भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानकः पथप्रदर्शकः

MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG, NEW DELHI 110002

हमारा संदर्भ : सीईडी 38/टी-13 **24 08 2016**

तकनीकी समिति : विशिष्ट संरचना विषय समिति, सीईडी 38

प्राप्तकर्ता :

1. **सिविल इंजीनियरी विभाग परिषद् के रूचि रखने वाले सदस्य**
2. **सीईडी 38 के सभी सदस्य**
3. **रूचि रखने वाले अन्य निकाय**

महोदय(यों),

निम्नलिखित मानक के मसौदे संलग्न हैं:

प्रलेख संख्या	**शीर्षक**
सीईडी 38 (10639) WC	**ऊंची इमारतों की संरचनात्मक सुरक्षा के लिए मानदंड** ICS 91.080.040

कृपया इस मानक के मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यदि ये मानक के रूप में प्रकाशित हो तो इन पर अमल करने में आपके व्यवसाय अथवा कारोबार में क्या कठिनाइया आ सकती हैं ।

सम्मतिया भेजने की अंतिम तिथि **31-10-2016.**

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को उपरलिखित पते पर संलग्न फोर्मेट में भेजें या ईमेल कर दें (ced38@bis.gov.in or abhishek.pal@bis.gov.in)।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा सम्बन्धी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दिया जाएगा । यदि सम्मित तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेख को अंतिम रूप दे दिया जाएगा ।

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट पर भी है ।

धन्यवाद ।

भवदीय,

ह0

(बी के सिन्हा)

प्रमुख (सिविल इंजीनियरी)

संलग्न : उपरलिखित

FOR COMMENTS ONLY DOC: CED 38 (10639) WC

August 2016

भारतीय मानक ब्यूरो

BUREAU OF INDIAN STANDARDS

MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG, NEW DELHI 110002

DOCUMENT DESPATCH ADVICE

DRAFTS IN WIDE CIRCULATION

Reference	**Date**
CED 38/T- 13	**24 08 2016**

TECHNICAL COMMITTEE:
Special Structures Sectional Committee, CED 38

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC;
2. All Members of CED 38;
3. All others interested.

Dear Sir (s),

Please find enclosed the following document:

Doc No.	**Title**
CED 38 (10639) WC	**CRITERIA FOR STRUCTURAL SAFETY OF TALL BUILDINGS,** ICS 91.080.040

Kindly examine the draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standards

Last Date for comments: 31 October 2016.

Comments if any, may please be made in the format as given overleaf and mailed to the undersigned at ced38@bis.gov.in and abhishek.pal@bis.gov.in.

In case no comments are received or comments received are of editorial nature, you will kindly permit us to presume your approval for the above document as finalized. However, in case comments of technical in nature are received then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The documents are also hosted on BIS website www.bis.org.in.

Thanking you,

Yours faithfully,

sd/-

(B K Sinha)
Head (Civil Engg.)

Encl: as above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to** ced38@bis.gov.in and abhishek.pal@bis.gov.in **shall be appreciated**.]

Doc. No.: CED 38(10639)WC **BIS Letter Ref**: CED 38/T-13 **Dated**: 24 August 2016

Title: ***Draft for*** **CRITERIA FOR STRUCTURAL SAFETY OF TALL BUILDINGS**

Name of the Commentator/ Organization: ________________________________

Clause/ Para/ Table/ Figure No. commented	Comments/Modified Wordings	Justification of Proposed Change

BUREAU OF INDIAN STANDARDS

Special Structure Sectional Committee, CED 38	Last Date for Comments: **31 October 2016**

Draft Indian Standard

CRITERIA FOR STRUCTURAL SAFETY OF TALL BUILDINGS

ICS 91.080.040

FOREWORD

Formal Clauses to be added later.

IS 456 has provisions for design of plain and reinforced concrete. IS 1893 lays down provisions for estimating the earthquake hazard and effects to be considered in earthquake design of buildings, and IS 875 helps estimate the load effects on structures due to effects other than earthquakes. IS 13920 lays down provisions for design and detailing of reinforced concrete structures to resist earthquake effects. But, there is no code in the country to address comprehensively the special issues associated with the design of Tall Buildings, whose design is governed not just by structural safety aspects, but by serviceability aspects, especially under wind effects.

This standard provides prescriptive requirements for design of Tall Buildings made of reinforced concrete buildings. The following are the salient issues addressed in this *prescriptive approach a*dopted by this standard:

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

Buildings that do not follow the requirements of this standard (*e.g.,* buildings with heights exceeding the limits specified in this code, buildings whose height exceeds the maximum suitable height specified for a particular structural system, or use of any other (irregular) lateral load resisting structural system), and those buildings that are not covered by this standard, shall be deemed to be *Code-Exceeding Tall Buildings*. Such Code-Exceeding Tall Buildings shall require a Performance-based Design Approach, to demonstrate that the performance of the building meets at least that intended by the prescriptive design code provisions laid down in this standard. For such Code-Exceeding Tall Buildings, Annex A provides design and approval processes.

The Sectional Committee responsible for the preparation of this standard has taken into consideration the views of manufacturers, 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 those international standards prevailing in different regions of the world.

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

1. ACI209.2R, (2008), Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete, American Concrete Institute, USA – for estimating creep and shrinkage effects;

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 2:1960 'Rules for rounding off numerical values (*Revised*)'. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

BUREAU OF INDIAN STANDARDS

Special Structure Sectional Committee, CED 29	Last Date for Comments: **31 October 2016**

Draft Indian Standard
CRITERIA FOR STRUCTURAL SAFETY OF TALL BUILDINGS
ICS 91.080.040

1 SCOPE

1.1 This code is applicable for reinforced concrete (RC) buildings of heights greater than 45 m, but less than 250 m, normally intended for use as residential, office and other commercial buildings.

1.2 This code is not applicable for tall buildings located in the near-field of seismogenic faults. For the purposes of this code, *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 code may be used for design of medium- and low-rise buildings (of heights equal to or less than 45m) also; the good practices mentioned in this standard will add value to the design of the said buildings.

On the other hand, this code is not applicable for design of buildings of heights more than 250 m.

1.4 This standard is a *prescriptive code* covering design aspects of tall buildings. These aspects include:

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

1.5 This code is applicable only for buildings that house 20,000 or fewer persons.

1.6 This standard addresses the following typical structural systems of Tall Buildings:

a) Structural Wall Systems;
b) Moment Frame Systems;
c) Moment Frame – Structural Wall Systems;
d) Structural Wall – Flat Slab Floor Systems with perimeter Moment Frame;
e) Structural Wall – Tube Frame Systems; and
f) Any of the above with additional framing systems, *e.g.,* Outrigger Trusses, Belt Trusses and Braced Frames.

1.7 This code 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 code shall govern.

1.8 For buildings that do not conform to the prescriptive requirements of this code, a more rigorous procedure is necessary for design and review. The general procedure to be adopted is given in Annex A to proportion, analyze, design, detail, gain approval and construct such buildings. Performance objectives or procedures more stringent than those specified in Annex A 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.

2 REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions 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 editions of the standards indicated below:

IS No.	*Title*
456 : 2000	Plain and Reinforced Concrete - Code of Practice (*Fourth revision*)
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 : 1987	Snow Loads (*Second Revision*)
Part 5 : 1987	Special Loads and Load Combinations (*Second Revision*)
1343 : 2012	Code of Practice for Prestressed Concrete (*Second Revision*)
1893	Criteria For Earthquake Resistant Design of Structures
Part 1 : 2016	General Provisions and Buildings (*Sixth Revision*)
Part 2 : 2014	Liquid Retaining Tanks – Elevated and ground supported
Part 4 : 2015	Industrial Structures including Stack-Like Structures (*First Revision*)
4326:2013	Earthquake Resistant Design and Construction of Buildings - Code of Practice (*Third Revision*)
16172:2014	Reinforcement Couplers for Mechanical Splices of Bars in Concrete - Specifications

3 TERMINOLOGY

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

3.1 Building Height — it is the difference in levels between its base (defined as the level at which inertia forces generated in the structure are transferred to the foundation, which then transfers these forces to the ground) and its highest level.

3.2 Connective Structure — it is a structure that links two or more towers, except at the podium levels. There are two distinctive types of connecting structures with each one requiring a different structural treatment, namely (1) the connecting structure has 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 (2) the connecting structure participates 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 Coupling Beams — see *Linking Beams*

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

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

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

3.7 Hybrid Building — it is a building, whose structural system is built partly in Reinforced Concrete, Structural Steel and/or RC-Structural Steel Composite.

3.8 Linking Beams — these are horizontal members spanning between two (vertical) structural walls.

3.9 Mixed Building or Hybrid Building — it is a structure, where select primary elements resisting vertical and/or lateral loads, comprise of more than one material; composite elements comprising of structural steel and reinforced concrete is a common example.

3.10 Multi-Tower Structures linked by Podium — it refers to two or more towers above a common podium structure which are not separated by a movement joint at the podium level.

3.11 Structural Systems and Sub-Systems — the following are considered in this standard:

3.11.1 *Structural Wall System* — it is 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 a structural wall elements connected either integrally or by link beam elements, also called the *coupled wall elements*. 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.

3.11.2 *Moment Frame System* — it is a structural system comprising of (beam-column) frames and resisting the vertical and lateral loads.

3.11.3 *Moment Frame – Structural Wall System* — it is a structural system comprising of (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.

3.11.4 *Structural Wall System with Flat Slab Floor System* — it is a structural system comprising of 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.

3.11.5 *Core and Outrigger Structural System* — it is a structural system comprising of a core element(s) and perimeter columns, resisting the vertical and lateral loads. Essentially, the perimeter columns are for resisting gravity loads only. The core element is connected to select perimeter column element(s) (often termed *outrigged columns*) by deep 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 outrigged 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 outrigged column(s).

3.11.6 *Core, Outrigger and Belt Wall System* — it is a structural system, which is an extension to the *Core and Outrigger Structure* to enhance the lateral stiffness further, where the outrigged 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.

3.11.7 *Tube System* — it is a structural system comprising closely spaced columns and deep beams in the perimeter frame for an efficient tube action. The internal vertical elements, comprising of core or columns is primarily utilized 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.

3.11.8 *Tube-in-Tube System* — it is 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 reserved for very tall buildings.

3.11.9 *Multiple-Tube System* — it is 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 allows to facilitate multiple tubes connected together, to enhance the lateral stiffness of the structure. Just as the *Tube Structure* and the *Tube-in-Tube Structure*, typically, even this system is reserved for very tall buildings.

3.12 Super Tall Building — it is it is a building of height greater than 250m.

3.13 Tall Building — it is a building of height greater than 45m, but less than 250m, normally intended for use as residential, office and other commercial buildings.

3.14 Transfer Structure — it is a structure, comprising of horizontal deep beams, trusses or thick slabs which transfers load actions and which supports vertical elements above to vertical elements below that are not aligned with each other, through *flexure* and *shear* actions. Alternatively, it can be a trussed structure that fulfills 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 the appropriate place. All dimensions are in *meters* (m), loads in *Newtons* (N), stresses in *Mega Pascals* (MPa) and time in *seconds* (s), unless otherwise specified.

a – Major Axis of elliptic plan shape of the building
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

D – Dimension of the building in plan along the considered direction of earthquake shaking;
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_w – Unsupported height of structural wall

L – Larger plan dimension of the building at its base

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

Δ_{max} – 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.

Table 1 Maximum values of Height h above top of base level of Buildings with different structural systems

Seismic Zone	*Structural System*				
	Structural Wall System + Flat Slab Floor System with perimeter Moment Frame	*Moment Frame System*	*Moment Frame + Structural Wall System*	*Structural Wall System*	*Structural Wall + Tube Frame System*
(1)	(2)	(3)	(4)	(5)	(6)
V	Not Allowed	Not Allowed	100 m	100 m	150 m
IV	Not Allowed	Not Allowed	100 m	100 m	150 m
III	70 m	60 m	160 m	160 m	220 m
II	100 m	80 m	180 m	180 m	250 m

5.1.2 *Slenderness Ratio*

The maximum values of the ratio of height h to minimum Base Width B shall not exceed values given in Table 2.

Table 2 Maximum Slenderness Ratio ($=h/B$)

Seismic Zone	*Structural System*				
	Structural Wall System + Flat Slab Floor System with perimeter Moment Frame	*Moment Frame System*	*Moment Frame + Structural Wall System*	*Structural Wall System*	*Structural Wall + Tube Frame System*
(1)	(2)	(3)	(4)	(5)	(6)
V	Not Allowed	Not Allowed	8	8	9
IV	Not Allowed	Not Allowed	8	8	9
III	5	4	8	8	10
II	6	5	9	9	10

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.

5.2 Plan

5.2.1 *Plan Geometry*

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

5.2.2 *Plan Aspect Ratio*

The maximum plan aspect ratio ($=L/B$) of the overall building shall not exceed 5.0.

5.3 Storey Stiffness and Strength

Parameters influencing stiffness and strength of the building should be so proportioned, that the following two clauses are maintained:
5.3.1 Lateral translational stiffness of any storey shall not be less than that of the storey above.
5.3.2 Lateral translational strength of any storey shall not be less than 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 elastic lateral drift ratio ($=\Delta_{max}/h_i$) under working loads (unfactored wind loads), which is estimated based on realistic section properties mentioned in **7.2** of this standard, shall be limited to h/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 lateral natural period in any of the two horizontal plan directions, shall not exceed 8 seconds.

5.6 Floor Systems

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

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 be have stability and adequate strength.

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

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. And, the minimum width of the slab beyond an opening to edge of slab shall not be less than 2 m. Further, the cumulative width of the slab at any location shall not be less than 50% of the floor width.

5.6.3 *Natural Frequency of Floor System*

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

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

Table 3 Permissible Maximum Vertical Floor Acceleration

Use	*Peak acceleration (m/s^2) at any excitation frequency*
Residential	0.05
Office	0.05
Commercial	0.18

5.7 Materials

5.7.1 *Concrete*

5.7.1.1 The minimum grade of concrete shall be M30.

5.7.1.2 The maximum grade of concrete shall be M70. 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 0.0020.

5.7.1.3 The grades of concretes used in slabs and beams shall not be less than 70% 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, as given below:

Column concrete shall be placed in the beam/slab at column location for a minimum of 0.6 m from face of column. This concrete shall be well integrated with the beam/slab concrete.

5.7.2 *Reinforcing Steel*

5.7.2.1 The characteristic yield strength of the steel reinforcement bars *used in construction* shall not exceed 1.2 times the value used in design.
5.7.2.2 The ultimate strength of reinforcement bars shall not exceed 1.25 times the characteristic yield strength.
5.7.2.3 No lapping of bars shall be allowed in RC beams, columns and walls, when diameter of bars is 16mm of higher; mechanical couplers shall be used to extend bars.

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) Choosing structural systems that are appropriate for ensuring structural integrity; and
(b) Adopting rigorous structural investigations that verify acceptable structural behavior, even when select critical members do not play their intended role.
(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, IS 1893 (Part 1) and IS13920 shall be applicable for Tall buildings also. In addition, requirements given in subsequent subsections shall be applicable.

6.2 Wind Effects

6.2.1 For buildings, (a) with heights greater than 150 m, (b) with complexities in plan or elevation geometry, (c) sited on complex topography with group effect or interference effect, (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 arrived at based on IS 875 (Part 3), the same shall be used in design.

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

a) The minimum design wind base shear shall be at least 70% 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% of critical for concrete buildings, 1.5% for composite buildings and 1% for steel buildings.

6.2.3 *Lateral Acceleration*

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

Table 4 Permissible Peak Combined Acceleration

Building Use	*Maximum Peak Combined Acceleration* a_{max} *(m/s²)*
Residential	0.15
Office / Commercial	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 Zones IV and V, deterministic site-specific design spectra shall be estimated and used in design. When site-specific investigations result in higher hazard estimation, the same shall be used.

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

Table 5
Minimum Design Base Shear Coefficient to be used in design

Building height, *H*	Seismic Zone			
	II	*III*	*IV*	*V*
H ≤ 120m	0.7%	1.1%	1.6%	2.4%
H ≥ 200m	0.5%	0.75%	1.25%	1.75%

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

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 modeling shall consider following:

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

(2) Floor diaphragm flexibility, as applicable;

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

(4) P-Δ effects.

Table 6 Cracked RC Section Properties

Structural Element	*Un-factored Loads*		*Factored Loads*	
	Area	*Moment of Inertia*	*Area*	*Moment of Inertia*
(1)	(2)	(3)	(4)	(5)
Slabs	1.0 A_g	0.36 I_g	1.00 A_g	0.25 I_g
Beams	1.0 A_g	0.7 I_g	1.00 A_g	0.35 I_g
Columns	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g
Walls	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g

7.3 Modelling

7.3.1 Modeling of buildings shall follow a simple approach, which reflects the distribution of mass and stiffness properties to account for properly 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 modeling (*i.e.,* frame element modeling), distributed modeling (i.e., finite element modeling) or a combination of the two.

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

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

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 6 of this standard.

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 seismic effects on buildings. For modeling flexibility of foundations, reference shall be made to Section 8 of this standard.

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% 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 always be considered.

7.3.10 In no case, the flexibility of the building shall be such that the value of inter-storey drift senility coefficient θ does not exceed 0.20.

7.3.11 Stiffness of flat slab frames (i.e., slab-column frames) shall be ignored in lateral load resistance, in all seismic regions, and especially in Seismic Zones III, IV and V.

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

7.3.13 Eccentricity shall be considered in analysis of loads applied by beams on columns or applied by offset columns above, if not dealt explicitly within the model.

7.3.14 Effect shall be considered of construction sequence in buildings taller than 150m.

7.3.15 Multiple towers connected by a single podium shall be modeled separately and integrally. When modeled separately, if the part of podium attached to the tower is with more than two spans, at least two spans to be modeled with the tower; the design of the podium shall be based on the worst effect from the two cases.

7.4 BUILDING MOVEMENTS

7.4.1 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.

7.4.2 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) after completion of the building.

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

7.4.4 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.

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

7.4.6 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.

7.4.7 Strain prediction models of concrete for effect of creep and shrinkage, shall be based on established principles of mechanics elaborated in state-of-the-art literature.

8 STRUCTURAL DESIGN

8.1 General Requirements

8.1.1 *Method of Design*

Limit State Design method (as outlined 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 3D structural model, and its elements designed as per forces induced in them under various load combinations.

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

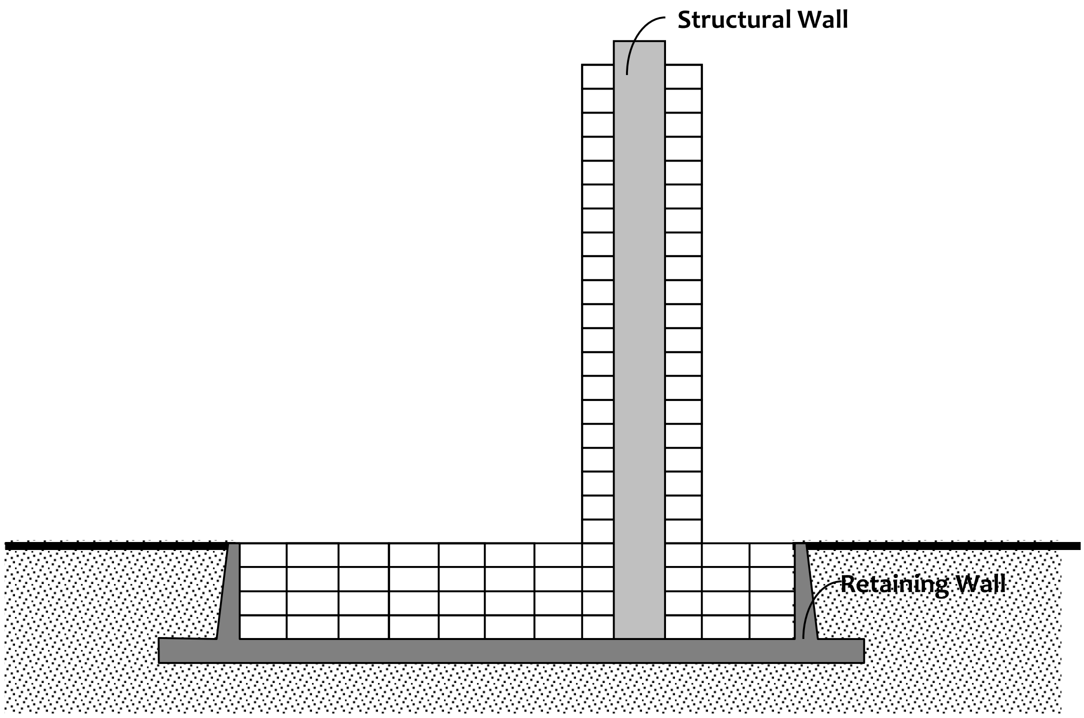
8.1.3.2 *Modeling*

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

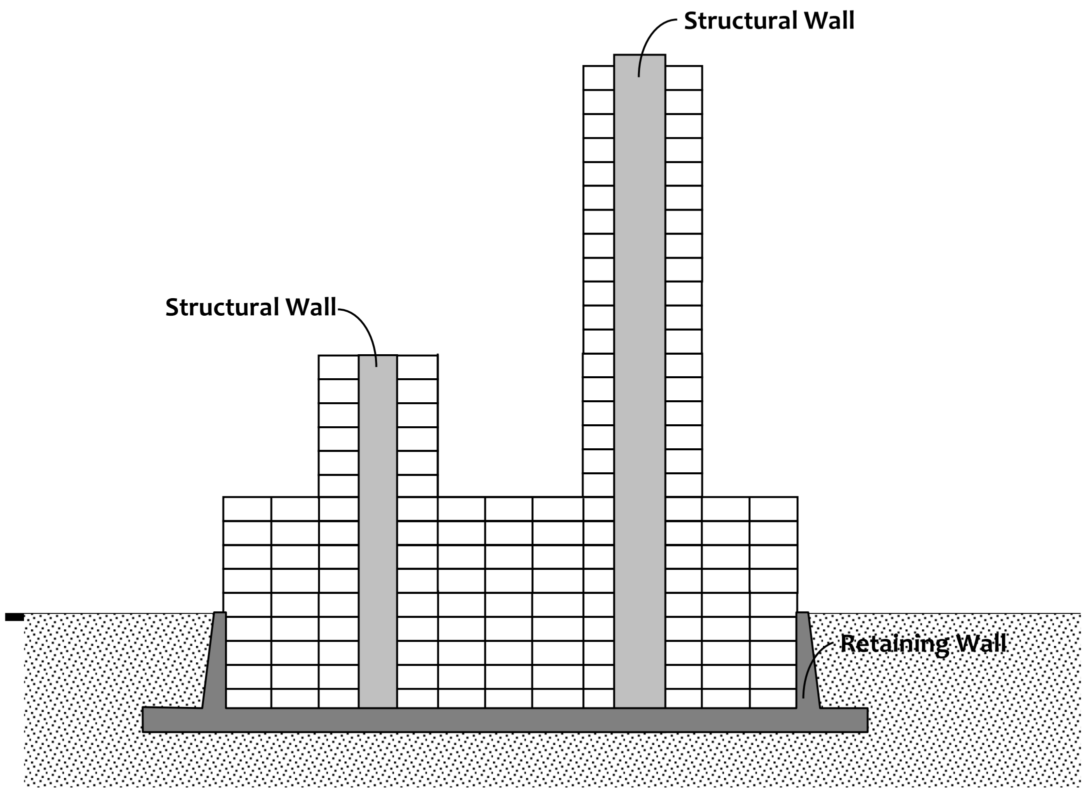
Table 7 Stiffness parameters for diaphragms and perimeter walls of podium and below the level of the backstay for Backstay Sensitivity Analysis

Stiffness Parameter	Values to be Adopted	
	Upper-bound	Lower-bound
I_{eff} / I_g	0.5	0.15
A_{cr} / A_g	0.5	0.15

(b) Besides that of the floor diaphragms, flexibility shall be considered of following structural elements also in the structural analysis with appropriate modification to their stiffness:
(i) Perimeter walls and their foundation supports; and
(ii) Foundation supports under the tower lateral load resisting system.



(a)



(b)

Figure 1: Tall Buildings with Podiums, Core Structural Wall, and below-grade Perimeter Retaining Wall: (a) Single Tower; and (b) Multiple Towers

8.1.3.3 *Buildings with Multiple Towers*

8.1.3.3.1 Backstay

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

The following shall be considered:

(a) In estimating backstay effects, two lateral loads paths shall be considered (Figure 2), namely:
   (i) *Direct Load Path*, where overturning resistance is provided by the tower elements and foundation directly beneath the tower; and
   (ii) *Backstay Load Path*, where overturning resistance provided by in-plane forces in the backstay elements (lower floor diaphragm and perimeter walls).

   In some Tall Buildings, backstay effects may not be considered. These configurations include:
   (i) Buildings without below grade levels or buildings without significantly increased lateral load resisting systems at the base;
   (ii) Buildings that extend below grade, but have structural separations between the superstructure and the podium portions of the building, which accommodate lateral load deformations without transfer of lateral forces from superstructure portion to podium portion; and
   (iii) Buildings with perimeter basement walls, where the walls are located directly below the lateral load resisting elements of the superstructure above. Here, there could be a marked change in lateral strength and stiffness at this level, but, lateral forces will not be transferred through the floor diaphragms.
(b) Backstay floor diaphragms shall be modeled considering their *in-plane* and *out-of-plane* floor flexibility. Any large discontinuity present in the slab shall be modeled.
(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 (Figure 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:

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

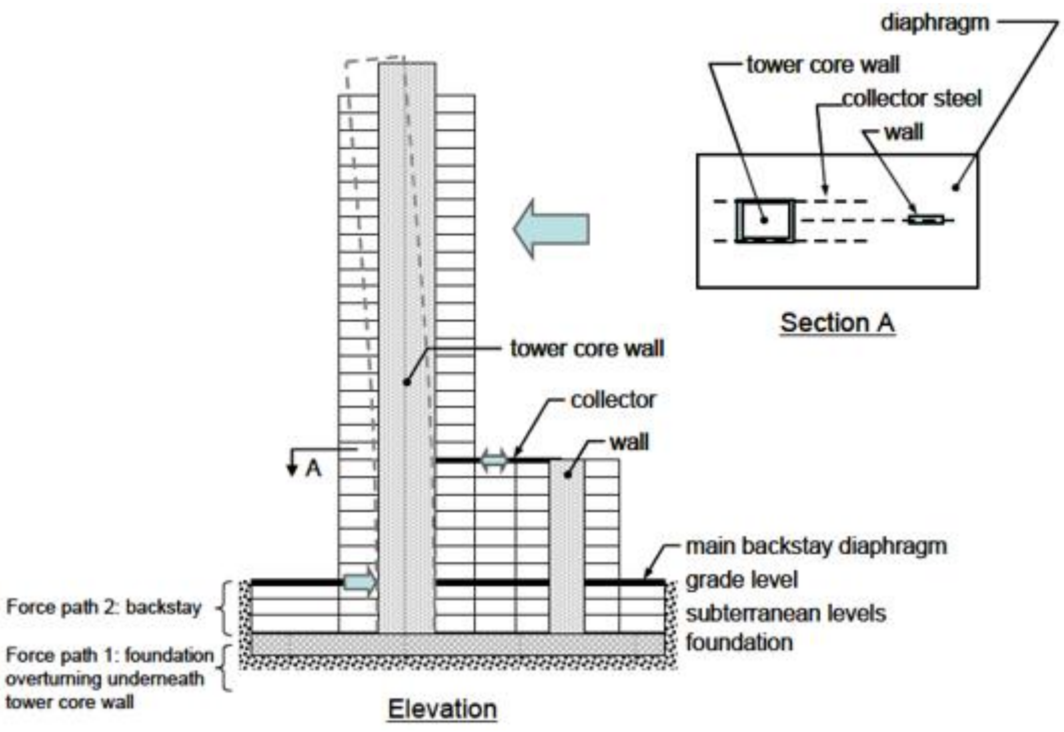
(ii) When the lateral force resisting system of a Tall Building has plan irregularity as per Table 5 of IS 1893 (Part 1) of Type I (torsion irregularity), Type II (re-entrant corners) and Type IV (out of plane offsets), and vertical irregularity as per Table 6 of IS 1893 (Part 1) of Type IV (in-plane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

1) Connections of diaphragms to vertical elements and to collectors; and
2) Collectors and their connections, including connections to vertical elements, of the seismic forces resisting system.

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

(iv) Backstay diaphragm floor shall be at least 150mm thick, and shall have two curtains of vertical and horizontal reinforcements of amount not less than 0.25% of cross section area in each direction.

(v) 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 45º. Additional reinforcements shall be provided to resist the shear force at the interface between diaphragm and structural walls.



(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

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

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 modeled as *separate* towers as well as *integral* towers. The podium shall be designed based on the worst of the two results.
(b) The estimation of natural period (for calculation of base shear) shall be based on *INDIVIDUAL* building model.
(c) In the integral tower modeling,
  (i) Directional effects for all worst possibilities (i.e. tower shaking in the same and in the opposite directions) should be considered in the design load combinations; and
  (ii) Equivalent static seismic forces can be used, provided they are scaled to match base overturning moments obtained from response spectrum analysis.
(d) Where significant changes occur to mass or stiffness between the floors, the floor diaphragms of upper and lower levels shall be modelled to capture
  (i) Diaphragm forces. Equivalent beam approach, finite element approach or strut and tie approach may be adopted to model the diaphragms.
  (ii) Potential cracking in the diaphragm by considering an upper bound and a lower bound axial stiffness. The lower and upper bound values of axial and flexural stiffnesses given in Table 5 for sensitivity analysis, may be considered for the cracked section properties, to arrive at the design level earthquake demand on the RC diaphragms.
(d) Plan irregularities shall not be present of Type I(torsion irregularity) and Type iii (diaphragm discontinuity) as per Table 5 of IS 1893 (Part 1), in the first connected floor and the first tower floor above the connected floor.
(e) Vertical irregularities shall not be present of Type I (soft story) as per Table 6 of IS1893 (Part 1), in the first connected level and the level above it.
(f) All floor slabs between the towers of connected podium shall be at least 150mm thick with double mesh reinforcements not less than 0.25% of cross section area in each direction.
(g) Peripheral columns of the tower shall be provided with confinement reinforcements as per IS 13920 at the first connected level and a level above.
(h) Structural walls of the tower shall be provided with boundary elements as per IS 13920 at the first connected level and a level above.
(i) A transfer structure shall not be provided at the first connected floor.

8.2 Ductility

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

a) Sufficient ductility capacity;
b) Acceptable energy dissipation mechanism; and
c) Desirable sequence of initiation of ductile behaviour in members.

8.3 Frame Buildings

8.3.1 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.

8.3.2 In Seismic Zones III, IV and V, Moment Frame Systems shall be detailed to have special moment frames.

8.3.3 The minimum dimension of a column shall not be less than

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

(b) 300 mm.

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

8.4.3 *Special requirements for Seismic Zone IV and 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 160mm or H_w/20, whichever is larger.

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

(a) When the opening size is less than 800 mm in height or length, and the influence of the opening may not be taken into account in the overall stiffness of the building.

(b) When the opening size is more than 800 mm in height or length, the size and location of the opening shall be such that the top and bottom 1/3 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 IS13920.

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 $0.5\tau_{c,\max}$, in structural walls 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, *i.e.,* at a stress level of f_y.

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

Table 8 Cracked RC Section Properties

Span – Depth Ratio	*Maximum reinforcement (%)*
$L_s/D \le 1.0$	0.6
$1.0 \le L_s/D < 2.0$	1.2
$2.0 \le L_s/D$	1.5

8.5.12 At each storey of the moment frame - structural wall interactive dual system, the structural walls shall be designed to resist at least 75% of the design storey shear, and the moment frame at least 25% of the design storey shear.

8.5.13 *Requirements for each storey resisting more than 35% of Design Base Shear*
Removal of a structural wall or wall pier with a height-to-length ratio greater than 1.0 within any storey, or collector connections thereto, shall not result in more than 33% reduction in storey strength, nor shall the resulting structural system have a torsional irregularity as per IS1893 (Part 1).

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

(a) Structural walls shall be continuous to the base without being transferred in plane or out of plane at any level;
(b) The thickness of structural wall shall not be less than 200 mm;
(c) The minimum longitudinal and transverse reinforcements shall not be less than 0.4% of gross cross sectional area in each direction;
(d) The reinforcements shall be distributed in two curtains in each direction;

(e) Structural walls shall be fully embedded and anchored at their base in adequate basements or foundations, so that the wall does not rock. In this respect, walls supported by slabs or beams are not permitted; and
(f) All openings in structural walls shall be aligned preferably vertically. Random openings, arranged irregularly, shall not be permitted in coupled walls, unless their influence is either insignificant.

8.6 Flat Slab – Structural Wall Systems

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

8.7 Frame Tube – Structural and Tube-In-Tube Wall 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 frame tube shall preferably be not more than 5m.

8.7.4 In a frame-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 walls and not on frame beams.

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

Table 9 Reinforcement requirements in beams

Reinforcement type	*Seismic Zone*	
	II	*III, IV and V*
(1)	*(2)*	*(3)*
Stirrup diameter	> 8 mm	> 10 mm
Stirrup spacing	< 150 mm	< 100 mm
Main reinforcements	> 16 mm	> 16 mm

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 factored design loads.

9.3 Geotechnical Investigations

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

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, when the foundation rests on hard rock, this requirement may be relaxed.

9.5 Podium / Basement roof slab should be capable of transferring in-plane shear from the tower to the foundation.

9.6 Expansion Joints are prohibited in basements of tall buildings.

9.7 Modeling of Soil

9.7.1 When spring constant or modulus of sub-grade reaction approach is used for modelling raft foundations, then zoned spring constants or zoned modulus of sub-grade reaction shall be utilized for design, at least for the case of (Dead Load + Live Load) condition. For design of rafts for buildings taller than 150m, 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 following load conditions:
(a) Dead + Live;
(b) Wind and Seismic (whichever governs) in X-direction; and
(c) Wind and Seismic (whichever governs) in Y-direction.

9.8 Settlements of Foundations

9.8.1 Maximum vertical settlement of raft or piled raft foundations under gravity loads shall be limited to
(a) on Soil: 50 mm for raft/pile-raft foundations and to 25 mm for isolated foundations; and
(b) on Rock: 50 mm for raft/pile-raft foundations and to 12 mm for isolated foundations.

9.8.2 These permissible total settlement values for foundations on soils given in **8.5.1** may be increased up to the total settlement values specified in IS 1904, if differential settlements between any two adjacent columns as determined from final foundation sizes and layout are calculated to be within permissible limits of differential settlement values specified in IS1904. Also, group settlement effects of piles shall be considered.

9.8.3 Maximum angular distortion of raft shall not exceed 1/400 under gravity loads.

10 NON-STRUCTURAL ELEMENTS

10.1 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 hospital. In addition, specifications laid down in this section 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 this section shall govern over similar clauses given in the prevalent relevant national standards.

10.2 Design Strategy

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

(1) *Acceleration-sensitive NSEs*: The lateral inertia forces generated in these NSEs during earthquake shaking cause their sliding or toppling to the level of their base or lower;
(2) *Deformation-sensitive NSEs*: The relative lateral deformation in these NSE spanning between two Structural Elements (SEs) (*e.g.,* a pipeline passing between two parts of a building with a separation joint in between) or between an SE and a point outside building (e.g., an electric cable between the building and ground/pole outside the building), causes them move or swing by large amounts in translation and rotation under inelastic deformations of SEs imposed on them during earthquake shaking; and
(3) *Acceleration-and-Deformation-sensitive NSEs*: Both of the conditions described in (1) and (2) above are valid. Here, one of the effects is more dominant (and hence called *Primary Effect*) and the other less dominant (and hence called *Secondary Effect*). The designer shall identify which of the two effects is the Primary Effect.

All NSEs in Tall Buildings shall be protected against the effects mentioned above. Positive systems are required to either anchor or release the restraint at the ends (depending whether the NSE is *acceleration-sensitive* or *displacement-sensitive*, respectively) to ensure there is no damage to NSEs.

10.3 Protection Strategies

Three approaches can be employed to secure NSEs, namely:

(1) *Non-Engineered Practice (Common Sense Approach)*: This approach is based on common sense and shall be applicable largely to secure small and light objects that cannot be physically connected individually with SEs, *e.g.,* bottles on a shelf.
(2) *Pre-Engineered Practice (Prescriptive Approach)*: This approach is based on design calculations, limited experiments and experiences from past earthquakes and shall be employed to secure moderate sized NSEs that are generic factory-made products and used commonly in houses and offices, *e.g.,* wall mounted TV sets, wall mounted geysers in bathrooms, cupboards rested against walls or completely kept away from them, and electrical and plumbing lines running between floors of buildings or across a construction joint in a building. It is imperative that manufacturers foresee all possible on-site conditions before setting prescriptive standards for securing NSEs; and
(3) *Engineered Design Practice (Calculation-based Approach)*: This approach is based on formal technical considerations. This approach is based on formal engineering design and performance considerations of both the hazard and the capacity of the NSE. The third strategy shall be used to secure massive and/or long (one-of-its-kind) NSEs. This section provided requirements for this *Engineered Design Practice*, which shall be complied with by NSEs and their connections to the SEs.

10.4 Design Guidelines – Acceleration-Sensitive NSEs

The design lateral force F_p for the design of acceleration-sensitive NSEs may be taken as:

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

where Z is the *Seismic Zone Factor* (as defined in IS:1893 (Part 1)), I_p the Importance Factor of the NSE (Table 10), R_p the Component Response Modification Factor (Table 11), a_p the Component Amplification Factor (Table 11), W_p the Weight of the NSE, x the height of point of attachment of the NSE above top of the foundation of the building, and h the overall height of the building.

Table 10: Proposed Importance Factors I_p of NSEs

NSE	I_p
Component containing hazardous contents	2.5
Life safety component required to function after an earthquake (*e.g.,* fire protection sprinklers system)	
Storage racks in structures open to the public	
All other components	2.0

Table 11 Coefficients a_p and R_p of Architectural, Mechanical and Electrical NSEs [adapted from FEMA 369, 2001]

S.No.	NSE	a_p	R_p
1. Architectural Component or Element			
1.1	Interior Non-structural Walls and Partitions		
	(a) Plain (unreinforced) masonry walls	1.0	1.5
	(b) All other walls and partitions	1.0	1.5
1.2	Cantilever Elements (Unbraced or braced to structural frame below its center of mass)		
	(a) Parapets and cantilever interior non-structural walls	2.5	2.5
	(b) Chimneys and stacks where laterally supported by structures	2.5	2.5
1.3	Cantilever elements (Braced to structural frame above its center of mass)		
	(a) Parapets	1.0	2.5
	(b) Chimneys and stacks	1.0	2.5
	(c) Exterior Non-structural Walls	1.0	2.5
1.4	Exterior Non-structural Wall Elements and Connections		
	(a) Wall Element	1.0	2.5
	(b) Body of wall panel connection	1.0	2.5
	(c) Fasteners of the connecting system	1.25	1.0
1.5	Veneer		
	(a) High deformability elements and attachments	1.0	2.5
	(b) Low deformability and attachments	1.0	1.5
1.6	Penthouses (except when framed by and extension of the building frame)	2.5	3.5
1.7	All Ceilings	1.0	2.5
1.8	Storage cabinets and laboratory equipment	1.0	2.5
1.9	Access floors		
	(a) Special access floors	1.0	2.5
	(b) All other	1.0	1.5
1.10	Appendages and Ornamentations	2.5	2.5

1.11	Signs and Billboards	2.5	2.5
1.12	Other Rigid Components		
	(a) High deformability elements and attachments	1.0	3.5
	(b) Limited deformability elements and attachments	1.0	2.5
	(c) Low deformability elements and attachments	1.0	1.5
1.13	Other flexible Components		
	(a) High deformability elements and attachments	2.5	3.5
	(b) Limited deformability elements and attachments	2.5	2.5
	(c) Low deformability elements and attachments	2.5	1.5
2. Mechanical and Electrical Component/Element			
2.1	General Mechanical		
	(a) Boilers and Furnaces	1.0	2.5
	(b) Pressure vessels on skirts and free-standing	2.5	2.5
	(c) Stacks	2.5	2.5
	(d) Cantilevered chimneys	2.5	2.5
	(e) Others	1.0	2.5
2.2	Manufacturing and Process Machinery		
	(a) General	1.0	2.5
	(b) Conveyors (non-personnel)	2.5	2.5
2.3	Piping Systems		
	(a) High deformability elements and attachments	1.0	2.5
	(b) Limited deformability elements and attachments	1.0	2.5
	(c) Low deformability elements and attachments	1.0	1.5
2.4	HVAC System Equipment		
	(a) Vibration isolated	2.5	2.5
	(b) Non-vibration isolated	1.0	2.5
	(c) Mounted in-line with ductwork	1.0	2.5
	(d) Other	1.0	2.5
2.5	Elevator Components	1.0	2.5
2.6	Escalator Components	1.0	2.5
2.7	Trussed Towers (free-standing or guyed)	2.5	2.5
2.8	General Electrical		
	(a) Distributed systems (bus ducts, conduit, cable tray)	2.5	1.0
	(b) Equipment	5.0	1.5
2.9	Lighting Fixtures	1.0	1.5

10.5 Design Guidelines – Displacement-Sensitive NSEs

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

(2) This imposed relative displacement can arise out of strong earthquake shaking, thermal conditions in the SEs 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 Eq. (6.1) of this guideline.

(3) NSEs 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 in **8.2.5.2** of this standard.

(4) Flexibility or clearance of at least the design relative displacement shall be provided
(a) within the NSE, if both supports on the SE offer restraints against relative translation between the SE and the NSE, or
(b) 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.

(5) The NSE can be supported between two levels of the same building, or between two different buildings, 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:

(a) 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 heights h_{z1} and h_{z2} from the base of the building) under the application of the load effects mentioned in this standard; and

(b) 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:

$$\Delta_X = \left|\delta_{z1}^{AX}\right| + \left|\delta_{z2}^{BX}\right|$$

$$\Delta_Y = \left|\delta_{z1}^{AY}\right| + \left|\delta_{z2}^{BY}\right|$$

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 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 RECOMMENDATIONS FOR SEISMIC MONITORING

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

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

11.3 Foundation Settlement and Pressure Measurement

11.3.1 Permanent settlement markers (at corners and center) should be provided at raft top level and referenced to a permanent benchmark. Records of settlement should 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) pressure pads below the raft. Alternatively, piles can be instrumented with strain gauges at their top to measure the load on them.

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ANNEX A

(*Foreword and clause* **1.8**)
SUGGESTED APPROVAL PROCESS FOR
DESIGN OF CODE–EXCEEDING TALL BUILDINGS

A-1. GENERAL

A-1.1 This Appendix is a recommendation for the way forward for review of Code-Exceeding Tall Buildings, to ensure an acceptable performance of such buildings under gravity, wind and seismic load conditions. Every code exceeding high-rise building will go through two processes.
(1) Review by a Structural Design Reviewer, and
(2) Review by Expert Review Panel.

A-1.2 The code-exceeding high-rise buildings referred by this document include:
(1) Buildings with height exceeding the maximum prescribed limit in the Tall Buildings code for a prescribed structural system.
(2) Buildings with overall height not exceeding the max prescribed limit in the Tall Buildings code but which have an irregular structure as prescribed in IS 1893 or in Tall Buildings code.
(3) Coupled structure with two (or more) significantly different towers;
(4) Complex structure with three or more of the following four structural features, namely transfer, strengthened story, split-level, and coupling structures;
(5) Buildings with structural systems not covered under the Tall Buildings Code; and
(6) Buildings not meeting all requirements laid down in this standard.

A-1.3 For code-exceeding high rise buildings specified by item 2, it is recommended that every state forms a State-level Code Committee which is tasked with review of such code-exceeding high-rise buildings.

A-1.4 The developer's application materials for the seismic safety review should meet the requirements in Section **A-2**. The expert panel's review comments should meet requirements in Section **A-6**.
Review information should be put in State/City Tall Building Database after reviewing as soon as possible. Information to be provided for review should include application for Review of Design Development of Seismic Fortification of Code-Exceeding Tall Buildings, along with the following attachments:
(a) Summary of Conditions that are code-exceeding with respect to this Tall Building Code;
(b) EPR Results of Code-Exceeding Tall Buildings; and
(c) Quality-Control Measurement of Design of Code-Exceeding Tall Buildings.

A-2 QUALIFICATIONS OF PEER REVIEWER, AND COMPOSITION OF SELECTION AND EXPERT REVIEW PANEL

A-2.1 Structural Design Reviewer

The Structural Design Reviewer will be independent of the Expert Review Panel from a Structural Advisory Committee, which is a formal, public body that the local building permit Authority will convene regarding matters pertaining to special features or special design procedures. The Structural Design Reviewer meets with the Structural Engineer of Record and with Department of Building Inspection staff as the need arises throughout the design process, providing the 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 Structural Engineer of Record, and the burden to demonstrate building performance standards in conformance with that of Tall Buildings Code resides solely with the Structural Engineer of Record. The responsibility for conducting the structural review for the plan check resides with the Authority, the Developer and any plan review consultants. The owner/developer will get design reviewed by independent registered design professionals qualified for the review.

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

The Structural Design Reviewer shall be a recognized expert in relevant fields such as structural engineering, earthquake engineering, performance-based earthquake engineering, nonlinear 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 Project Owner/Developer may then engage a Structural Design Reviewer as a consultant for assistance as appropriate. 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 Authority in ensuring compliance of the structural design with the performance standards as implicit in the Tall Buildings Code. While the Structural Design Reviewer will contract with the Project Owner/Developer, their responsibility is to the Authority. The Structural Design Reviewer shall be registered as a licensed Structural Engineer qualifies to design unlimited height of building in at least one city of the country of Seismic Zone III or higher. The Structural Design Reviewer shall sign all written communication to the Director.

Administration of Structural Design Review: The Project Owner/Developer is responsible for the payment of hourly fees and other expenses for the professional services of the Structural Design Reviewer. The Structural Design Reviewer shall provide to the Department of Building Inspection a written copy of a proposed scope of work of their contract with the Project Sponsor. The proposed scope of services in the contract and any changes proposed to be made thereto shall be approved by the Director.

A-2.1.2 *Scope of Structural Design Review Services*

The scope of services for the Structural Design Reviewer shall be indicated by the Authority to provide required expertise to supplement the Authority review. This scope of services may include, but shall not be limited to, review of the following:

(1) Basis of design, design methodology and acceptance criteria;
(2) Mathematical modeling and simulation;
(3) Seismic performance goals;
(4) Foundation review;
(5) Interpretation of results of analysis;
(6) Member selection and design;
(7) Detail concepts and design;
(8) Construction Documents, including drawings and specifications;
(9) Isolator or damper testing requirements and quality control procedures; and
(10) Design for wind resistance, design of special foundation or earth retaining systems, or the design of critical non-structural elements.

The Structural Design Reviewer should 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 should jointly establish the frequency and timing of Structural Design Reviewer 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 Structural Engineer of Record, and the Structural Engineer of Record shall prepare written responses thereto. The Structural Design Reviewer shall maintain a log that summarizes Structural Design Reviewer 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 Director 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 and guidelines in this bulletin.

A-2.1.3 *Dispute Resolution*

The Engineer of Record and the Structural Design Reviewer shall work in a collegial manner, as independent and reasonable professionals. The Structural Design Reviewer shall prepare comments in a respectful manner and shall make reasonable requests of the Engineer of Record for additional analyses or backup information. The Engineer of Record shall address the Structural Design Reviewer comments cordially and respond directly and clearly. 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 Authority. The Authority, as Building Official, shall make final decisions concerning all permits. The 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 Authority also may engage additional outside experts to assist in issue resolution.

A-2.2 Expert Review Panel

The Expert Panel shall be constituted by each State (and if needed by each city) and comprise of following professions:

(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 at least 150m or greater;
(b) One academic (preferably a structural engineering professor from IIT or equivalent) recognized as subject expert in analysis and design of Tall buildings (including Earthquake and/or Wind Engineering);
(c) One practicing Geotechnical Engineer or academic recognized as subject expert in geotechnical issues of Tall Buildings; and
(d) One Construction Engineer recognized as subject expert in Construction of Tall buildings.

A-3. Basic Submittals

A-3.1 The developer should submit the following documents when applying for review.

(1) Application statements and condition statements for review of code-exceeding high-rise buildings (at least 5 copies).
(2) Design Basis Report on structural design of the code-exceeding high-rise building (Attachment 6, at least 5 copies).
(3) Geotechnical survey report of the project.
(4) Calculation book of structural design development (main results, at least 5 copies).
(5) Design development documents (architectural and structural, at least 5 copies).
(6) When referring to international design standards, project examples, earthquake damage reports, or calculation software programs, provide relevant underpinning rationale.

(7) If structural tests are planned to be performed to verify the seismic performance of the structure, a proposal for the test should be provided.
(8) Provide a proposal for wind tunnel experiment.

A3.2 Documents submitted for EPR should meet the following specific requirements

A-3.2.1 *Design Basis Report of code-exceeding high-rise buildings*

This should specify in which way (for high-rise buildings whose height exceed the height limit or whose structure is particularly irregular, like height, transfer story's location and transfer method, multiple towers, coupled towers, split-level, strengthened level, vertical irregularity and horizontal irregularity; for Code-Exceeding Tall Buildings, like the irregularities of span length, cantilever length, total length of the structural unit, roof structures that differ from the conventional structural type, support restriction condition, underneath supporting structures, etc.) and to what degree the building exceeds limit, and propose effective safety-control technical measures in regarding to the applicability and reliability of the seismic and wind technical measures, strengthening measures for the entire structure or for weak parts, proposed performance objectives and technical measures to efficiently ensure the stability of the roof structures in Code-Exceeding Tall Buildings.

A-4. Principles of EPR

A-4.1 The following items will be reviewed in the EPR:
(1) The structural concept and basis for building's lateral load design;
(2) Site survey results and foundation design scheme;
(3) Seismic concept design and performance objective of the building structure;
(4) Engineering evaluation of overall calculation and calculation of critical spots;
(5) Seismic measures of weak spots; and
(6) Other potential problems which might affect structure safety.
For wind loads on buildings with unusual shapes (including roof structure) or those having significant difference in wind tunnel results and code wind loads, or special code-exceeding high-rise buildings (large scale or large height-width ratio) with the base isolation or shock absorption design, it is recommended to have separate reviews by experts of the relevant profession before the seismic fortification EPR.

A-4.2 The focus of the EPR is safety of structure and expected performance objective in lateral load condition. For that, the design of code-exceeding high-rise buildings should meet the following minimum requirements:
(1) Reinforce mandatory clauses in codes and regulations strictly, and pay attention to grasp systematically and understand comprehensively their accurate meaning and relevant clauses.
(2) For height exceeding or regularity exceeding projects, there should be no more than four out of the five complicated structures—transfer story, strengthened story, split-level, coupled towers, and multiple towers—in a single building simultaneously. Quite regular high-rise buildings with a building height within the Height Category B range according to *Specification for High-rise Concrete Structure* should comply with *Specification for High-rise Concrete Structure*. For other code-exceeding high-rise buildings, seismic resistance measures and expected performance objectives that are stricter and more specific than current codes and regulations should be specified for structural safety based on the quantity and degree of the buildings' irregularities and their weak spots specifically. If the building height exceeds Height Category B according to *High-rise Concrete Structure* and if neither building height, nor plane regularity, nor vertical regularity follows the regulations, then full evidence should be provided to prove the buildings reach the expected performance objectives, e.g., detailed proof through testing results, adopted new seismic techniques and measures, and comparative analysis with different structural systems.
(3) For code-exceeding roof structures, detailed measures and expected performance

objectives that are stricter and more specific than current codes and regulations should be specified for slenderness ratio, stress ratio and control of global stability crucial members. If the roof structure is overly complicated, full evidence should be provided to prove the buildings reach the expected performance objectives.

(4) With the existing technical and economical conditions, in case of any conflict between structural safety and building shape, the safety should be given precedence; architectural schemes (including schemes for local areas in the building) should meet the needs of structural safety.

A-4.3 For buildings with significantly excessive height, overtly complicated structural systems, or unusual structural types (including roof type), if there is no design basis for reference, then the overall structural model or models of structural members, components, or joints should be selected for necessary testing study of seismic performances.

A-5. EPR CONTENTS FOR BUILDINGS WITH HEIGHT AND REGULARITY EXCEEDANCE

A-5.1 Seismic Concept Design of Building Structure

(1) Each type of structure should have its own applicable height limit, appropriate self-weight per unit area, and wall thickness. The overall stiffness of the structure should be appropriate (the relationship between stiffness along the two main axes shall also meet code requirements), and deformation characteristics should make sense, and the maximum story drift and torsion drift ratio should comply with codes and regulations.

(2) Requirements for multiple seismic defensive lines shall be clearly requested. In all types of structures where the frame resists lateral forces together with shear walls or the core, proportion of seismic shear forces in the frame should be increased appropriately according to code based on how much the building exceeds the limit. The stiffness ratio of inner concrete cores and exterior frame should be appropriate for supper tall core-frame system; the seismic story shear distributed on the frame shall not be less than 8% of the base shear, the maximum value shall not be less than 10% and the minimum shall not be less than 5%.For main lateral-resistant members, measures should be taken for full-height single-leg wall (wall without opening) to make up for its insufficient ductility.

(3) For buildings exceeding the height limit, use stricter regularity requirements. Clarify the degree of vertical and horizontal irregularity, pay attention to possible adverse impact from big openings in floor slabs, which results in shear sharing among long and short columns or a plan with a narrow waist, and avoid excessive seismic torsion effect. Seismic design requirements for irregular buildings can be differentiated based on the differences in their seismic fortification intensities and heights. When there is a seismic joint between the main building and the podium, the joint shall be wider, or other measures should be taken.

(4) Do not let any story be both weak and soft. Control the stiffness ratio above and below a transfer level. Strengthening measures should be taken specifically for walls transferred by secondary beams and for wall with openings and are supported by columns. The quantity, location, and structural form of horizontally strengthened story should be studied and compared carefully. Flexile diaphragm should be assumed for calculation of internal force of outrigger members; the top and bottom chords should run through the core wall, and measures should be taken at the joints between the walls and the outrigger diagonals to avoid damage due to concentrated stress.

(5) For structures with complicated geometry such as multiple towers, coupled towers and split-levels, try to reduce irregularity in types and in degree. Pay attention to analysis of potential problems in spots, or locations that may have trouble when seismic action is along a particular direction, and take strengthening measures correspondingly. For complex coupled

tower, shall determine whether to supplement analysis check in different cases for each single tower, according to specific condition (including construction condition).

(6) In case of weak connection among structures, consider the reliability of actual detailing and connection of all members at the connection, consider the least favorable situation found through calculation in overall and local structural models when necessary, or require part of the structure to stay elastic under Fortification Intensity.

(7) Pay attention to the integrity of floor slabs, and avoid shear failure in weakened area of the floor slabs in a rare earthquake. In case of a large opening on the slab, the slab's section's shear capacity should be calculated.

(8) If a structure above the roof or a decorative structure is tall or complicated in shape, it should be included in analysis of the overall building structure. If its material is different from the rest of the building, then the impact of difference in damping ratio should be considered, and its connection with the main structure should be particularly strengthened.

(9) In case of large height-width ratio, check carefully the bearing capacity and stability of the foundation in an earthquake.

(10) The embedded locations need to be determined appropriately.

A-5.2 Structure's Seismic Performance Objectives

(1) Set seismic performance objectives based on the way and degree the structure exceeds limit, earthquake damage, difficulty to repair, and the criterion of no collapse in a rare earthquake, i.e., performance objective on member capacity, deformation, level of damage, and ductility of the structure, spots, or members under seismic action of expected magnitude (e.g., moderate or rare earthquake or earthquake with certain return period).

(2) In selection of design parameters for seismic effect for the expected magnitude, the design parameters from the code can be used for moderate and rare earthquakes. When the peak value of the frequent earthquake acceleration exceeds the codes and regulations by much, it is appropriate to adjust the frequent earthquake acceleration using multiplier.

(3) Examples of objectives in strengthened structural capacity in earthquakes:

(a) Check horizontal transfer members' ultimate capacity to bear moment and shear forces in a rare earthquake.

(b) Check "No Yield" of vertical members and members at critical spots under bending-compression, bending-tension, and shear capacity in a moderate earthquake with the yielding capacity of the member, and make sure the section under shear force meets the section size control conditions in a rare earthquake.

(c) Check "Remain Elastic" of vertical members and members at critical spots under bending-compression, bending-tension, and shear capacity in a moderate earthquake with the design strength of the member.

(4) Determine what ductile detailing grade is needed. Concrete members where small eccentric tension occurs in a moderate earthquake should be of Super Grade 1 structure according to *Specification for High-rise Concrete Structure*. Steel member should be embedded to bear tension when the average wall total cross section tension stress, which is generated by the axial force, exceeds the standard value of concrete's tensile strength, and the stress shall not exceed two times of the standard tension strength of concrete.(may consider steel section effect based on equivalent elastic modulus). Allow appropriate lower threshold when total cross section steel ratio exceed 2.5%).

(5) Demonstrate and prove the soundness and feasibility of seismic measures (e.g., internal force adjustment coefficient, main reinforcement percentage, stirrup reinforcement percentage, and steel percentage) based on seismic performance objectives.

A-5.3 Structural Analytical Model and Calculation Results

(1) Determine the validity and reliability of calculation results correctly, pay attention to difference between analysis assumptions actual conditions (including distinction among rigid diaphragm, flexible diaphragm, and multiple rigid diaphragms), and determine unfavorable situations in the structure based on variation of force distribution throughout the structure and the location/distribution of maximum story drift.

(2) The total seismic shear and the ratio of seismic shear on each floor to the accumulative representative gravity load at that floor should meet limit in the *Seismic Code*, and the limit should be increased appropriately for Site Types III and IV. 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.

(3) For structures with base period larger than 6s and base shear coefficient only *20%* less than the specified value, and for structures with base period between 3.5 and 5s, whose base shear coefficient is only 15% less, the minimum value of the base shear coefficient specified by the code can be used. For structures with base period between 5 and 6s, the base shear coefficient can be interpolated accordingly.

(4) For structures in fortification intensity 6 (0.05g) with base period larger than 5s, when the calculated base shear coefficient is lower than the specified value but the inter-story drift based on 0.8% base shear coefficient meets the requirement, seismic capacity check can be conducted using the minimum base shear coefficient specified by the code.

(5) The restraint condition in time history analysis should be same as that in response spectrum analysis, the horizontal and vertical seismic time history records applied should meet code requirements, and the duration should be usually no shorter than 5 times the structure's primary period (i.e., the roof's drift response to the basic period is no less than running back and forth for 5 times). The results of elastic time history analysis should also meet code requirements, i.e., select the enveloping values with three sets of time history data, and select the average with seven sets of time history data.

(6) The values of adjustment coefficients of seismic shear force of a soft level and the internal seismic force transferred from a transferred member (that does not touch the ground) to a horizontal transfer member should be greater than the code value based on the way and degree the structure exceeds limit. The story stiffness ratio still needs to meet code requirements.

(7) Horizontal transfer members supporting walls above with side door openings should be strengthened based on actual conditions. When necessary, check the calculation manually for the situation under gravity load without considering the coupling effect of the walls.

(8) When calculating vertical seismic effect for coupled structure with spans over 24m, refer to vertical time history analytical results.

(9) For elasto-plastic analysis of structures, dynamic elasto-plastic analysis should be used for structures higher than 200m or those with significant torsion effect.Two independent elasto-plastic dynamic analyses for structures higher than 300m. Calculate based on members' standard strengthen, and focus on discovery of weak spots and corresponding strengthening measures.

(10) When necessary (e.g., for particularly complicated structures, composite structures higher than 200m, and structures with great vertical compression deformation of members under static load), do a construction simulation analysis of structures under gravity load. If the construction scheme differs from the construction simulation calculation analysis, the corresponding calculation should be adjusted.

(11) Any calculation result obviously questionable should be reviewed separately.

A-5.4 Structural Seismic Strengthening Measures

(1) Enhancement of seismic protection grade, internal force adjustment, axial pressure ratio, shear pressure ratio, and steel material selection should be treated differently and considered comprehensively depending on the seismic intensity, the degree the structure exceeds limit, the member's position in the structure, and the impact of member's damage.
(2) Based on the structure's actual conditions, take measures to increase ductility by adding core columns, restraining edge members, using SRC or CFT members, using shock-absorbing and energy-dissipating components, etc.
(3) Comprehensive measures that address both capacity and detailing at weak spots.

A-5.5 Geotechnical Survey Results

(1) The number and locations of wave velocity measurement holes should meet code requirements; and the quantity of measurement data should comply with regulations; the depth of the wave velocity measurement holes should meet the requirement determined by the thickness of the overlaying layer.
(2) The numbers of liquefaction evaluation holes, number of standard penetration test blows in sandy clay stratum and silt stratum, and the quantity of clay content analysis should meet requirements. The water table should be determined appropriately using liquefaction.
(3) Site categorization, liquefaction evaluations, and liquefaction classification should be accurate and reliable; site pulsating testing results are for reference only.
(4) The way to determine overburden thickness and wave velocity should be reliable. Where close to the boundary between different site categories, interpolation should be required to calculate the characteristic period of seismic effect.

A-5.6 Foundation Design Scheme

(1) Appropriate foundation type, and reliable foundation-bearing stratum;
(2) Correct analysis of advantages and disadvantages of using settlement joints between the main building and the podium; and
(3) Keep the total settlement and the differential settlement of the building within limits.

A-5.7 Testing Results, Project Examples and Seismic Hazard Experiences

(1) For projects that require seismic testing study per regulations, specify the degree to which the testing model is similar to the actual structural construction and the applicable parts in the testing results;
(2) When referring to foreign experiences, distinguish seismic design from non-seismic design, find out if the project has undergone any earthquake, and determine if the reference is similar to specific conditions of the project; and
(3) A dynamic performance test of the actual structural construction should be required for projects with height much higher than the limit, with very complicated structural system, or with unusual structural system.

A-6. REVIEW OF CODE-EXCEEDING ROOF STRUCTURES

A-6.1 Structural System and Layout

(1) Specify the structural form, force characteristics, force transmit characteristics, characteristics of the supporting condition underneath, and specific control load and control goals for structural safety;
(2) Major differences between the adopted roof structural form and the conventional ones

should be listed, if the roof structure system is not conventional;
(3) The supporting restriction condition of the supporting structure underneath shall be equivalent to force performance requirements of roof structure; and
(4) Explicitly provide structure supporting layout and detailing requirements out of plane to stabilize the structures, when the structure is truss, arch truss and structure with tension chord.

A-6.2 Performance Objective

(1) Indicate critical members, critical joints and weak spots, propose specific measures to ensure the capacity and stability of roof members, and prove their technical feasibility in detail;
(2) Suggest explicit performance objective for critical joints, critical members and their supporting parts (including the supporting structure member underneath). When expected seismic design properties are selected, code-based design properties still can be applied on medium and rare seismic;
(3) Performance target example: compression and tension ultimate capacity check for critical member under rare earthquake; compression and tension design capacity check for critical member under moderate earthquake; supporting ring beam design capacity check under moderate earthquake; yielding capacity check of bottom supporting vertical member under moderate earthquake, at the same time meeting the cross section-control requirement under rare earthquake; connection and support shall be satisfied with requirement of strong connection week member; and
(4) Prove the feasibility of seismic measure (e.g., member cross section type, wall thickness joints etc.) base on seismic performance objective.

A-6.3 Structural Calculation Analysis

A-6.3.1 *Actions and Combination of Effects*

1) If the fortification intensity is Intensity 7 (0.15g) or above, the vertical seismic effect of the roof should be determined in reference to the time history analysis results of the overall structure.
2) Select basic wind pressure and basic snow pressure for the return period of 100 years for roof structure. For Cable structure, membrane structure, long cantilever structure, space grid structure with a span over 120 m, and complicated roof shapes, the roof snow (including variation during snow melting process) distribution coefficient, the wind load shape coefficient, and the wind vibration coefficient should be appropriately greater than the required value or be determined by wind tunnel test or by numerical simulation study. For roofs with sharp slope, consider potential sliding impulsive load due to thawing snow. Also one may consider wind force potentially greater than that in load code based on local meteorological data. Consider the superimposed load caused by impeded drainage for roof gutter and roof with internal drainage.
3) The thermal effect should be determined based on appropriate temperature difference value. Consider unfavorable temperature differences in three different phases—construction, top-out, and service.

A-6.3.2 *Analysis Model and Design Parameters*

Structural analysis software should accurately reflect the loads and the load-transfer mechanism of the structures when new members or structures are chosen. The calculation model should include the interaction of the roof structure and the structure underneath. The detailing of the main connection restriction condition and details of main connection between a roof structure and its supporting structure underneath should match restriction condition, the calculation model.

In overall structural calculation analysis, one should consider the impact of difference in damping ratios between the supporting structure and the roof structure. If units of the supporting structure have different dynamic characteristics and weak connections between them, then one should compare analyses of interaction among all parts under static load, seismic, wind force, and thermal effect by using an overall model and separate individual models, in order to select appropriate values for design.

Construction and installation process analysis needs to be conducted if necessary. The static load internal force at the end of construction should be regarded as the initial condition of seismic effect and load combination in service condition. For extra-long structure (e.g., total length >300m), consider making analytical comparison of multi-point seismic input to consider wave passage effect as required by the *Seismic Code*. For extra-long span structure (e.g., span >150m) or extremely complicated structure, elasto-plastic analysis should also be done for rare earthquakes considering both geometrical and material non-linearity.

(a) Stress and deformation

For Cable structure, entire tension membrane structure, cantilever structure, space digrid structure with a span over 120m, and reinforced concrete thin shell structure, one shall strictly control the stress and deformation of roof under static, wind and snow load.

(b) Stability Analysis

For single layer grid shell, double layer grid shell with a thickness smaller than 1/50 span length, arch (solid web or lattice), reinforced concrete thin shell, one shall check the global stability; the initial geometric defect shall be appropriately select, and the global stability analysis should be done considering geometrical non-linearity or both geometrical and material non-linearity in the entire process. The impact of concrete creep and shrinkage to stability shall be considered for reinforcement concrete thin shell at same time.

A-6.4 Seismic Measures of Roof Members

A-6.4.1 Indicate main structural members, and take strengthening measures, and check continuity and uniformity of their stiffness.

A-6.4.2 Strictly control the stress ratio and stability requirements of critical members. Under a combined effect of gravity and moderate earthquakes and a combined effect of gravity, wind load and temperature, the stress ratio of critical members should be controlled more strictly or meet the proposed performance target.

A-6.4.3 Special connection details should be safe and reliable under rare earthquakes; at complex joints, detailed finite element analysis needs to be applied and if necessary, results need to be proved by experiments.

A-6.4.4 For some complex structural system, the entire roof's progressive collapse caused by failure of key elements should be considered.

A-6.5 Roof-supporting Structure, below Supporting Structure and Foundation

A-6.5.1 The differential settlement of the roof structure supports caused by the foundation uneven settlement and supporting structure's deformation (including vertical, horizontal deformation, shrinkage and creep etc.) should be controlled strictly.

A-6.5.2 Key elements of the supporting structure should ensure seismic safety and should not be damaged before the roof. If its irregularity belongs to the category that requires EPR, then it should meet relevant requirements in this document.

A-6.5.3 Measures should be provided to ensure the capacity and detailing of the roof supports are safe and reliable under rare earthquake effect, to ensure the seismic forces on the roof can be transferred to the supporting structure directly. When laminated rubber cushion for seismic isolation is used, the actual stiffness and damping ratio of the supporting structure needs to be considered and the strength and displacement requirements need to be met by the connections and the supporting structure itself.

A-6.5.4 Site geotechnical investigation and foundation design should satisfy the requirements of item 15 and 16 in this technical note. For structures with large horizontal support forces, the foundation should be designed for thrust forces.

A-7. EPR COMMENTS

A-7.1 EPR comments include mainly the following three sections:

a) *General Comments:* Brief evaluations on seismic fortification standard, regularity of building geometry, structural system, site condition, detailing measures, and calculation results.

b) *Problems:* Problems that affect structural seismic safety should be discussed and studied, main safety problems should be brought up in written review comments, and main control indices (including performance objectives) should be listed for convenience of CD review by relevant institute(s).

c) *Conclusions:* Three conclusions - *pass*, *revise* and *resubmit*.

1) *Pass* means that the seismic fortification standard is correct and that the seismic measures and performance objectives basically meet requirements. The survey/design company explain how to address problems and suggestions made in the EPR comments. After completing administrative approval procedure in accordance with the law, the CD review institute will check how the issues are addressed during CD review.

2) *Revise* means that the seismic fortification standard is correct but that the architectural and structural configuration, calculation, and detailing are not completely appropriate and have apparent defects. The specific indices that the design reaches after the survey/design company addresses the problems and suggestions in the EPR comments need to be rechecked by the original review expert panel. Therefore, the written report produced after the revisions needs to be confirmed by the original expert panel to have met the requirements for pass. Then after completing administrative approval procedure in accordance with the law, the CD design can start, and the CD review institute can check how the issues are addressed during CD review.

3) *Resubmit* means the scheme has apparent seismic safety problems, does not meet seismic fortification requirements, and needs significant adjustments in architectural and structural schemes. The developer needs to submit a detailed report of revisions and restart the EPR review from the beginning.

A-7.2 For projects that are already approved by EPR, when significant changes regarding the project take place, application for a new EPR review needs to be initiated.

A-7.3 After the EPR review, the expert team needs to comment on the quality-control aspect and economical feasibility of the design, and provide the Quality-Control Measurement of Code-Exceeding High-Rise Building Structures.