Design of RC Tall Buildings
Salient Points from Draft Code IS 16700

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Tall Buildings in India

Tall Buildings in India

- **Large scale urbanization and shortage of land**
  - *Led to development in vertical direction in the form of tall buildings*
- **1959 The LIC Building, Chennai, 15 floors**
- **1961 Usha Kiran Building, Mumbai, 25 floors**
- **Presently,**
  - *There are at least 50 buildings in India which are above 200 m, and*
  - *More than 5 projects are in pipeline which are above 300 m height*
  - .

IS 16700 - Tall Building Code

- **The code has guidelines for 50-250 m buildings**
- **It gives prescriptions for the following:**
  - *Selection of appropriate structural system;*
  - *Geometric proportioning of the building;*
  - *Integrity of structural system;*
  - *Resistance to wind and earthquake effects; and*
  - *Other special considerations related to tall buildings*

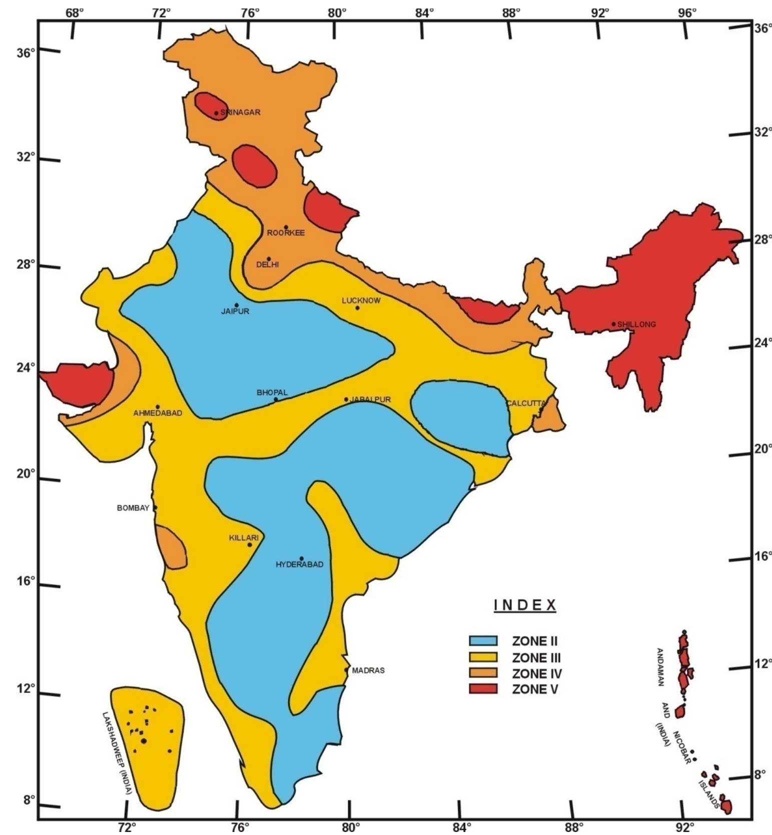
Tall Building Code

- **This standard is not applicable for tall buildings located in the near-field of seismogenic faults.**
  - *NOTE – For the purpose of this standard, near-field is taken as 10 km (shortest distance) from a seismogenic fault.*
  - *For buildings located within 10 km (shortest distance) of seismogenic faults, more rigorous approach is needed to proportion, analyze, design, detail and construct such buildings.*
  - *The prescriptive requirements mentioned in this standard shall be used for proportioning such buildings, but more stringent specifications may be specified by the client/owner of the building or by the tall building committee appointed by the local authority administering the building project.*

Hazard Estimation

Hazard levels

Methods of estimation



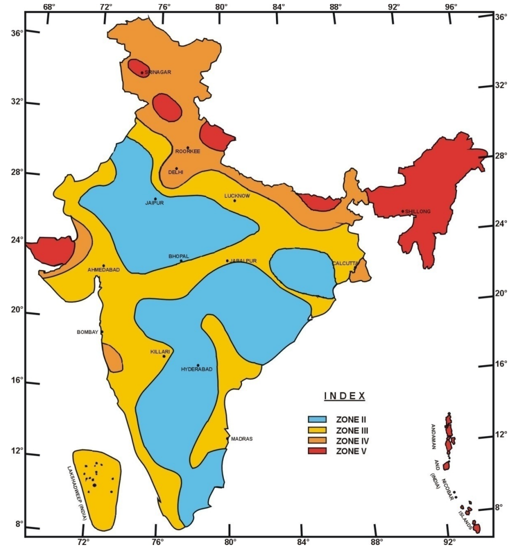
Seismic Hazard Assessment

- **What?**
  - *It is a process of evaluating the design parameters of earthquake ground motion at a given site*
  - *Design parameters include amplitude, duration and frequency content*
- **How?**
  - *Deterministic framework*
  - *Probabilistic framework*
- **Why?**
  - *To understand the behaviour of building when subjected to the such ground motion*

Seismic Hazard Assessment

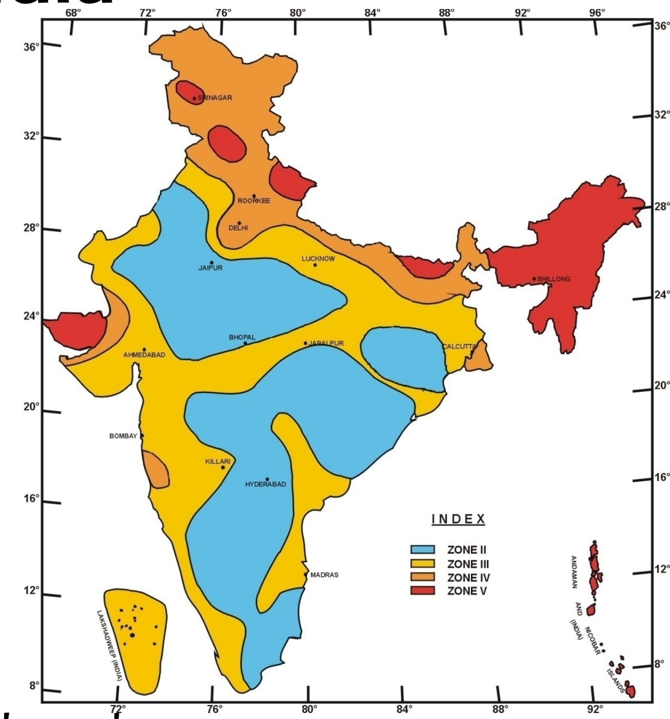
- **Estimating the probability with which a prescribed level of strong ground motion say 0.1g is exceeded over a period, say 50 years**
- **Estimating a pga which is exceeded with prescribed probability, say 10% in a period of 50 years**

- **Our hazard map is based on likely intensity**
  - *It does not address the question; how often such a shaking may take place*
  - *Area A may experience intensity of VIII every 50 years*
  - *Area B may experience intensity of VIII every 200 years*
  - *IS 1893 keeps both in the same zone.*



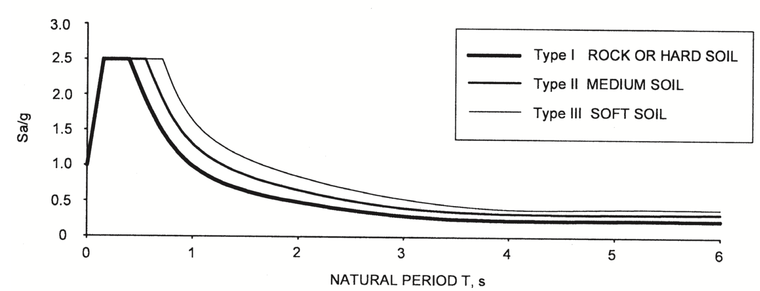
Macro Hazard

- **Seismic MACRO Zone Map of India**
  - *Seismic Zone Map of India*



  - *Purpose*
    - **Design of Normal Structures**
      - *Increase confidence of Safety*
      - *Examine adequacy of design in next earthquake*

300 – 100 km

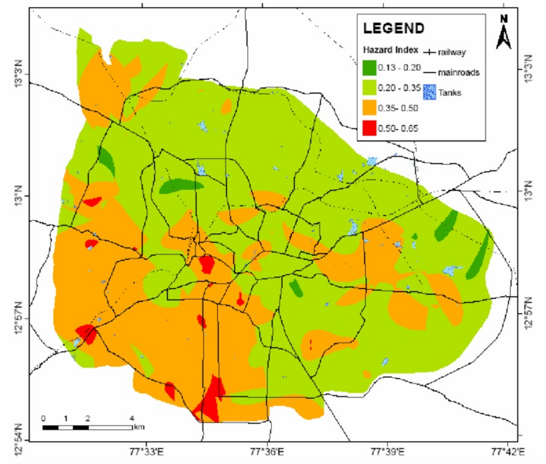


2B SPECTRA FOR RESPONSE SPECTRUM METHOD

Micro Hazard

- **Seismic MICRO Zone Map of REGIONS in India**
  - *Effect*
    - **OF built Environment**
    - **ON built Environment**
  - *Purpose*
    - **Risk Assessment and Disaster Management**
    - **Land Use Planning**
    - **Building Design**

10.0 – 0.5 km

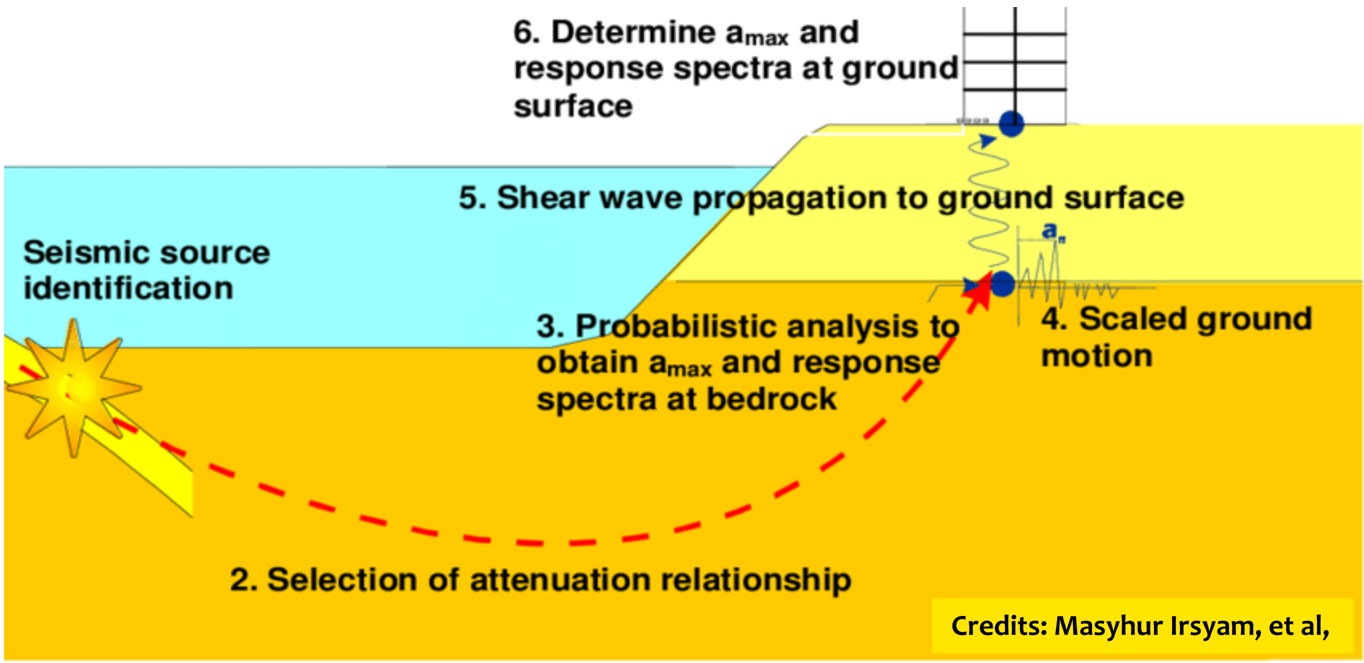


Anbazhagan Panjamani

Site-Specific Hazard

- **Seismic SITE-SPECIFIC Hazard Assessment of a Location**
  - *Better estimate of Hazard than from Seismic Microzonation*
  - *Purpose*
    - **Design of Special Structures**
    - **Design of Tall Buildings**

100 m – 1 m



Credits: Masyhur Irsyam, et al,

IS 16700 Tall Building Code

- ✓ *Changes Proposed*

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Following Changes have been Proposed

- **Systems with structural walls at core have been deleted in Table 1 and 2. All structural wall systems should now have well distributed walls.**
- **The return period of wind for natural drift under wind conditions has been revised in clause 5.4.1.**
- **Requirements for maximum vertical acceleration of floors have been deleted.**
- **Maximum horizontal acceleration requirement has been revised for residential buildings.**
- **A new expression for estimating the approximate fundamental natural period of buildings over 50 m has been provided in clause 6.3.4.**
- **Load combination has been specified considering the P-Δ effects.**
- **An expression for inter-storey drift stability coefficient θ has been introduced in clause 7.3.10.**
- **The minimum requirement for transverse reinforcement in structural walls has been revised in clause 8.5.13.**
- **The procedure for approval of buildings that do not conform to the prescriptive requirements of this standard has been revised in Annex A.**

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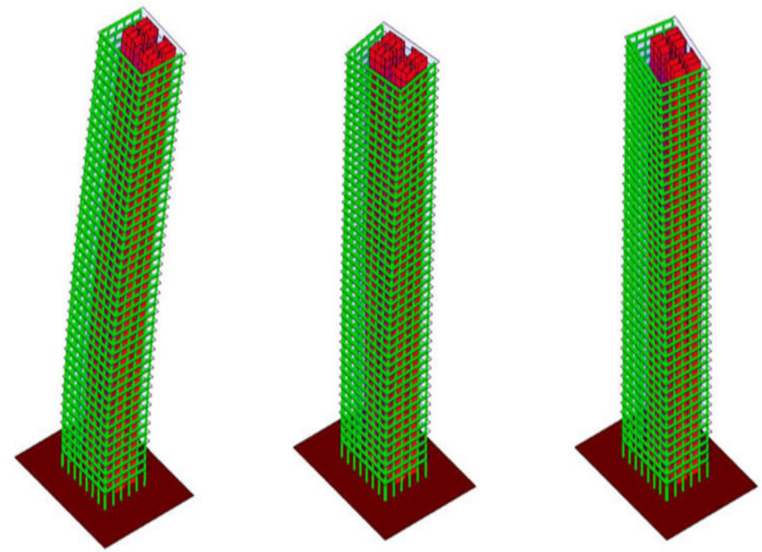
Systems with Structural Walls

- ✓ *Height*
- ✓ *Slenderness ratio*
- ✓ *Plan aspect ratio*
- ✓ *Openings in floor slab*



Structural Systems

Table 1 Maximum values of Height, *H* above Top of Base Level of Buildings with Different Structural Systems, in metre
(*Clause* 5.1.1)

Sl No.	Seismic Zone	Structural System					
		Moment Frame	Structural Wall		Structural Wall + Moment Frame	Structural Wall + Perimeter Frame	Structural Wall + Framed Tube
			Located at Core	Well-Distributed[1)]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i)	V	NA	100	120	100	120	150
ii)	IV	NA	100	120	100	120	150
iii)	III	60	150	200	160	200	220
iv)	II	80	180	220	180	220	250

[1)] Well-distributed shear walls are those walls outside of the core that are capable of carrying at least 25 percent of the lateral loads.

Current

Table 1 Maximum Values of Height *H* above Top of Base Level of Buildings with Different Structural Systems, in metre
(*Clause* 5.1.1)

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

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

Proposed

Height

- **Maximum height as per the code is 250 m**

Table 1 Maximum Values of Height *H* above Top of Base Level of Buildings with Different Structural Systems, in metre
(*Clause* 5.1.1)

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

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

High Seismic Zones
180 m

Moderate Seismic Zone
225 m

Low Seismic Zone
250 m

Moment Frame Structure not permitted in zones IV & V

Moment Frame Structure not permitted above 80 m

Slenderness Ratio

Table 2 Maximum Slenderness Ratio (H_t/B_t)
(*Clause* 5.1.2)

Current

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

Table 2 Maximum Slenderness Ratio (H_t/B_t)
(*Clause* 5.1.2)

Proposed

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

Slenderness Ratio

- **Depending on the height, zone and structural system, slenderness ratio is allowed up to 10**

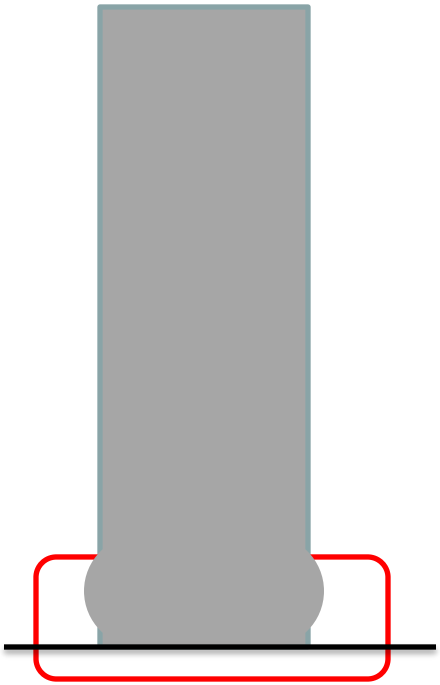
Table 2 Maximum Slenderness Ratio (H_t/B_t)
(*Clause* 5.1.2)

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

- **Issues?**
  - *Structural damage*
  - *Non-structural damage*
    - **Should be controlled by limiting drift ratio, usually 0.4% of storey height**

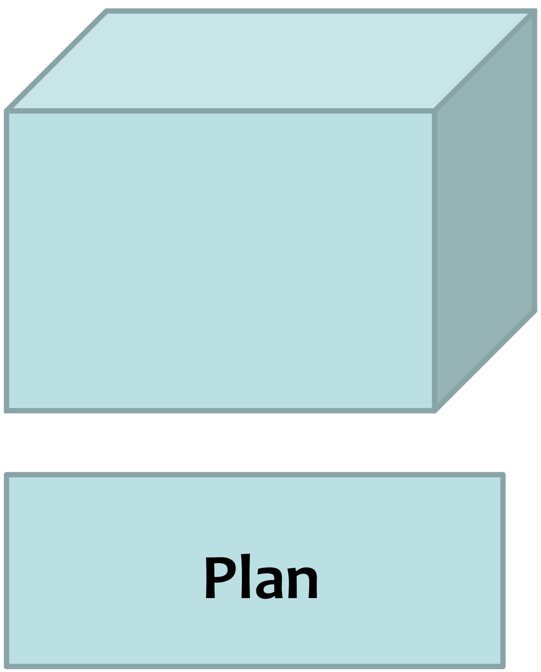
Slenderness Ratio

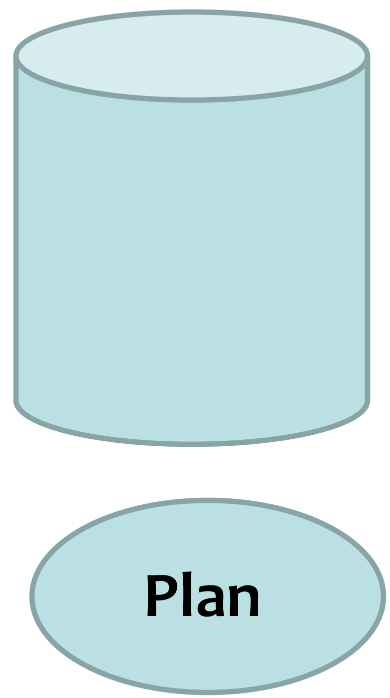
- **Maximum damage is expected to be confined to the first few storeys in buildings with large slenderness ratio.**
  - *This is attributed to the Poisson's effect in the lower section of the building (close to the base) where end effects dominate up to a height equal to the base width of the building.*



Cl. 5.2 Plan

- **5.2.1 Plan Geometry**
  - *The plan shall preferably be rectangular (including square) or elliptical (including circle).*
  - *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.*

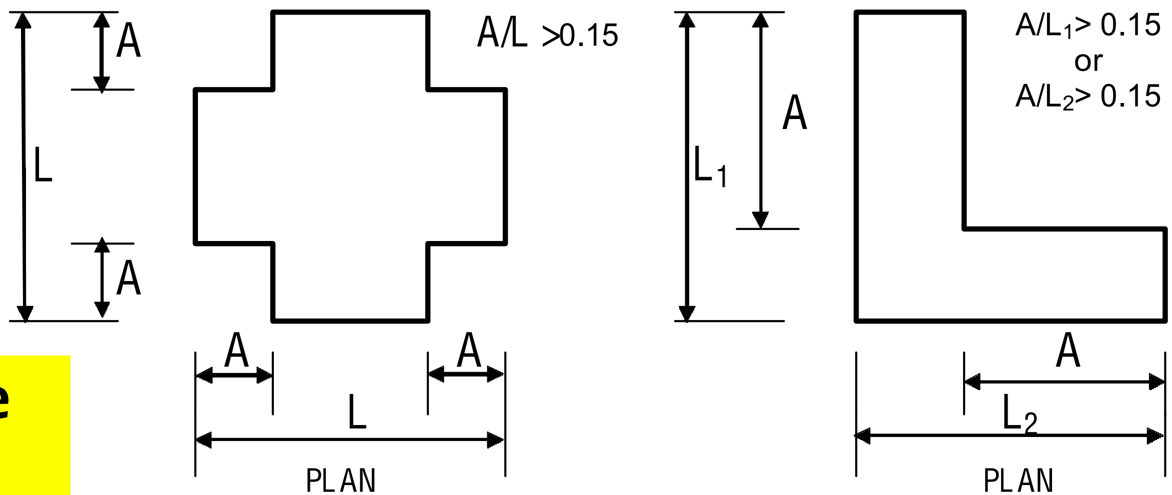




Cl.7.1. Plan Irregularity – Re-entrant Corners

1893-2016

- **A building is said to have a re-entrant corner in any plan direction, when its structural configuration in plan has a projection of size greater than 15% of its overall plan dimension in that direction**



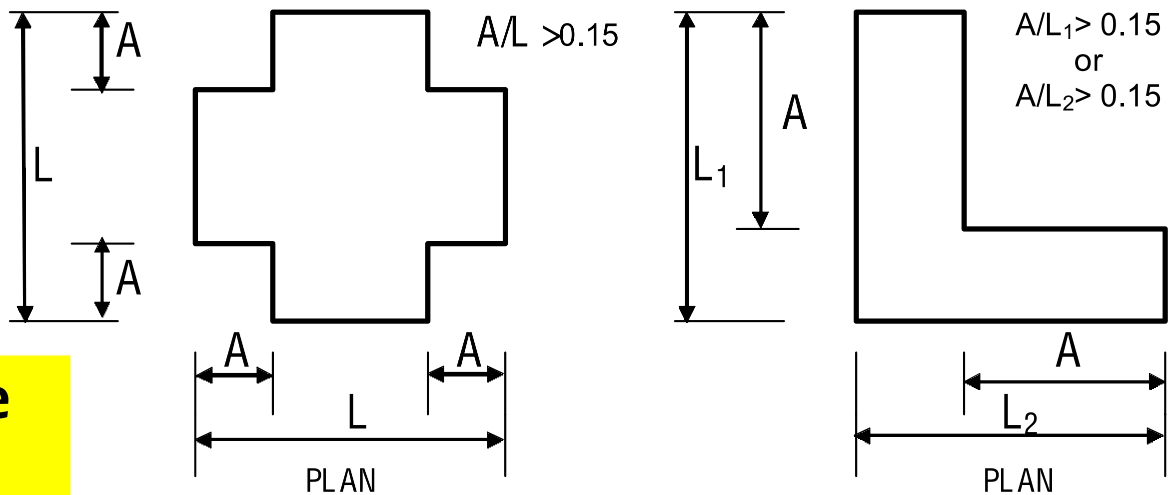
3B RE-ENTRANT CORNERS

Poor EQ performance
Stress Concentration

Cl.7.1. Plan Irregularity – Re-entrant Corners

1893-2016

- In a building with re-entrant corners, three-dimensional dynamic analysis method with flexible floor diaphragm shall be adopted to capture the concentration of forces generated in the re-entrant corners especially in the floor diaphragm and special elements adjoining the re-entrant corner.
- This is in addition to the case of rigid diaphragm analysis, if applicable, and the worst effect considered.

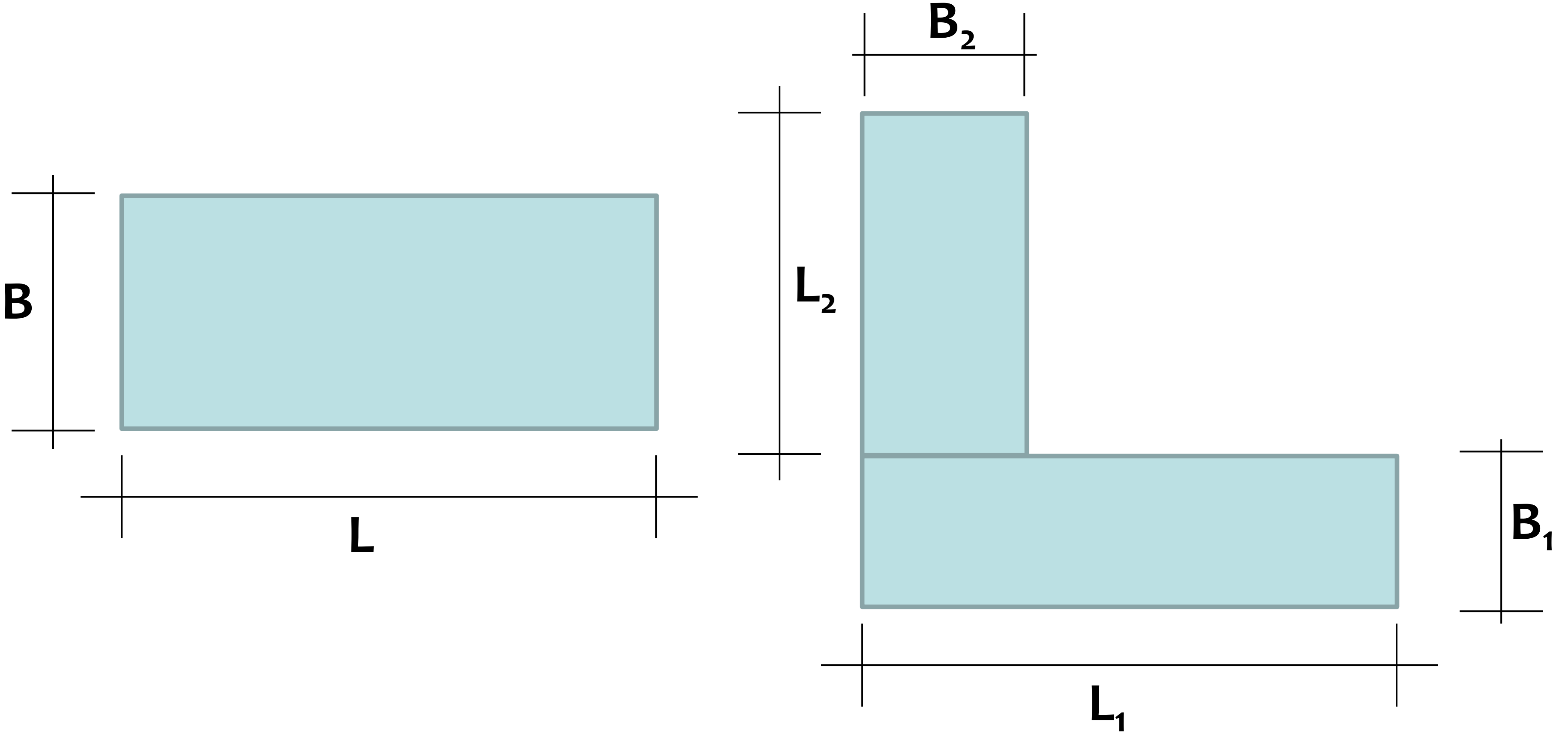


3B RE-ENTRANT CORNERS

Poor EQ performance
Stress Concentration

Cl. 5.2 Plan

- **5.2.2 Plan Aspect Ratio**
  - *The maximum plan aspect ratio (L_1/B_1) of the overall building shall not exceed 5.0.*
  - *In case of and L shaped building L_1 and B_1 shall refer to the respective length and width of each leg of the building.*



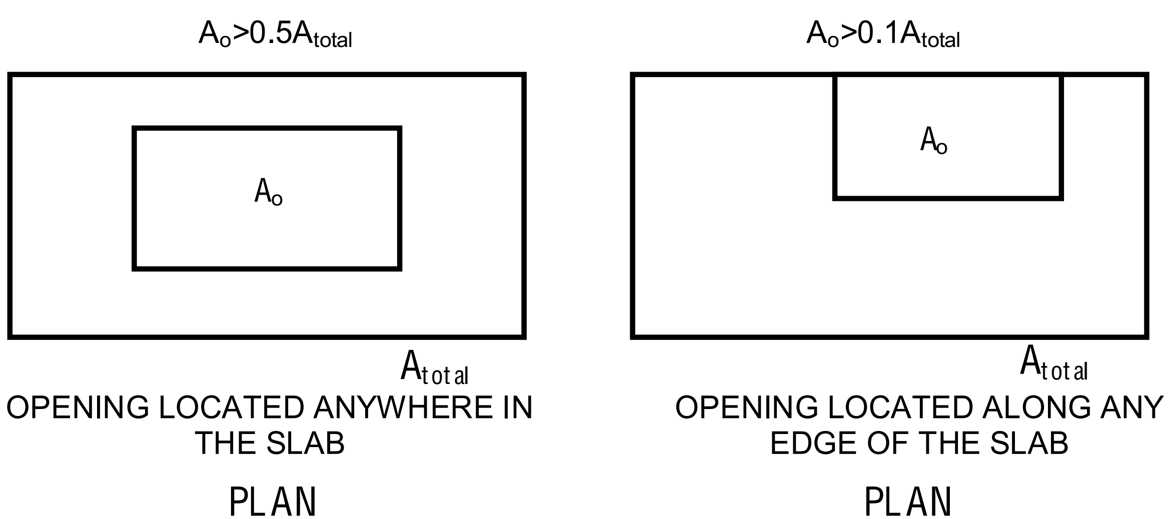
Floor Slabs with Openings

- ***"A building is said to have discontinuity in their in-plane stiffness, when floor slabs have cut-outs or openings of area more than 50 percent of the full area of the floor slab."***
  - *Openings in slabs result in flexible diaphragm behavior, and hence the lateral shear force is not shared by the frames and/or vertical members in proportion to their lateral translational stiffness.*
  - *The problem is particularly accentuated when the opening is close to the edge of the slab.*

Rigid diaphragm action diminishes with more opening area

Floor Slabs with Openings

- **In buildings with discontinuity in their in-plane stiffness, if the area of the geometric cut-out is,**
  - *less than or equal to 50 percent, the floor slab shall be taken as rigid or flexible depending on the location of and size of openings; and*
  - *more than 50 percent, the floor slab shall be taken as flexible.*

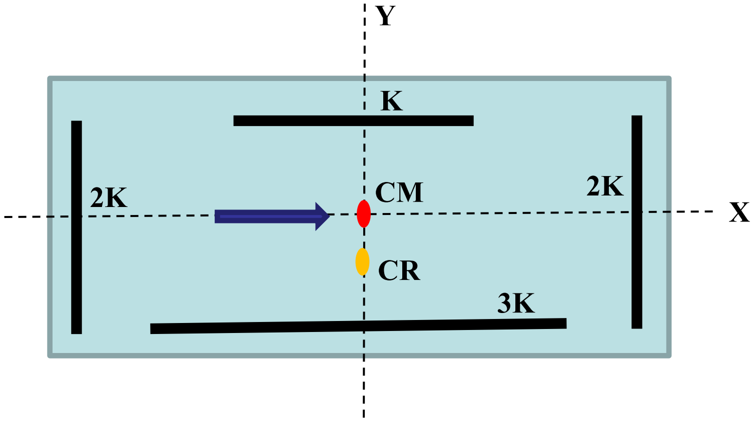


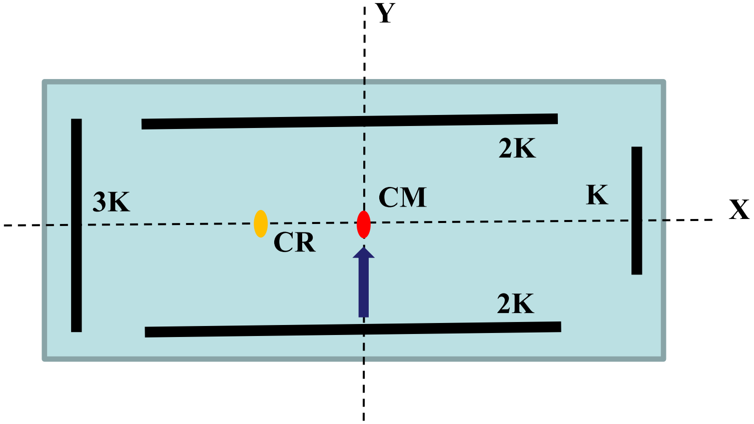
3C FLOOR SLABS HAVING EXCESSIVE CUT-OUT AND OPENINGS

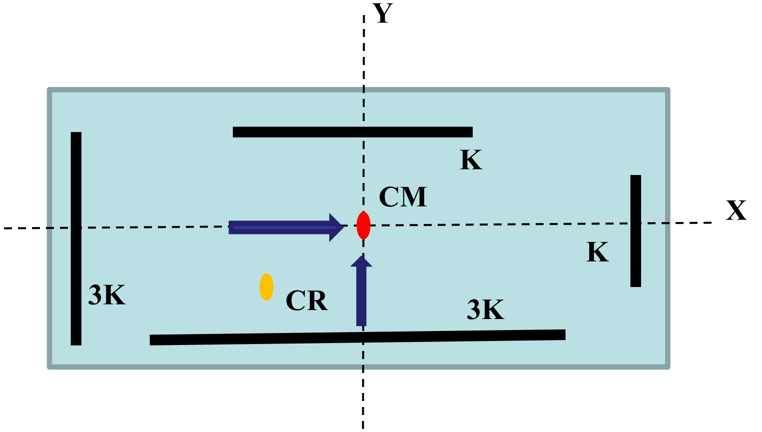
Cl.7.1. Plan Irregularity – Torsional Irregularity

- **Usually, a well-proportioned building does not twist about its vertical axis, when**
  a) *the stiffness distribution of the vertical elements resisting lateral loads is balanced in plan according to the distribution of mass in plan (at each storey level); and*

Cl.7.1. Plan Irregularity – Torsional Irregularity





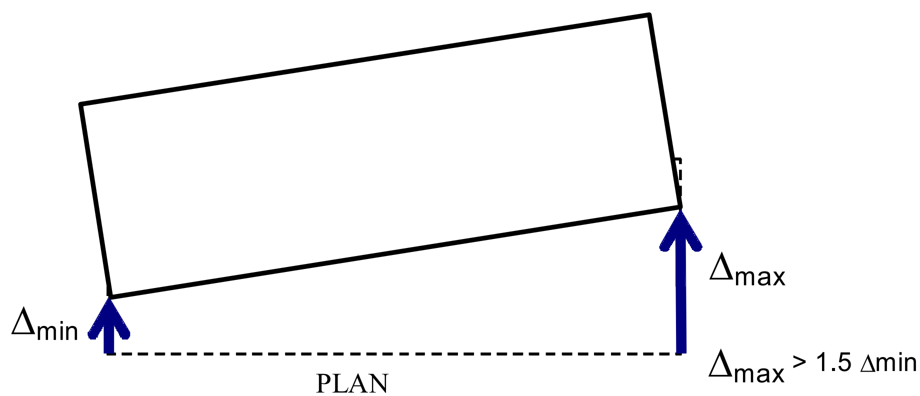


Cl.7.1. Plan Irregularity – Torsional Irregularity

- **Usually, a well-proportioned building does not twist about its vertical axis, when**
  a) *the stiffness distribution of the vertical elements resisting lateral loads is balanced in plan according to the distribution of mass in plan (at each storey level); and*
  b) *the floor slabs are stiff in their own plane*
     - **this happens when its plan aspect ratio is less than 3**

Cl.7.1. Plan Irregularity – Torsional Irregularity

- **A building is said to be torsionally irregular, when,**
  1) *the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction; and*
  2) *the natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan directions*



3A TORSIONAL IRREGULARITY

Cl.7.1. Plan Irregularity – Torsional Irregularity

- **In a building with torsional irregularity, when the horizontal total displacement Δ_{max} (which is larger in amplitude) at one end of the building in plan is:**
  i. *in the range of 1.2 Δ_{ave} to 1.4 Δ_{ave}*

     (where $\Delta_{ave}=(\Delta_{max}+\Delta_{min})/2$, in which Δ_{min} is the horizontal total displacement, which is smaller in amplitude at the other end),

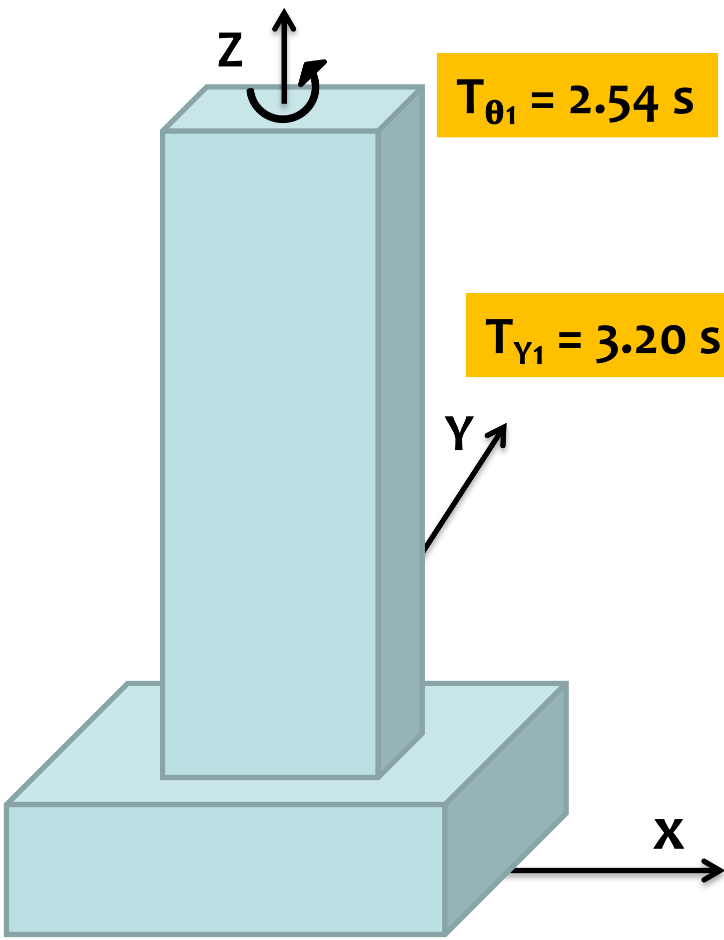
     a) the building configuration shall be revised to ensure that the natural period of the fundamental torsional mode of oscillation shall be smaller than those of the first two translational modes along each of the principal plan directions, and then

     b) three-dimensional dynamic analysis method shall be adopted.

  ii. *more than 1.4$_{\Delta ave}$, the structural configuration of the building shall be revised.*

Cl. 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.



$T_{\theta 1} = 2.54$ s

$T_{\theta 1} = 2.18$ s

$T_{Y1} = 3.20$ s

$T_{X1} = 2.70$ s

$T_{X1} = 2.55$ s

$T_{X1} < T_{Y1}$

$0.9T_{X1} = 0.9 \text{x} 2.7 = 2.43$ s

$T_{\theta 1} > 2.43$ s   Not Good

Revise the design

$0.9T_{X1} = 0.9 \text{x} 2.55 = 2.30$ s

$T_{\theta 1} < 2.30$ s   Good

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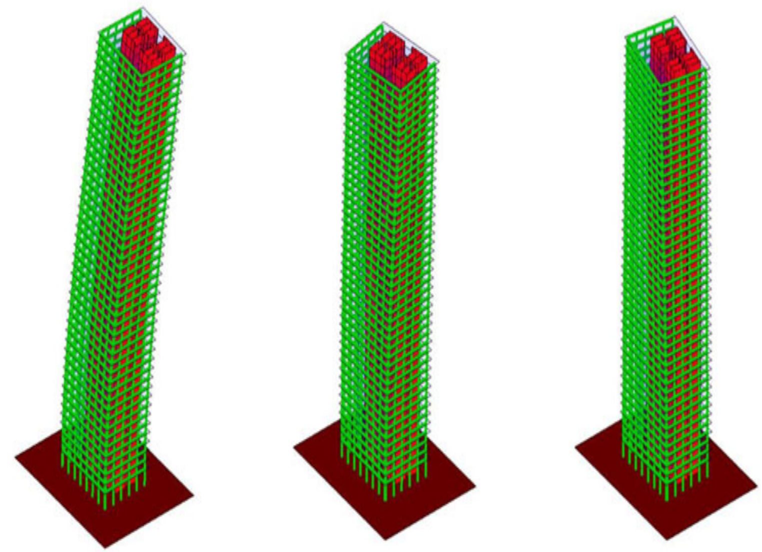
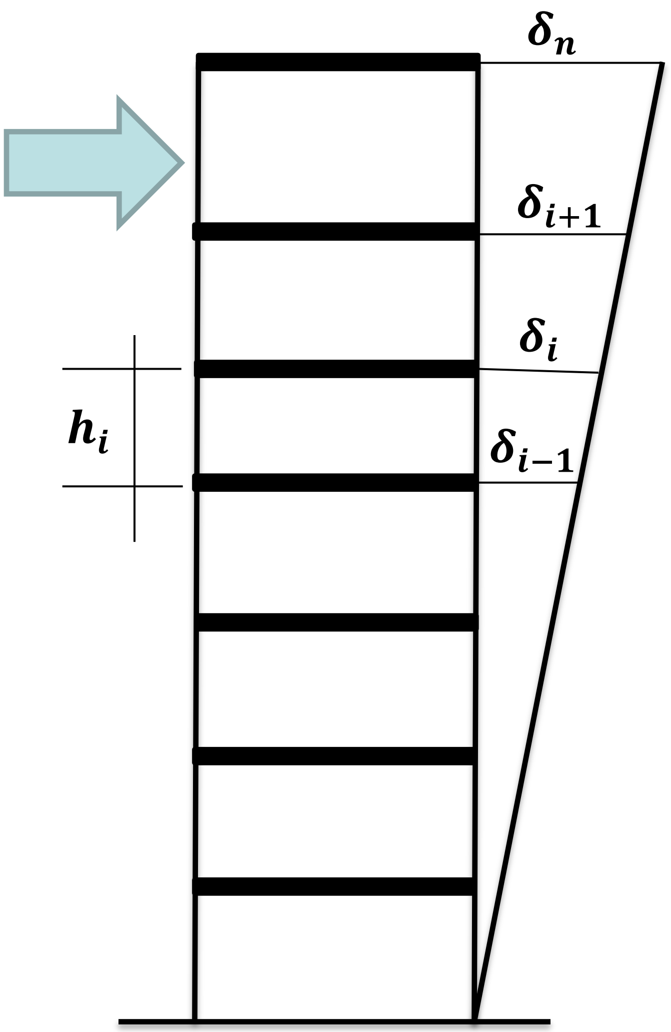
Return Period for Wind

✓ *Drift Calculation*



IS 1893-2016 Def 4.21 Storey Drift

- **It is the relative displacement between the floors above and/or below the storey under consideration.**



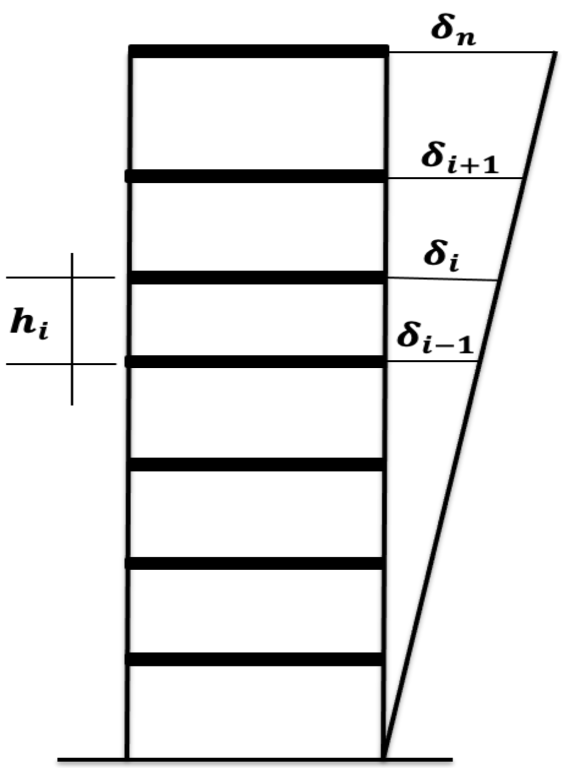
Displacement = δ_i

Drift =Δ_i= $\delta_i - \delta_{i-1}$

Drift ratio =Δ_i/h_i= $(\delta_i - \delta_{i-1})/hi$

Cl. 5.4.1 Lateral Drift

- **When design lateral forces are applied on the building, the maximum inter-storey elastic drift ratio (Δ_{max}/h_i) under serviceability loads,**
  - *which is estimated based on the sectional properties for serviceability loads mentioned in 7.2 shall be limited to H/500.*



20 Floors building = 20x3 = 60 m

$\Delta_i = \delta_i - \delta_{i-1} = 5$ mm

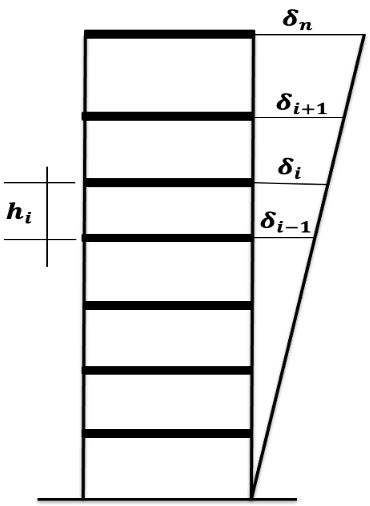
$\Delta_{max}/hi = 5/3000 = 0.00167$

1/500= 1/500= 0.002 **Allowable i.e., 6 mm**

H/500= 60000/500= 120 mm

Cl. 5.4.1 Lateral Drift

- **When design lateral forces are applied on the building, the maximum inter-storey elastic drift ratio (Δ_{max}/h_i) under serviceability loads,**
  - *which is estimated based on the sectional properties for serviceability loads mentioned in 7.2 shall be limited to H/500.*
  - *For a single storey, the drift limit may be relaxed to $h_i/400$.*



h_i/500= 3000/400= 7.5 mm

Table 6 Cracked RC Section Properties
(*Clause* 7.2)

Sl No.	Structural Element	Un-factored Loads		Factored Loads	
		Area	Moment of Inertia	Area	Moment of Inertia
(1)	(2)	(3)	(4)	(5)	(6)
i)	Slabs	1.0 A_g	0.35 I_g	1.00 A_g	0.25 I_g
ii)	Beams	1.0 A_g	0.7 I_g	1.00 A_g	0.35 I_g
iii)	Columns	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g
iv)	Walls	1.0 A_g	0.9 I_g	1.00 A_g	0.70 I_g

- ***Serviceability Loads***
  - *Wind load with 20-year return period*

Cl. 5.4.1 Lateral Drift

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

$h_i/250 = 3000/250 = 12$ mm **Earthquake**

$h_i/500 = 3000/500 = 6$ mm

Wind

$h_i/400 = 3000/400 = 7.5$ mm

$$\Delta_i = \delta_i - \delta_{i-1} = 5 \text{ mm}$$

Lateral Drift (5.4.1)

- **When design lateral forces are applied on the building, the maximum inter-storey elastic lateral drift ratio (Δ_{max}/h_i) under working loads;**
  - *Shall be limited to H/500.*
  - *For a single storey the drift limit may be relaxed to $h_i/400$.*
- **For earthquake load (factored) combinations**
  - *The drift shall be limited to $h_i/250$.*

- **Working Loads**
  - *unfactored wind load combinations with return period of* ***20 years***
  - *which is estimated based on realistic section properties mentioned in 7.2*

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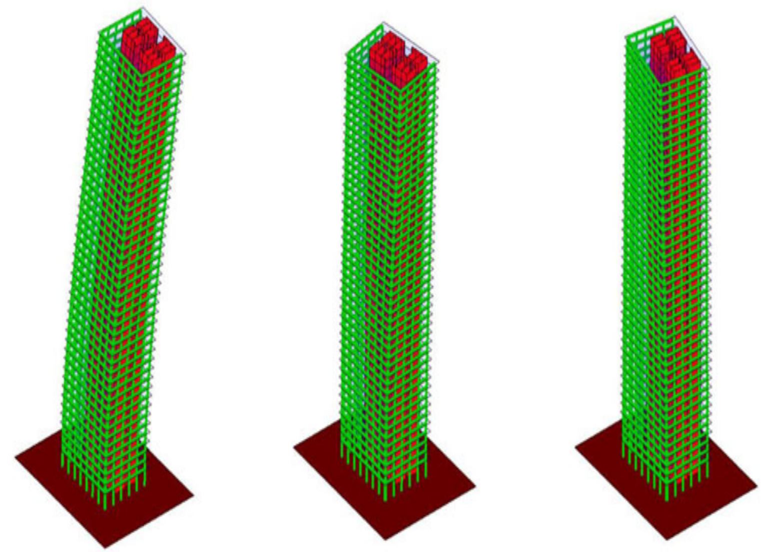
Max Vertical Floor Acceleration

✓ *Deleted*



5.6.4 Maximum Vertical Floor Acceleration

- **Requirements for maximum vertical acceleration of floors have been deleted.**

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
(*Clause* 5.6.4)

Sl No.	Use	Peak Acceleration at any Excitation Frequency m/s^2
(1)	(2)	(3)
i)	Residential	0.05
ii)	Office	0.05
iii)	Mercantile	0.18

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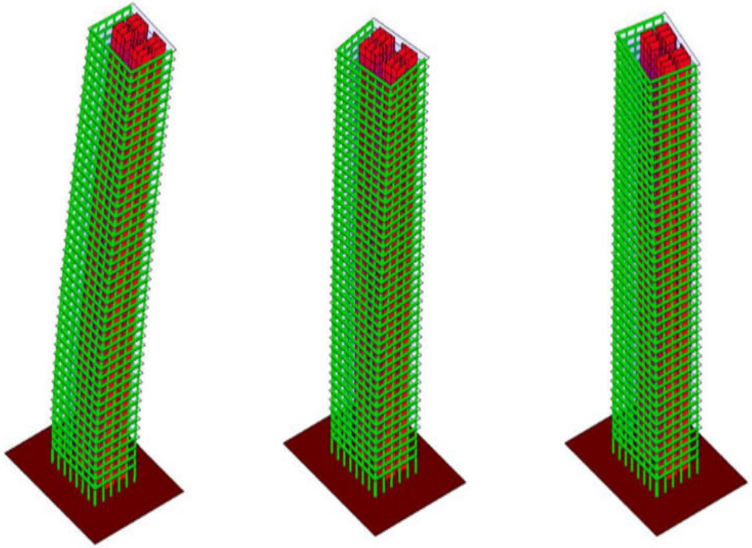
Max Horizontal Acceleration

- ✓ *Revised*



Cl 6.2.3 Horizontal Acceleration Value - Revised

- **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
(*Clause* 6.2.3)

Current

Sl No.	Building Use	Maximum Peak Combined Acceleration, a_{max} m/s^2
(1)	(2)	(3)
i)	Residential	0.15
ii)	Mercantile	0.25

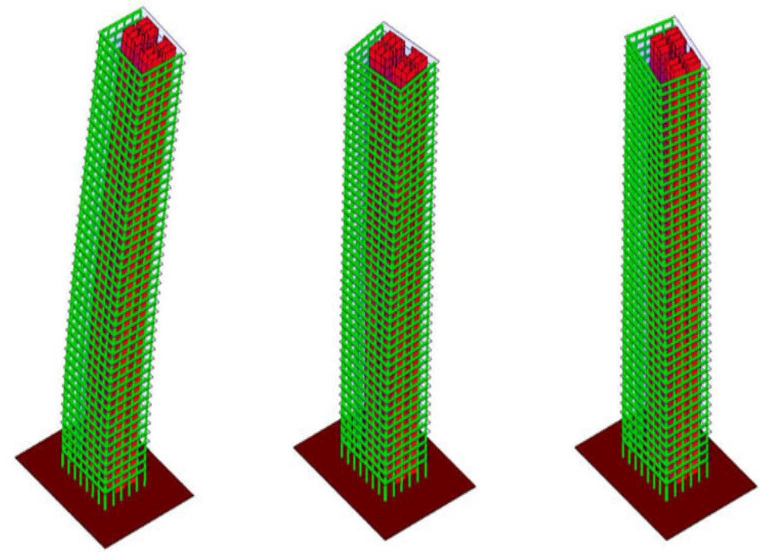
Proposed

Table 3 Permissible Peak Combined Acceleration
(*Clause* 6.2.3)

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

Proposal for Natural Period of Tall Buildings

- ✓ *Ambient vibration tests*
- ✓ *Regression analysis*
- ✓ *Proposal*



Empirical Expression, T

- **Method is introduced for arriving at the approximate natural period of buildings with basements, step back buildings and buildings on hill slopes;**

$$T_a = \frac{0.09h}{\sqrt{d}}$$

Bare Frame

$$T_a = \begin{cases} 0.075h^{0.75} & \text{for RC MRF building} \\ 0.080h^{0.75} & \text{for RC - Steel Composite MRF building} \\ 0.085h^{0.75} & \text{for Steel MRF building} \end{cases}$$

RC Structural Wall

$$T_a = \frac{0.075h^{0.75}}{\sqrt{A_w}} \leq \frac{0.09h}{\sqrt{d}} \qquad A_w = \sum_{i=1}^{N_w}\left[A_{wi}\left\{0.2 + \left(\frac{L_{wi}}{h}\right)^2\right\}\right]$$

Cl 6.3.4 Empirical Expression, T

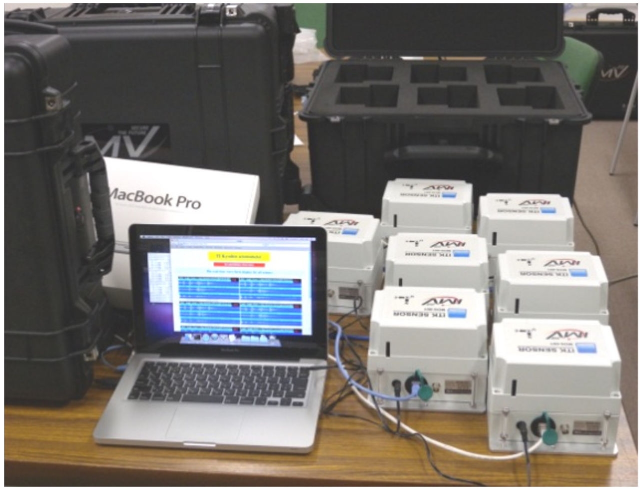
- **For buildings of height 50 m and more, the fundamental Period *T* (in second) for a structure shall be determined by accounting for all structural properties and inherent stiffness of the building through rigorously validated structural analysis procedures.**
- **The fundamental period shall however not exceed the value obtained from the approximate fundamental translational natural period *T*a (in second) of oscillation, estimated by following expression:**
  - $T_a = 0.0644H^{0.9}$ *for concrete moment resisting frame systems, and*
    $T_a = 0.0672H^{0.75}$ *for all other concrete structural systems*

Empirical Expression, T

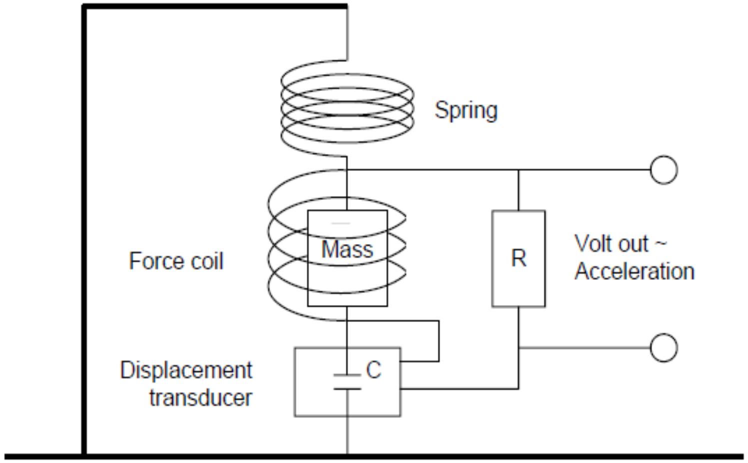
- **The empirical expression for natural period T of buildings is based on field measurements on to medium rise buildings.**
  - *Evaluate the same for its suitability for highrise buildings*
  - *Propose new empirical expression for RC Tall buildings*

Ambient Vibration Tests

- **High performance micro-tremor portable 'ITK Kyoshin' vibration sensor**
  - ***Principle:*** *Forced Balance Accelerometer (FBA)*
  - ***Frequency:*** *Natural frequency of the pendulum is about 200 Hz*
  - ***Range:*** *+0.25g to -0.25g with an accuracy of $5x10^{-3}$ gal*
  - ***Sampling Rate:*** *100 Hz*



Instruments used in the study

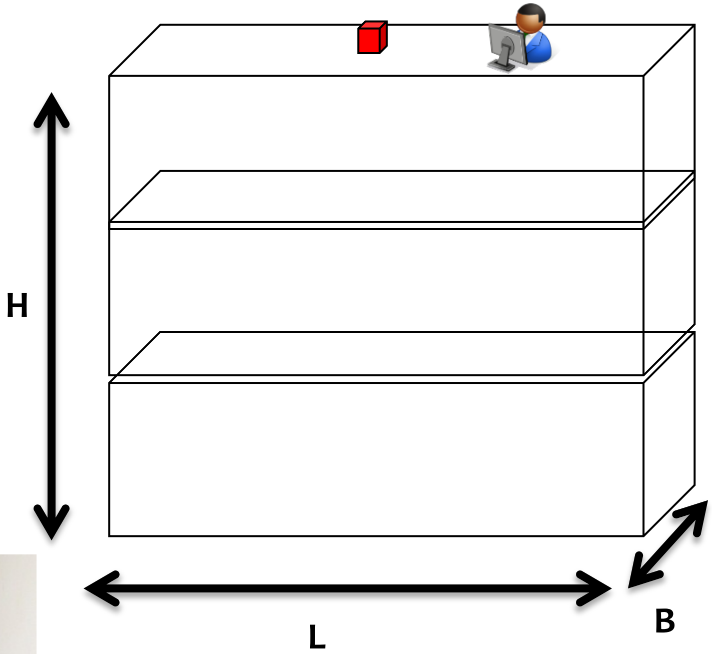


Principle of Force Balance Accelerometer

Credits: Pulkit D Velani, et al.,

Test Procedure

- A single point observation for 15-45 minutes.
- Sensor kept parallel to major and minor dimension of the building.
- Power supply and LAN connection to vibration sensor.
- 100 data points per second.
- Post processing of data in lab.

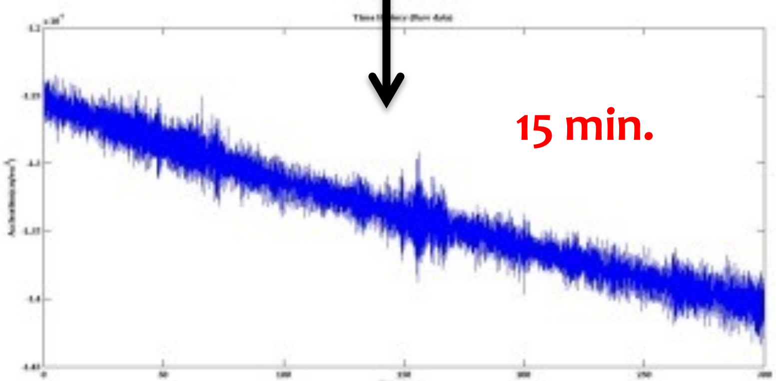


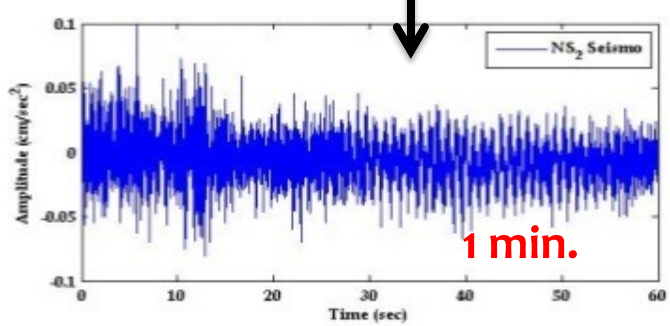
Post Processing

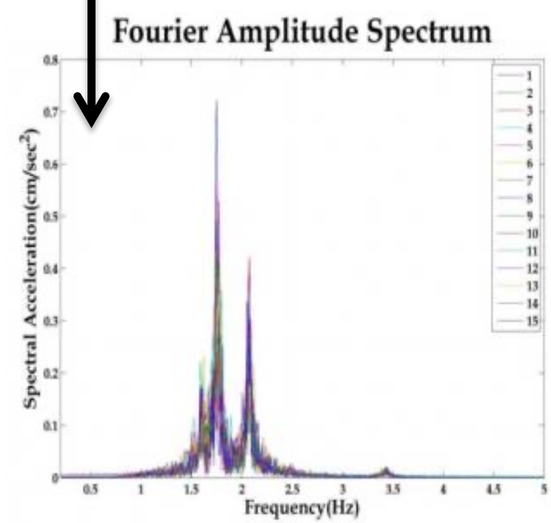
Raw data

Baseline correction and Filtering

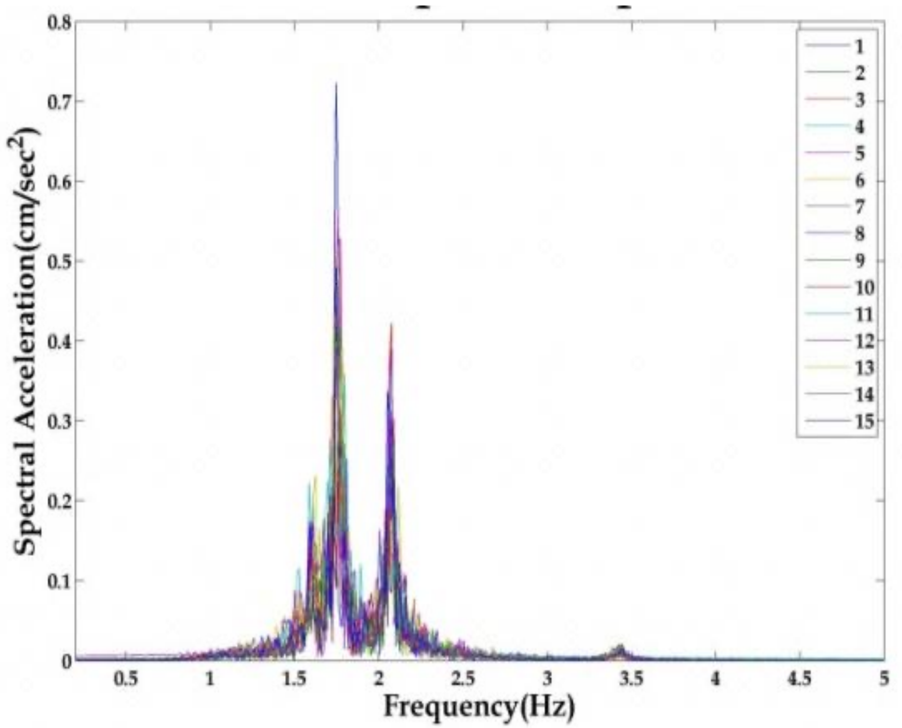
FFT to get Natural Frequency



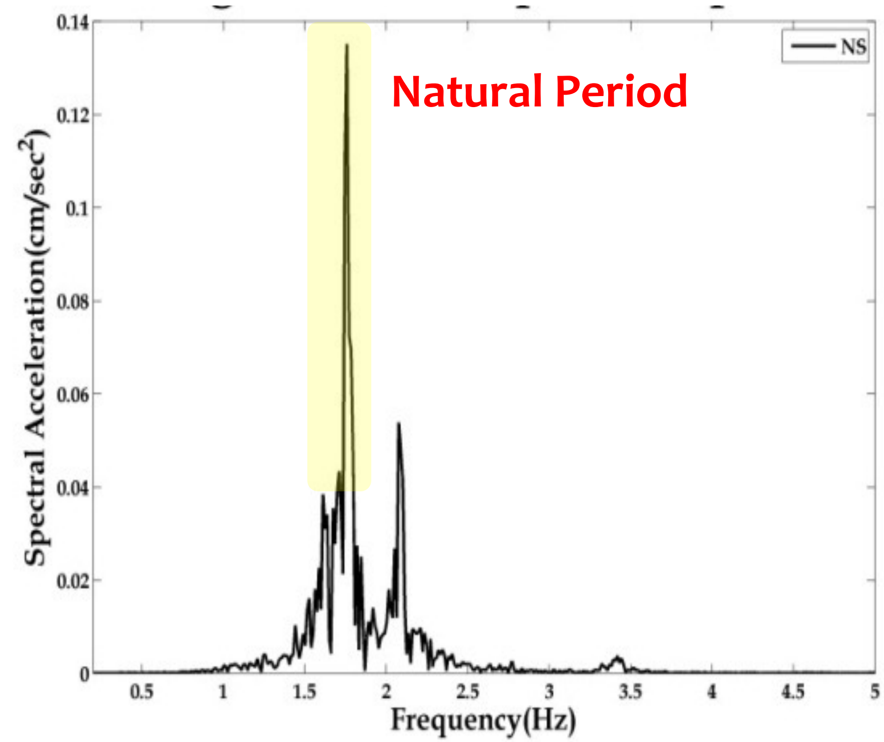




Post Processing

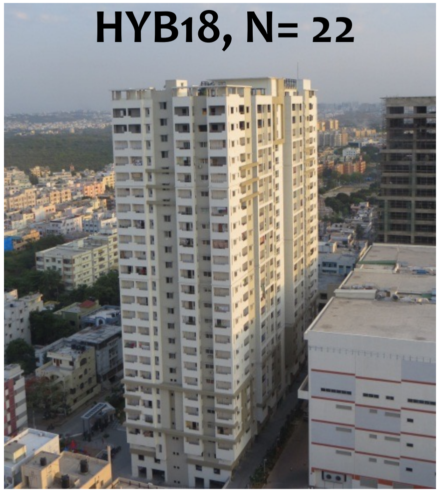


Sample of Fourier Amplitude Spectrums of fifteen one minute window of building (HYB52) along one shorter(NS) direction



Sample of Average Fourier Amplitude Spectrum of building (HYB52) along one shorter(NS) direction

Surveyed Buildings



Surveyed Buildings

Number of Storey	Height	Dimensions (m)		Time period (sec)	
		Longer	Shorter	Longer	Shorter
16	46.21	53.420	43.280	0.630	0.671
16	47.95	27.270	27.130	0.671	0.602
16	47.95	28.000	24.000	0.573	0.671
16	47.95	27.270	27.140	0.677	0.522
17	50.81	45.820	42.750	0.620	0.738
17	51.15	27.270	27.140	0.700	0.569
17	51.15	28.000	24.000	0.593	0.688
17	51.15	27.270	27.140	0.688	0.630
17	51.15	27.270	27.140	0.682	0.625
17	51.15	27.270	27.130	0.645	0.616
17	51.15	40.530	28.000	0.650	0.569
17	52.98	43.110	40.380	0.694	0.751
20	58.60	30.74	19.91	0.987	0.811
21	63.00	49.07	24.80	1.137	1.154
22	65.60	28.940	26.560	0.920	0.963
22	65.60	44.550	28.970	0.952	0.910
22	66.00	27.000	27.000	1.050	1.050
22	66.00	26.40	23.30	1.365	1.204
22	66.00	81.080	25.450	1.078	1.154
17	66.23	67.640	24.450	0.871	1.154
23	69.00	49.07	24.80	1.122	1.388
25	71.86	24.67	13.63	1.107	1.545
25	75.00	48.19	40.62	1.412	1.365
26	77.86	37.60	16.80	1.222	1.545
27	81.00	73.430	20.580	1.170	1.280
26	83.60	50.455	42.310	1.138	1.122
28	86.37	43.110	40.380	1.388	1.154
24	87.14	80.260	46.030	1.241	1.204
31	90.95	52.54	35.18	1.517	1.638
37	119.60	46.39	29.72	1.780	2.340
37	137.70	51.54	37.85	2.340	2.642
42	146.75	33.340	29.500	3.033	3.033

Regression analysis

- **Linear Regression analysis**

$$Y = m\,X + C$$

- **Power Law**

$$\boxed{Y = a\,X^{n}}$$

$$\boxed{log(Y) = n\,log(X) + log(a)}$$

$Y = m\,X + C$ and $\log a_{t_{low}} = \log a - S_e$

Regression analysis…

- Standard error of estimate

$$S_e = \sqrt{\frac{\sum(\log T_i - \log \bar{T}_i)^2}{n-2}}$$

- Coefficient of determination

$$R^2 = 1 - \frac{n\sum(\log T_i - \log \bar{T}_i)^2}{\left(n\sum \log {T_i}^2\right) - (\log T_i)^2}$$

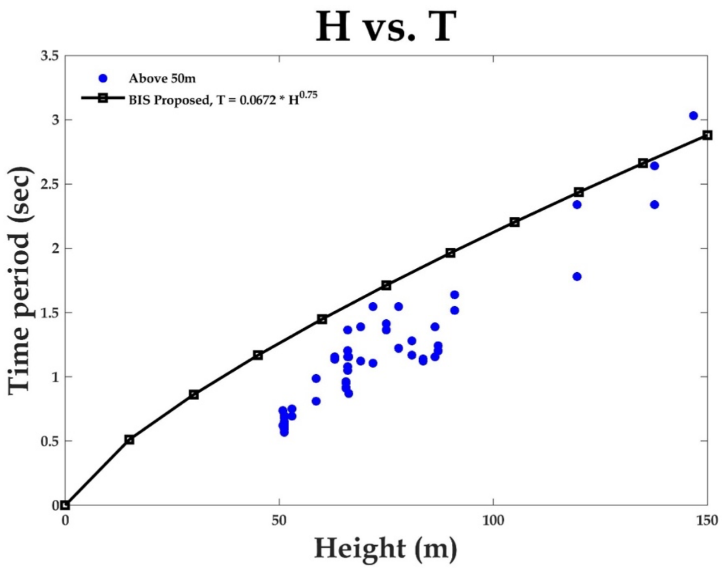
Where, T_i and $\bar{T}_i$ are the i^{th} data and regression estimate values of natural periods, respectively

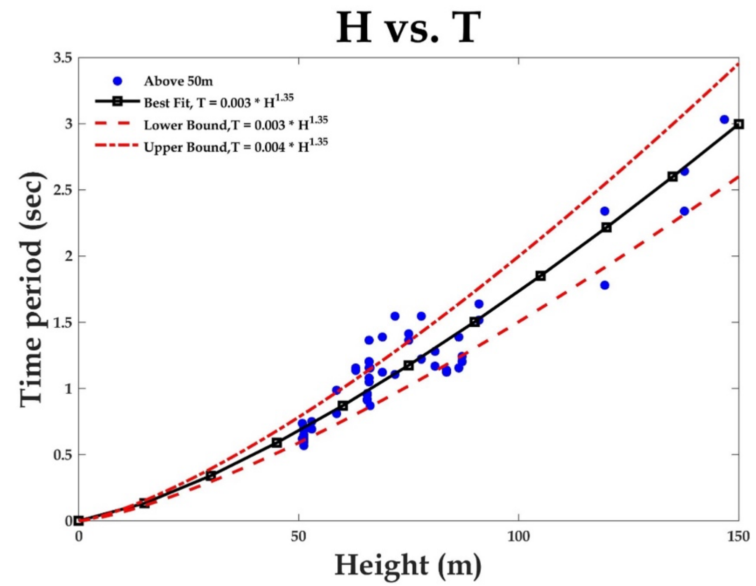
n is the total number of data points

Regression analysis...

	Parameter
Single Variable	H
Two Variable	$\frac{H}{D}, \frac{H}{\sqrt{D}}$
Three Variable	$\frac{H}{A}$

Proposed Empirical Expressions





Type	Proposed Formula	S.E.E. (S_e)	IS 1893:2016	S.E.E. (S_e)
RC MRF	$T = 0.032\ H^{0.75}$	0.189	$T = \frac{0.09H}{\sqrt{D}}$	0.318
RC SW	$T = 0.01\ H^{1.1}$	0.135		0.238
Up to 60	$T = 0.032\ H^{0.75}$	0.192		0.325
Above 60	$T = 0.009\ H^{1.1}$	0.143		0.213
Proposal	$T = 0.0035\ H^{1.35}$	0.142	$T = 0.0672\ H^{0.75}$	0.482

Credits: Pulkit D Velani, et al.,

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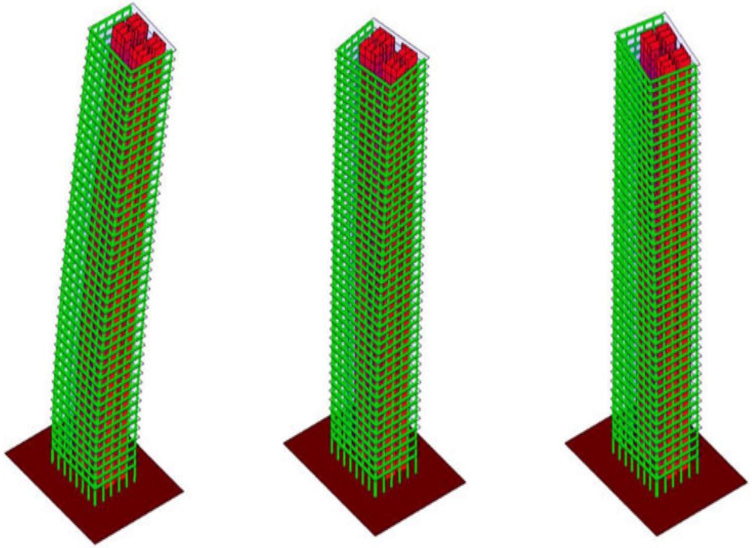
P-Delta Effects

- ✓ *Load Combinations*
- ✓ *Inter-storey stability coefficient*



Cl 7.2 Load Combination for P-Δ effects

- **The load combination for the initial analysis considering P-Δ effects shall be taken as follows:**
  - 1.2 *DL* + 0.5 *IL* ±1.5 *EL*/*WL*

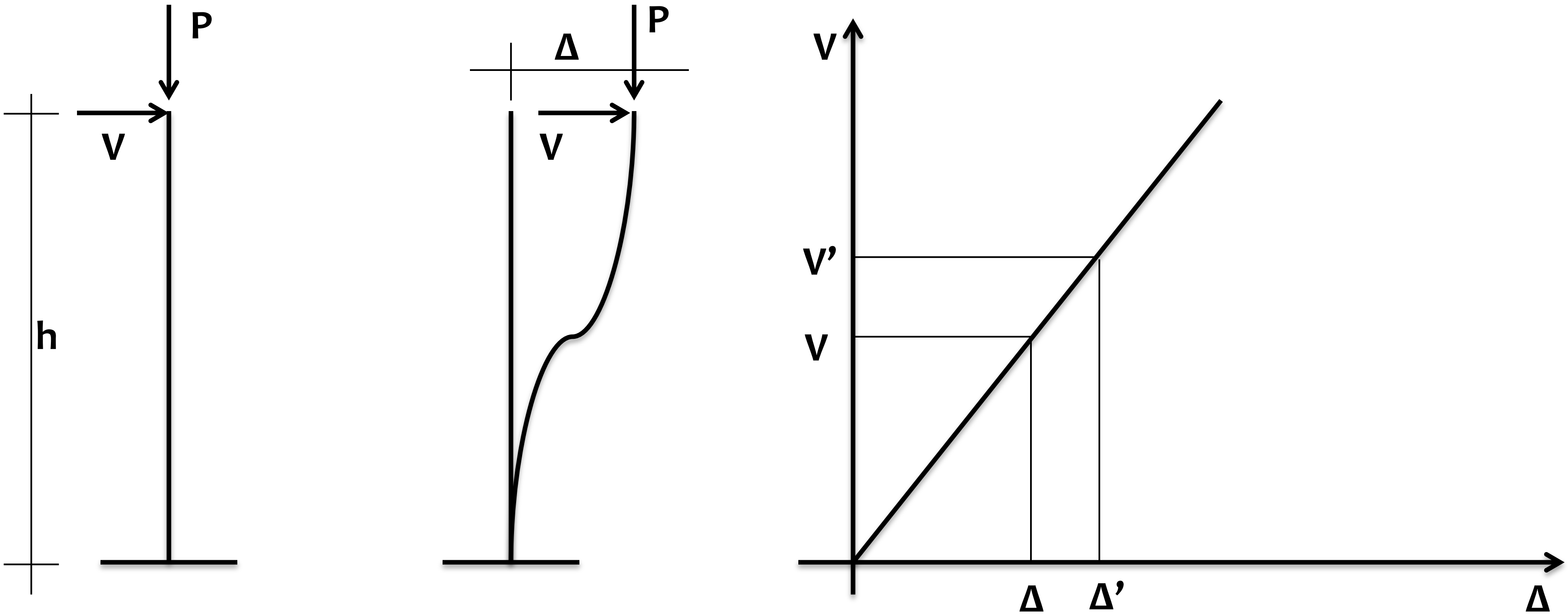
Cl 7.3.10 Inter-storey Drift Stability Coefficient

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

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

  - P_i *Total design vertical load at level i*
  - Δ_i *Design storey drift at level i*
  - V_i *Design shear force at level i*
  - h_{i-1} *Storey height below level i*
  - R *Response Reduction Factor*

P-Δ effects



$M_P = Vh$	Primary Moment
$M_s = P\Delta$	Secondary moment
$M_T = Vh + P\Delta$	Total moment
$V' = V + P\Delta/h$	Equivalent Shear
$V'/V = 1 + (P\Delta/Vh)$	Stability Factor $\ngtr 0.2$

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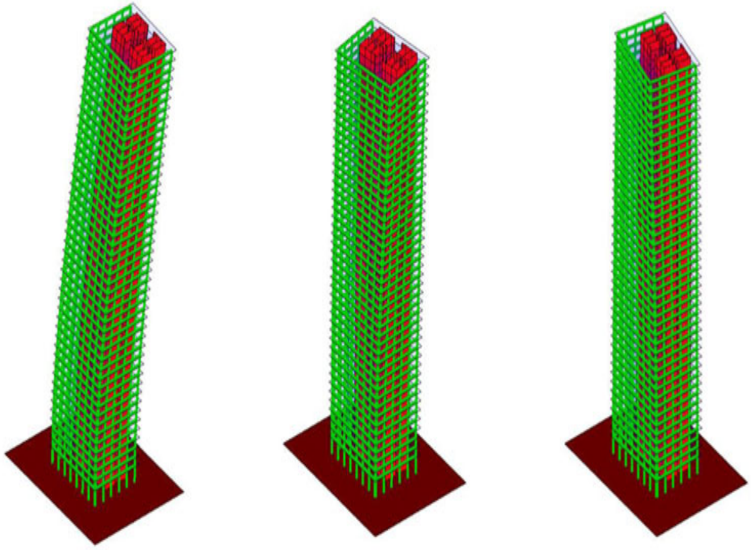
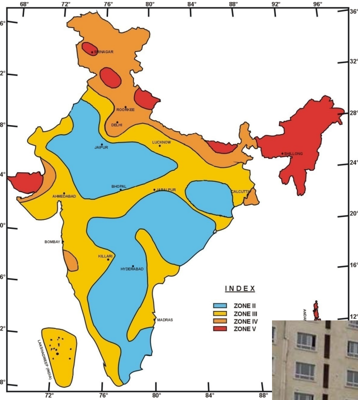
Structural Walls

✓ *Transverse Reinforcement*



Cl 8.5.13 Special Requirements in Zones IV and V - Structural Walls

- **Structural Walls**
  a) *Structural walls shall be continuous to the base without being transferred in plane or out of plane at any level;*
  b) *The minimum longitudinal reinforcement in Structural Walls shall not be less than 0.4 percent of gross cross-sectional area;*
  c) ***The minimum transverse reinforcement in Structural Walls shall not be less than 0.25 percent of gross cross-sectional area;***
  d) *The reinforcements shall be distributed in two curtains in each direction;*
  e) *Structural walls shall be fully embedded and anchored at their base in adequate basements or foundations, so that the wall does not rock. In this respect, walls supported by slabs or beams are not permitted; and*
  f) *All openings in structural walls shall preferably be aligned vertically. Random openings, arranged irregularly, shall not be permitted in coupled walls, unless their influence is insignificant.*



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Summary…

Acknowledgements

ASCE INDIA SECTION

Southern Region

- **All my students**
  - *Research work*
- **Internet**
  - *Clipart*

Thank you…

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Thank you…