirements stipulated in this standard.

B-1.3 A generic checklist for identifying tall buildings not conforming to the prescriptive requirements is given in Table 11. This checklist is by no means a comprehensive list and may be revised as deemed fit by the BAHJ and to suit the particulars of a given project.

B-1.4 Every state/major city shall identify and maintain a list of experts qualified to perform the role of structural design reviewer and serve on a SDR panel. Further, it shall constitute a panel of appropriately qualified experts to review tall buildings not conforming to the prescriptive requirements designated as such by the BAHJ as per the process described in this Annex. The states/major cities that are unable to constitute such panels locally shall establish procedures to empanel experts from elsewhere or shall alternatively not permit the approval of buildings not conforming to the prescriptive requirements.

Every state/major city, in tandem with national building authorities, shall develop and maintain a publicly accessible database of submissions to and results of SDRs completed. Requirements for submission to the database shall be published to every applicant for a SDR panel review.

B-1.5 The engineer-of-record's submission materials to the SDR panel for shall meet the requirements as stipulated in **B-3** of this Annex.

B-1.6 The SDR panel shall issue a decision whether to grant permission for the project under review to proceed into the Construction Document phase upon final review of the materials described in **B-3** at the end of the design development phase. The construction document phase of a project shall not commence until permission to proceed as described has been issued by the SDR panel.

B-1.7 The technical documents submitted for review and results of each SDR shall be put into a state/major city tall building database after the completion of the process.

Table 11 Generic Format for Checklist for Code Exceedance of Buildings

(*Clause* B-1.3)

[If any of the queries (i) to (xiv), returns 'Yes' as an answer, the building will need to go through SDR panel review process. If any of the queries (xv) to (xxix), returns 'No' as an answer, the building will need to go through SDR panel review process.]

Sl No.	Reference to Clause	Description	Code Compliance		
			Yes	No	NA
i)	**1.1**	Is building height greater than 250 m tall?			
ii)	**1.2**	Is the building located less than 10 km (shortest distance) away from any seismogenic fault?			
iii)	**1.5**	Does the building house more than 20 000 occupants?			
iv)	**3.15**	Does the building have any transfer structure in the lateral load resisting system?			
v)	**5.1**	Does the building's structural system exceed the height restrictions specified in Table 1?			
vi)	**5.1**	Does the building's slenderness ratio exceed the requirements specified in Table 2?			
vii)	**5.1**	Structural walls are not well distributed			
viii)	**5.2**	Does the building exceed plan aspect ratio?			
ix)	**5.3**	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?			
x)	**5.4**	Is the lateral translational strength of any storey more than that of the story above?			
xi)	**5.4**	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?			
xii)	**5.5.1**	Is the first or second natural mode of vibration a torsional mode?			
xiii)	**5.5.2**	Is the fundamental translational lateral natural period in exceedance of specified limits?			
xiv)	**5.6.1**	For a precast floor system, is the structural topping thickness provided less than that specified requirements?			
xv)	**5.6**	Are floor openings, if any, in conformance to size and location requirements as per **5.6.2**?			
xvi)	**5.7**	Is minimum structural concrete greater or equal to grade M30?			
xvii)	**6.2**	Are wind tunnel studies in conformance with specified requirements?			
xviii)	**6.3**	In seismic zones IV and V, is the design based on deterministic site specific design spectra?			
xix)	**7.2**	Is the design based on cracked section properties, as noted in Table 5?			
xx)	**7.3**	Is the stability coefficient less than or equal to 0.20?			
xxi)	**8.1**	For project with multiple towers connected with a single podium, are the requirements specified in **8.1.3** satisfied?			
xxii)	**8.4**	Where moment frame — structural wall system is provided in seismic zone IV and V, are the special moment frames and shear walls continuous?			
xxiii)	**8.5**	Where structural wall system is provided:			
		a) Is the minimum wall thickness 160 mm of $h_i/20$, whichever larger?			

		b) Are all openings per requirements of 8.5.2?			
		c) Are the nominal design shear stresses in structural walls within the specified limits of 8.5.8?			
		d) Is the longitudinal reinforcement ratio in Coupling Beam less than the limits specified in Table 8?			
		e) For projects in seismic zones VI and V, are the requirements of **8.5.14** satisfied?			
xxiv)	**8.6**	Where flat slab-structural wall system is provided, do the structural walls carry all lateral loads without any contribution from the column strips of flat slab system?			
xxv)	**8.7**	Where framed tube or tube-in-tube or multiple tube system is provided:			
		a) Is the plan shape of the system regular?			
		b) Is length to width ratio less than or equal to 2?			
xxvi)	**9.3**	Is the geotechnical investigation completed as per the requirements of **9.3.1**?			
xxvii)	**9.4**	Is the minimum depth of foundation provided as per the requirements of **9.4**?			

B-2 STRUCTURAL DESIGN REVIEWER AND EXPERT REVIEW PANEL

B-2.1 Structural Design Reviewer

The structural design reviewer is a structural engineer empaneled with the local authority having jurisdiction authority responsible for issuing permits who is appointed to review the specialized aspects of the project and related analysis and design procedures. The structural design reviewer is independent of and distinct from the expert review panel. The structural design reviewer shall perform all the tasks mentioned herein of a peer reviewer including meeting with the engineer of record and with the building authority's inspection staff as the need arises throughout the design process, providing the building authority with a report of its findings after completion of their work. Review by the structural design reviewer is not intended to replace quality assurance measures ordinarily exercised by the engineer of record in the structural design of a building. Responsibility for the structural design remains solely with the engineer of record, and the burden to demonstrate building performance conformance with the requirements of this standard resides solely with the engineer of record. The responsibility for conducting the structural plan check review resides with the building authority, the owner/developer and any plan review consultants they choose to engage.

B-2.1.1 *Qualifications and Selection of Structural Design Reviewer*

The structural design reviewer shall be a recognized expert in field of structural engineering and must have proven experience in field of tall building design. The reviewer's team shall possess required depth in the fields of earthquake engineering, performance-based earthquake engineering, non-linear response history analysis, building design, earthquake ground motion, geotechnical engineering, geological engineering, and other areas of knowledge and experience relevant to the project. The structural design reviewer shall be selected by the project owner/developer from a project-specific list provided by the building authority. The structural design reviewer shall bear no conflict of interest with respect to the project and shall not be considered part of the design team for the project. The responsibility of the structural design reviewer is to assist the building authority in ensuring compliance of the structural design with the performance standards as implicit in this standard. While the structural design reviewer contracts with the project owner/developer, his responsibility is to the building authority. The structural design reviewer shall be registered as a licensed structural engineer qualified to design buildings of unlimited height in at least one city of the country of seismic zone III or higher. The structural design reviewer shall direct all written communication to the building authority.

B-2.1.2 *Administration of Structural Design Review*

The project owner/developer is responsible for the payment of fees and other expenses for the professional services of the structural design reviewer. The structural design reviewer shall provide to the building authority a written copy of a proposed scope of work of its contract with the project owner/developer. The proposed scope of services in the contract and any changes proposed to be made thereto shall be approved by the building authority.

B-2.1.3 *Scope of Structural Design Review Services*

The scope of services for the structural design reviewer shall be defined by the building authority to provide required expertise to supplement its own review. This scope of services may include, but shall not be limited to, review of the following:

a) Basis of design, methodology and acceptance criteria;
b) Mathematical modelling and simulation;
c) Lateral loads performance goals;
d) Foundations;
e) Interpretation of results of analyses;
f) Member selection and design;
g) Detail concepts and design;
h) Construction documents, including drawings, calculations and specifications;
j) Isolators and energy dissipation devices including testing requirements and quality control procedures;
k) Design of special foundation or earth retaining systems; and
m) Design of critical non-structural elements.

The structural design reviewer shall be engaged as early in the structural design phase as practicable. This affords the structural design reviewer an opportunity to evaluate fundamental design decisions, which could disrupt design development if addressed later in the design phase. Early in the design process, the engineer of record and the structural design reviewer shall jointly establish the frequency and timing of review milestones, and the degree to which the engineer of record anticipates the design will be developed for each milestone. The structural design reviewer shall provide written comments to the engineer of record, and the engineer of record shall prepare written responses thereto. The structural design reviewer shall maintain a log that summarizes the structural design reviewer's comments, engineer of record responses to comments, and resolution of comments. The structural design reviewer shall make the log available to the engineer of record as requested. The structural design reviewer may also issue interim reports as appropriate relative to the scope and project requirements. At the conclusion of the review the structural design reviewer shall submit to the building authority a written report that references the scope of the review, includes the comment log and supporting documents, and indicates the professional opinions of the structural design reviewer regarding the design's general conformance to the requirements of this standard.

B-2.1.4 *Dispute Resolution*

The engineer of record and the structural design reviewer shall attempt to develop a consensus on each issue raised by the structural design reviewer. If the engineer of record and the structural design reviewer are unable to resolve particular comments, the structural design reviewer shall report the impasse to the building authority. The authority, as building official, shall make final decisions concerning all permits. The building authority, should the need arise, may address differences of opinion between the engineer of record and the structural design reviewer in whatever method it deems appropriate. The building authority also may engage additional outside experts to assist in issue resolution.

B-2.2 Structural Design Review (SDR) Panel

The SDR panel for a project is the group of structural engineers and pertinent subject experts empaneled by the BAHJ responsible for issuing permits to review buildings not conforming to the prescriptive requirements and specialized aspects of the project and related analysis and design procedures. The SDR panel shall perform all the tasks mentioned in this Annex in the capacity of a peer review group including meeting with the engineer-of-record and with the building authority's inspection staff as the need arises throughout the design process, providing the BAHJ with reports of its findings at various stages in the design process as agreed, and after completion of its work. Review by the SDR panel is not intended to replace quality assurance measures ordinarily exercised by the engineer-of-record in the structural design of a building. Responsibility for the structural design remains solely with the engineer-of-record, and the burden to demonstrate building performance conformance with the requirements of this standard, including this Annex, resides solely with the Engineer-of-Record. The responsibility for conducting the structural plan check review resides with the BAHJ and any additional plan review consultants the owner/developer might choose to engage.

B-2.1.1 *Qualifications and Selection of Structural Design Review* (*SDR*) *Panel Members*

Each structural design reviewer selected to serve on a SDR panel shall be a recognized expert in a pertinent field of structural engineering and must have proven experience related to tall building design. The panel members shall possess theoretical depth and practical experience in the fields of earthquake engineering, performance-based earthquake engineering, non-linear response history analysis, building design, earthquake ground motion development, geotechnical engineering, geological engineering, wind engineering, and other areas of knowledge and experience as appropriate and relevant to the project.

The recommended make-up of a typical SDR panel shall be as follows:

a) Two practicing structural engineers recognized as subject experts in analysis and design of tall buildings, who have designed at least 10 buildings of height 150 m or greater; The engineers shall be licensed to practice structural engineering in a state with equal or greater seismic, wind and geotechnical conditions to those of the project under review.
b) One academic expert in structural engineering recognized as subject expert in analysis and design of tall buildings (including earthquake and/or wind engineering as appropriate to the project).
c) One practicing geotechnical engineer or academic recognized as subject expert in geotechnical issues of tall buildings and, if applicable, ground motions.
d) One or more specialists in wind design, base isolation and damper design, wind design, special construction techniques or materials as appropriate for the project.

One of the two structural engineers on the panel shall be nominated as the chairperson of the panel and shall serve as the point of contact for the panel.

Each SDR panel member shall be selected by the project owner/developer from a project-specific list provided by the BAHJ. The structural design review panel members shall bear no conflict of interest with respect to the project and shall not be considered part of the design team for the project. The responsibility of the SDR panel is to assist the BAHJ in ensuring compliance of the structural design with the performance intent implicit in this standard. While each structural design review panel member contracts with the project owner/developer, his/her responsibility is to the BAHJ. The SDR panel shall direct all written communication to the BAHJ and copy the building owner/developer and engineer-of-record.

All written communication from the SDR panel shall bear the names and signatures of the panel members.

B-2.1.2 *Administration of Structural Design Review* (*SDR*)

The project owner/developer is responsible for the payment of fees and other expenses for the professional services of the SDR panel members. The SDR panel shall provide the BAHJ with a written copy of a proposed scope of work from its contract with the project owner/developer. The proposed scope of services in the contract and any changes proposed to be made thereto shall be approved by the BAHJ.

B-2.1.3 *Scope of Structural Design Review Panel's Services*

The scope of services for the SDR panel shall be defined by the BAHJ to provide required expertise to supplement its own review. This scope of review services is described in more detail in **B-3**, **B-4**, and **B-5**.

The SDR panel shall be engaged as early in the structural design phase as practicable. This affords the SDR panel the opportunity to evaluate fundamental design decisions, which could disrupt design development if addressed later in the design process. Early in the design process, the engineer-of-record and the SDR panel shall jointly establish the frequency and timing of review milestones, and the degree to which the engineer-of-record anticipates the design will be developed for each milestone. The milestones and timing shall be developed keeping in mind the necessity of establishing the viability of the project's structure and the need for the panel to issue a letter of permission for the project's design to proceed into the construction document phase as described in **B-1.6**. The SDR panel shall provide written comments to the engineer-of-record, and the Engineer-of-Record shall prepare written responses thereto. The SDR panel shall maintain a log that summarizes its comments, engineer-of-record responses to comments, and resolution of comments. The SDR panel shall make the log available to the engineer-of-record as requested. The structural design review panel may also issue interim reports as appropriate relative to the scope and project requirements. At the conclusion of the review at the end of the design development phase, the SDR panel shall submit to the BAHJ a written report that references the scope of the review, includes the comment log and supporting documents, and indicates the professional opinions of the SDR panel regarding the design's general conformance to the requirements and intent of this standard. It shall also indicate the fitness of the project to move into the construction document phase.

It is expected that most of the SDR panel's work will be completed by the end of the design development phase and the issuance of the panel's permission for the design team to proceed into the construction document phase of design. Depending on the specifics of the project, selected members of the SDR panel may be required to stay involved through the construction document and construction phases as defined in the panel's scope-of-work.

B-2.1.4 *Dispute Resolution*

The engineer-of-record and the SDR panel shall attempt to develop a consensus on each issue raised by the SDR panel. If the engineer-of-record and the SDR panel are unable to resolve particular comments, the SDR panel shall report the impasse to the BAHJ. The authority, as building official, shall make final decisions concerning all permits. The BAHJ, should the need arise, may address differences of opinion between the engineer-of-record and the SDR panel in whatever method it deems appropriate. The BAHJ also may engage additional outside experts to assist in issue resolution.

B-3 SUBMITTALS FOR REVIEW TO SDR PANEL

B-3.1 The engineer-of-record shall submit the following documents to the SDR panel during the review culminating in final versions satisfactorily addressing the SDR panel comments at the end of the design development phase in connection with obtaining the panel's permission to proceed into the construction document phase:

a) Design basis report;
b) Mathematical modeling for static, dynamic, linear and nonlinear analyses;
c) Lateral loads and performance goals;
d) Ground motion selection for various hazard levels and design checks;
e) Foundations — Selection and design;
f) Interpretation of results of analyses;
g) Member selection and design;
h) Key detail concepts and design;
j) Construction documents, including drawings, calculations, and specifications;
k) Isolators and energy dissipation devices including testing requirements and quality control procedures;
m) Wind engineering and wind-tunnel study requirements and results;
n) Design of special foundation or earth retaining systems; and
p) Design of critical non-structural elements.

B-3.1.1 *Design Basis Report for Tall Buildings not Conforming to the Prescriptive Requirements*

The design basis report for the tall buildings not conforming to the prescriptive requirements shall include all key building data and design parameters as well as design methodology and acceptance criteria. The report shall specify how and to what degree the building exceeds prescribed limits as given in **B-3.1** and propose effective safety control technical measures to ensure the reliability of the seismic and wind designs, strengthening measures for the entire structure or for weak parts, proposed performance objectives and technical measures to efficiently ensure strength and the stability of the buildings not conforming to the prescriptive requirements.

B-4 GENERAL FOCUS OF THE STRUCTURAL DESIGN REVIEW (SDR)

B-4.1 The focus of the SDR panel review process is safety of the structure and satisfaction of equivalent performance to the intent of this prescriptive standard's requirements particularly under lateral load conditions. Items focused on will include but not be limited to:

a) Structural concept and basis for the building's gravity and lateral load design including all building data and design parameters;
b) Geotechnical investigation results and foundation design strategy;
c) Wind design concept and performance objectives;
d) Seismic design concept and performance objectives for the building structure in seismic zone III and above;
e) Special measures for weak/critical areas;
f) Engineering evaluation of the overall calculations and calculations of weak/critical areas; and
g) Other project specific conditions such as use of base isolation and/or energy dissipation devices, or which might affect structural safety.

B-4.2 For buildings with overly complicated structural systems, or unusual structural types (including roofs) where there is no design basis for reference, the overall structural model or models of key portions of the structure shall be selected at the SDR panel's discretion for scaled testing to study seismic performance.

B-5 DESIGN APPROACH FOR BUILDINGS NOT CONFORMING TO THE PRESCRIPTIVE REQUIREMENTS UNDERGOING SDR PANELREVIEW

B-5.1 Design Team Actions for Building Structures not Conforming to the Prescriptive Requirements

The following design actions are recommended:

a) Satisfy all requirements of applicable codes for structures not conforming to the prescriptive requirements;
b) Identify key elements and areas of weakness critical areas; design key

elements and areas of potential weakness and critical areas to higher standard (for example, with over-strength factors or using earthquake forces from higher earthquake hazard events in load combinations;

c) In seismic zone III and above, ensure that the key elements and critical areas do not fail before other members achieve required levels of ductility and structure behaves as intended;
d) Perform special analytical studies and/or tests as appropriate to address unique aspects of the structure (for example, model special joints with sufficiently sophisticated finite element software, perform creep and shrinkage column or wall differential shortening studies, construction sequence modeling, etc);
e) Perform wind tunnel studies and incorporate results as required by this standard; and
f) Perform linear dynamic response spectrum or time history analyses for all buildings not conforming to the prescriptive requirements in seismic zone III and higher.

B-5.2 Structural Analytical Models and Calculation Results

a) Determine the validity and reliability of calculation results, pay attention to any difference between analysis assumptions and actual conditions (including the distinctions between rigid diaphragms, flexible diaphragms, and multiple rigid diaphragms), and determine unfavorable situations in the structure based on variation of force distribution throughout the structure and the location and distribution of maximum story drift;
b) The total seismic shear and the ratio of seismic shear on each floor to the cumulative representative gravity load at that floor should meet limit in the IS 1893 and the limit shall be increased appropriately for seismic zones III, IV and V. If the total seismic shear force at the bottom of the structure is too small and needs adjustment, then the shear force on all the floors above should be adjusted appropriately; and
c) Linear dynamic response spectrum analysis shall be performed for all buildings not conforming to the prescriptive requirements in seismic zones III and above and time-history analyses shall be performed as per the requirements of IS 1893 (Part 1) and shall capture site specific and higher mode effects in determining design level earthquake force demands. The restraint conditions in the time history analysis shall be same as those in response spectrum analyses. Dynamic analyses performed shall satisfy following requirements:

   1) Linear analysis shall be performed for code design level earthquakes;
   2) Nonlinear time history analysis shall be performed for design basis earthquake (475 year return period-DBE) and maximum considered earthquake (2 500 year return period-MCE) performance evaluation for all buildings not conforming to the prescriptive requirements exceeding height limits for the structure type, for base-isolated structures, for structures with energy dissipating devices, for structures not addressed by this standard and for complex structures deemed to require it at the discretion of the SDR panel;
   3) Duration of ground motion shall be at least five (5) times fundamental lateral translational natural period of building;
   4) Bi-directional combination of pairs of ground motions shall be performed;
   5) Cracked section properties shall be used in both linear and non-linear analyses. In linear response spectrum analyses and time-history analyses, damping shall be taken as 5 percent. In nonlinear analyses, appropriate values of inherent damping shall be utilized backed by suitable references;
   6) Time history analysis shall be performed using recorded ground motions of past earthquakes corresponding to similar magnitudes, fault distances and fault mechanisms as design event for the subject project;
   7) At least three pairs of appropriate horizontal ground motions shall be used. Spectral matching may be adopted at the natural period of the building to select ground motions that

simulate the design event;

8) The maximum response from at least three linear time history analyses shall be used for design and performance verification at the code design hazard level, and

9) Nonlinear time history analyses, where required to be performed, shall serve to confirm building behavior as described in the design basis report. Inter-storey drift at any storey shall not exceed three percent in the MCE event at any location.

ANNEX C

(*Clause* 5.7.1.2)

SPECIFICATIONS FOR CONCRETE IN TALL CONCRETE BUILDINGS

C-1 specifications of using concrete in tall concrete buildings are as follows:

a) Concrete required for tall buildings shall preferably be sourced from ready-mixed concrete facility, either from a site-based captive plant or from a nearby commercial RMC plant.

b) The minimum grade of concrete shall be M 30. In view of the twin advantages of high-strength concrete in reducing the section sizes and percentage of steel reinforcement in structural elements, such concrete with grades ranging from M 45 to M 70 shall be used, wherever essential. Prior to starting construction, specified properties shall be verified through prior laboratory testing. When higher grades are required, the designer shall ensure through testing that such concretes shall have a minimum crushing strain in compression of 0.002 0. Grades higher than M 70 (up to M 100) shall be used with utmost caution under the guidance and supervision of a recognized subject expert in concrete technology with appropriate values for parameters of modulus of elasticity, shrinkage, creep and durability.

c) Concrete grade shall be specified for 28 days compressive strength. However, depending upon the application requirements, the 56 days or 90 days strength may be specified and it shall be ensured that the concrete develops the requisite strength at specified days before predominant loads are imposed on it.

d) Selection of different ingredients as well as mix proportioning is critical. The contractor and/or ready-mixed concrete producer shall demonstrate by conducting laboratory and field trials that the specified properties of concrete at specified ages are achievable with the mix proportions and ingredients proposed. This needs to be done prior to the commencement of the project.

e) Considering the durability and sustainability advantages, along with OPC, the use of quick reacting ultrafine materials such as silica fume, ultrafine GGBS or ultrafine fly ash conforming to relevant codes shall be permitted, provided the permissible replacement limits specified in relevant codes are not exceeded and the specified properties of concrete are obtained at specified ages. With a view to compensate loss of early strengths while using fly ash and GGBS, the use of silica fume, ultra-fine GGBS, etc shall be permitted, provided these materials conform to the requirements of relevant codes for silica fume and GGBS. While the chemical admixtures shall conform to the requirements of IS 9103, the compatibility issues between the cement, supplementary cementitious materials (SCM) and chemical admixture shall be resolved satisfactorily beforehand through laboratory trials.

f) High strength concretes are quite sensitive to changes in properties of ingredients, variations in mix proportions and testing procedures. Hence, special efforts shall be taken to enforce strict quality assurance (QA) and quality control (QC) during production and testing of such concrete. The contractor/RMC producer supplying concrete shall provide a detailed QA and QC Plan. The owner or its representatives shall approve it and devise measures to monitor the strict implementation of the QA and QC plan. Concrete obtained from the plant certified under Ready-Mixed Concrete Plant Certification Scheme shall be preferred (*see* IS 4926).

g) For high-strength concrete, the static modulus of elasticity (MoE) derived from calculations based on compressive strength may vary significantly from the tested values. Hence, the MoE value of the specified concrete mix assumed in design shall be verified through tests on samples taken from concrete produced from batching plant for field trials.

h) The concrete used in massive raft foundations, thick shear walls and columns, deep beams, etc., shall be designed to appropriately control the evolution of high heat of hydration. The design of such concrete shall be done in such a manner that the peak temperature in concrete shall not exceed 70 °C and that the thermal gradient within the concrete mass does not exceed 20 °C. While appropriately designed mock trials shall be conducted prior to actual concreting to demonstrate that these parameters are satisfied, temperature monitoring shall be done in structural elements containing mass concrete by installing adequate number of temperature sensors to record temperature data on a continuous basis to verify that the temperature rise and thermal gradients are within the specified limits.

j) With a view to overcoming the explosive spalling tendency of high strength concrete subjected to fire, higher fire endurance in concrete shall be achieved by providing bent ties at 135° back into the concrete core and with closer tie spacing (say, at 0.75 times that required for normal-strength concrete under non-ductile detailing). To further mitigate the adverse effects of fire on high strength concrete, the concrete shall contain polypropylene fibres needed to minimize spalling shall be about 0.1 percent to 0.15 percent by volume of concrete.

k) Concrete used in tall building construction shall be durable. For ensuring long-term durability, concrete shall satisfy the following test criteria:

   1) Rapid chloride ion permeability test in:

      i) Foundations – Not more than 1 000 Coulamb; and

      ii) Superstructure – Not more than 1 500 Coulamb.

   2) Water penetration test in:

      i) Foundations – 15 mm, *Max*; and
      ii) Superstructure – 20 mm, *Max.*

m) Effective steps shall be taken in the design of high strength concrete having low water-cementitious materials ratio (for example, less than 0.3) to guard against the adverse effects of autogenous shrinkage. Measures suggested in specialist literature shall be adopted and got approved by the engineer-in-charge. The total shrinkage stain of concrete shall not exceed 0.04 percent.

n) The grades of concrete used in slabs and beams shall not be less than 70 percent of that used in columns and walls in contact. When grade of concrete used in columns is different from that used in beams and slabs beyond the above limit, concrete used in columns and walls shall be used in the beam-column joints also; in such a case, puddling of concrete shall be done in such a way that column concrete is 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.

p) Batching, mixing, transporting, placing and control procedures for high strength concrete are essentially similar to procedures used for normal-strength concretes. Special care is however essential to ensure that variations in the properties of the ingredients used in concrete are minimal and that strict controls measures are exercised during the production of high strength concrete.

q) high strength concrete usually do not exhibit much bleeding; hence adequate measures shall be taken to protect the green concrete so as to avoid plastic shrinkage cracking. Curing shall begin immediately after finishing and shall continue for a minimum period of 10 days. In view of the use of low water-cementitious materials ratio in such concrete, water curing shall be preferred.

ANNEX D

(*Foreword*)

COMMITTEE COMPOSTION

Special Structures Sectional Committee, CED 38

Organization	*Representative(s)*
VMS Consulants Private Limited, Mumbai	MS ALPA SHETH (***Chairperson***)
Indian Institute of Technology Madras, Chennai	DR DEVDAS MENON (***Former Chairperson***)
Assystem Stup Consultants Limited, Mumbai	REPRESENTATIVE
Bharat Heavy Electricals Limited, New Delhi	DR ANIMESH DAS
Central Public Works Department, New Delhi	SHRI A. K. RAJDEV SHRI SAUROBH KUMAR (*Alternate*)
CSIR - Central Building Research Institute, Roorkee	REPRESENTATIVE
CSIR - Central Road Research Institute, New Delhi	DR RAJEEV GOEL SHRI G. K. SAHU (*Alternate*)
CSIR - Structural Engineering Research Centre, Chennai	DR S. PARIVALLAL DR AMAR PRAKASH (*Alternate* I) DR B. ARUN SUNDARAM (*Alternate* II) DR P. HARIKRISHNA (*Alternate* III)
Central Warehousing Corporation, New Delhi	REPRESENTATIVE
Consulting Engineers Association of India, New Delhi	REPRESENTATIVE
Engineers India Limited, New Delhi	SHRI RAJANJI SRIVASTAVA DR SUDIP PAUL (*Alternate*)
Food Corporation of India, New Delhi	REPRESENTATIVE
Gammon Engineers and Contractors Private Limited, Mumbai	REPRESENTATIVE
GE Power India Private Limited, New Delhi	SHRI SANJAY ARORA
Indian Association of Structural Engineers, New Delhi	SHRI MANOJ MITTAL SHRI AMAN DEEP GARG (*Alternate*)
Indian Concrete Institute, Chennai	SHRI N. P. RAJAMANE
Indian Institute of Technology Bombay, Mumbai	DR RAVI SINHA DR SIDDHARTHA GHOSH
Indian Institute of Technology Delhi, New Delhi	DR DIPTI RANJAN SAHOO DR A. K. JAIN (*Alternate*)
Indian Institute of Technology Kanpur, Kanpur	DR SUDHIR MISRA DR NIHAR RANJAN PATRA (*Alternate*)

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(*Continued from second cover*)

In the formulation of this standard, assistance has been derived from the following publications:

ACI 318-14 Building code requirements for structural concrete, American Concrete Institute

ASCE 07-16 Minimum design loads for buildings and other structures, American Society of Civil Engineers

ASCE 41-17 Seismic evaluation and retrofit of existing buildings, American Society of Civil Engineers

EUROCODE 2 EN 1992-1-1 Design of concrete structures, European Committee for Standardization

FEMA 369-2001-NEHRP Recommended provisions and commentary for seismic regulations for new buildings and other structures

JGJ 3 - 2010 Technical specifications for concrete structures of tall buildings, Ministry of Housing and Urban-Rural Development People's Republic of China

NZS 3101.1 The design of concrete structures, New Zealand Standards

PEER/ATC 72-1 Modelling and acceptance criteria for seismic design and analysis of tall buildings

AB-058 - 2008 San Francisco building code administrative bulletin — Procedures for seismic instrumentation of new buildings

AB - 082 - 2018 San Francisco building code administrative bulletin — Guidelines and procedures for structural design review

AB-083 - 2008 San Francisco building code administrative bulletin — Requirements and guidelines for the seismic design of new tall buildings using non-prescriptive seismic design procedures

Technical notes on expert panel review of seismic fortification of code-exceeding high-rise buildings [Version 2015.05] (Ministry of Housing and Urban-Rural Department, People's Republic of China)

An alternative procedure for seismic analysis and design of tall buildings located in the Los Angeles region (2020 Edition); Los Angeles Tall Building Structural Design Council

The composition of the Committee responsible for the formulation of this standard is given in Annex D.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

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