Training on NBC Compliant Computer Aided Design of buildings for Engineers/Designers of Kathmandu Valley

Earthquake Resistant Design Philosophy& Load Calculation as per NBC105 & IS1893

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Kathmandu

Technical support from CoRD

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Content

- Earthquake Resistant Design Pholisophy
- Earthquake Loads on building according to NBC105 and comparison with IS1893:2002

Design Philosophy

- Ordinary loads design vs. earthquake load design
- Earthquake proof vs. earthquake resistant construction
- Philosophy of earthquake resistant design

What we accept…

Taplejung Earthquake

What we accept...

What we do not accept...

What we do not accept…

Kashmir Earthquake

Taplejung Earthquake

What we do not accept…

Taplejung Earthquake

Why ?

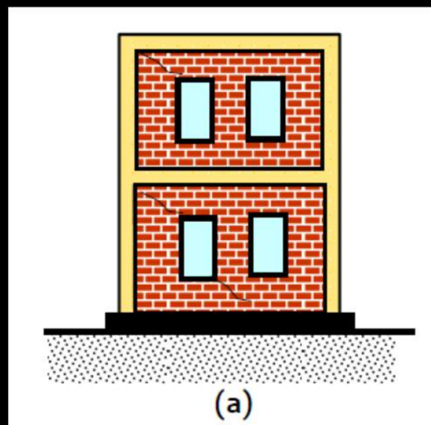
- **Life safety criteria :** If the building has not partly or fully collapsed, life is saved
- **Reparability criteria :** If the building is still standing, it can be repaired and/or strengthened

Design Philosophy

Group	Magnitude	Annual Average Number
Great	8 and higher	1
Major	7 – 7.9	18
Strong	6 – 6.9	120
Moderate	5 – 5.9	800
Light	4 – 4.9	6,200 (estimated)
Minor	3 – 3.9	49,000 (estimated)
Very Minor	< 3.0	M2-3: ~1,000/day; M1-2: ~8,000/day

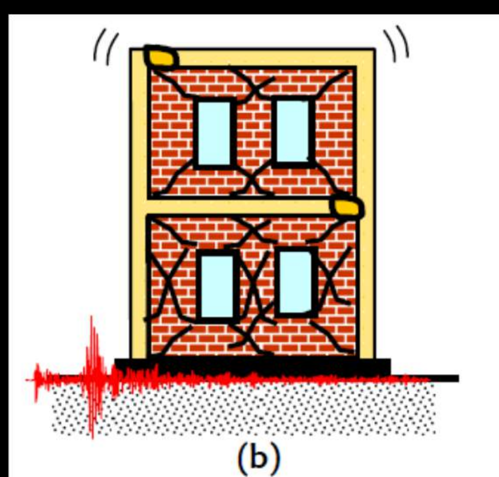
Source: http::/neic.usgs.gov/neis/eqlists/eqstats.html

Design Philosophy



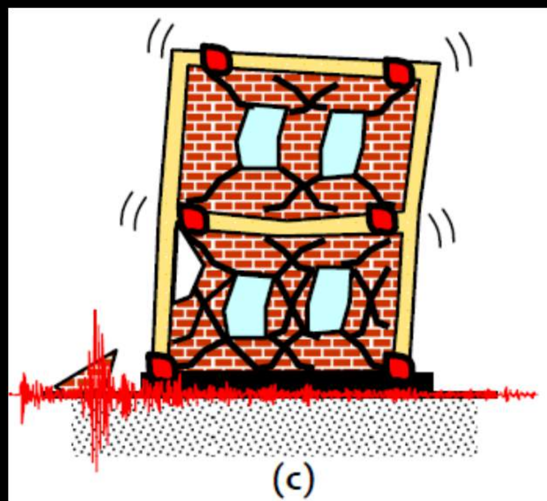
- a)Under minor shaking, structural members should not be damaged; however building parts that do not carry load may sustain repairable damage.

Design Philosophy



- b) Structure should be able to resist occasional moderate ground shaking without significant damage

Design Philosophy



- c) Structure should be able to resist major earthquakes without collapse

Earthquake Resistant Design

We thrive for

Earthquake resistant design & construction

not

Earthquake proof

Earthquake Resistant Design

- No earthquake-proof buildings that will not get damaged even during the strong earthquake - Instead, earthquake resistant building.
- such buildings resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake.
- Thus, safety of people and contents is assured in earthquake-resistant buildings, and thereby a disaster is avoided.

This is a major objective of seismic design codes throughout the world.

Damage - Unavoidable

earthquake resistant design involves controlling the damage to acceptable levels at a reasonable cost.

Different types of damage occur in buildings during earthquakes. Some of these cracks are acceptable (in terms of both their size and location), while others are not.

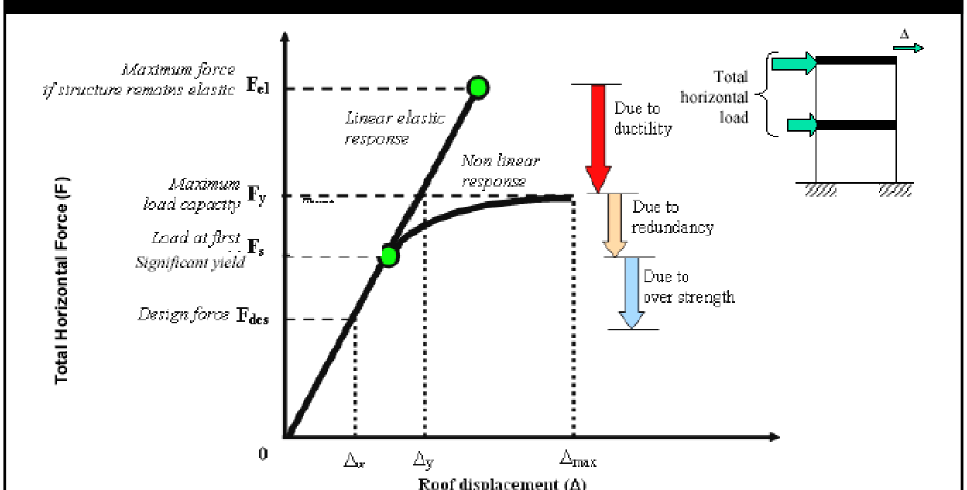
Damages during earthquakes should be of the acceptable variety, and also that they occur at the right places and in right amounts.

To save the building from collapsing, you need to allow some pre-determined parts to undergo the acceptable type and level of damage.

What does this mean ?

- Buildings and other structures are designed for much lesser load than imparted by a large earthquakes
- Why?
  - Affordability
  - Large earthquakes are rare
- Properly designed Buildings has Ductility, Redundancy
- Building has over strength due to considered safety factors in loads and materials

Actual Design EQ Force Level



Recommended seismic behavior objectives, Vision 2000

Level of seismic design	Permanent Operation	Immediate Occupation	Protection of lives	Collapse Prevention
Frequent (50% over 30 years)	✖		Unacceptable performance (new facilities)	
Occasional (50% over 50 years)	◆	✖		
Rare (10% in 50 years)	●	◆	✖	
Very Rare (10% in 100 years)		●	◆	✖

✖ = Basic or conventional facility, such as offices or homes

◆ = Essential or hazardous facility or component, such as telephone switchboards and buildings with toxic materials stored inside

● = Critical security, as in hospitals and fire stations, Transmission tower

ATC (Report 33-03). *Guidelines for Seismic Rehabilitation of Buildings.* 75% Submittal, Third Draft, 3 Volumes. Redwood City, 1995. NEHRP Guidelines for Seismic Rehabilitation of Buildings (FEMA 273)

Slide 88

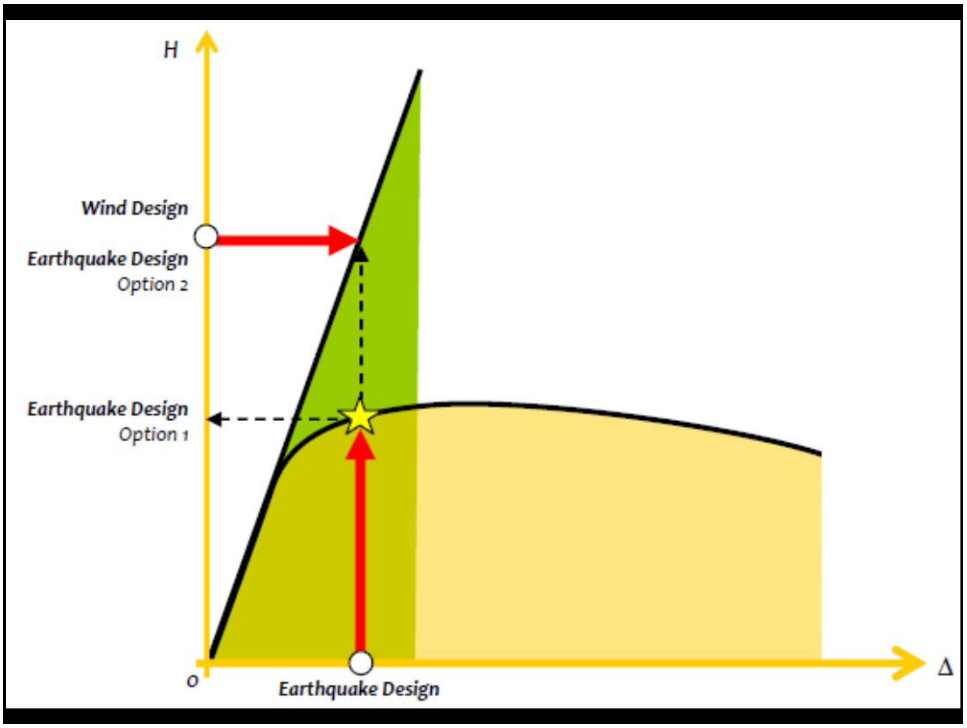
Earthquake load calculation as per code

Kashmir Earthquake, October 8, 2005

Ordinary Load vs Earthquake Load

- **In Ordinary Load** design (dead/ Imposed, wind etc), it is expected that structure will essentially remain elastic even during severe most design loading

- Where as in earthquake resistant design it is expected that structure could go in inelastic regime and suffer severe damage during a major earthquake



Gravity Loading

- **Dead Load: self-weight, superimposed load -** The dead loading is calculated from the designed member sizes and estimated material densities
- **Imposed load: occupancy type -** The magnitudes of live loading specified in the codes are estimates based on a combination of experience and results of typical field surveys

Lateral Loading

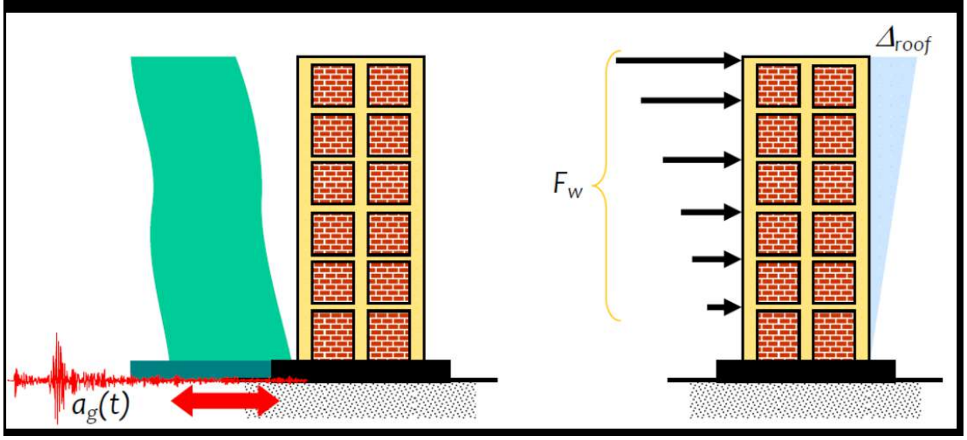
- **Earth pressure –** Predominantly static type of loading; calculated from density and depth
- **Wind –** Dynamic - pressure on exposed surface area
- **Earthquake –** Dynamic - Random motion of the ground at the base

Earthquake vs. Wind Loading

Dynamic actions are caused on buildings by both *wind* and *earthquakes*.

But, design for wind forces and for earthquake effects are distinctly different.

Earthquake vs. Wind Loading



Design for Wind Loading

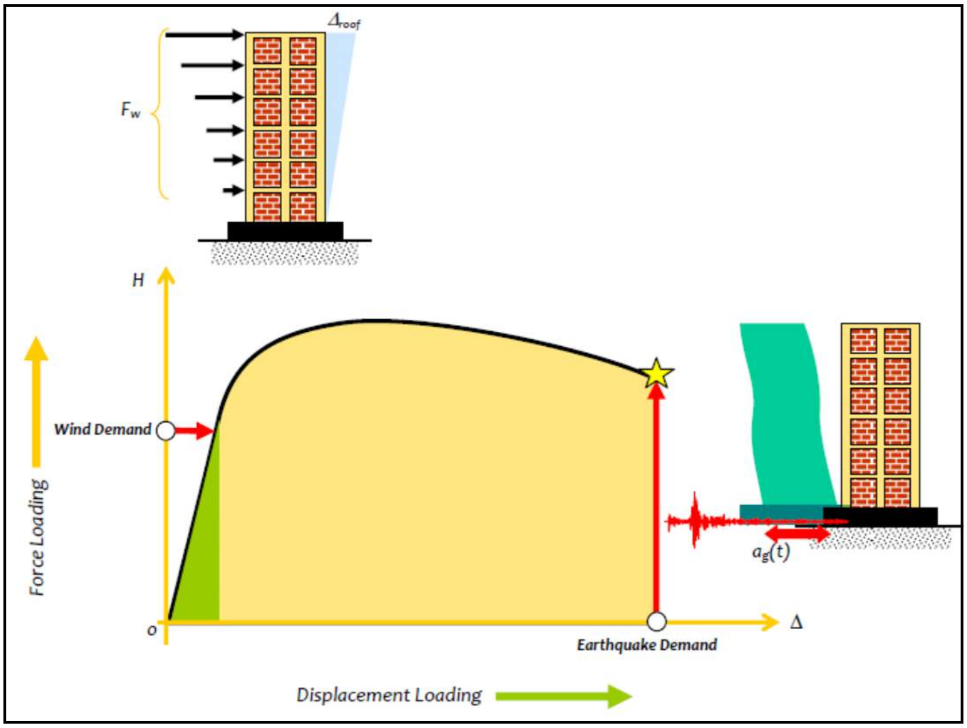
wind design:

– is *force-type* loading - use force design, wherein the building is subjected to a *pressure* on its exposed surface area.

Design for Earthquake Loading

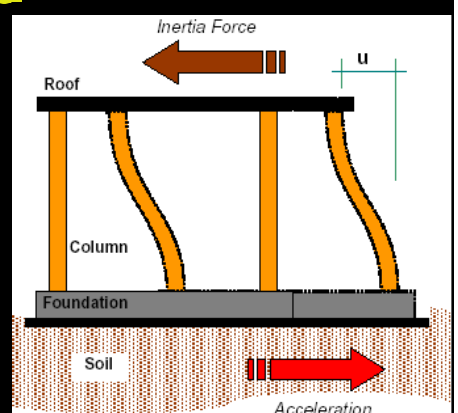
Displacement loading –

the building is subjected to random motion of the ground at its base - which induces inertia forces in the building that in turn cause stresses.



Earthquake Loading

Earthquake loading consists of the inertial forces of the building mass that result from the shaking of its foundation by a seismic activity.



Concentrates particularly on the translational inertia forces, whose effects on a building are normally more significant than the vertical or rotational shaking component

Earthquake induces inertia force:

- **The mass of the building.**
- **Building Stiffness.**

Elastic behavior without damage render the project economically unviable.

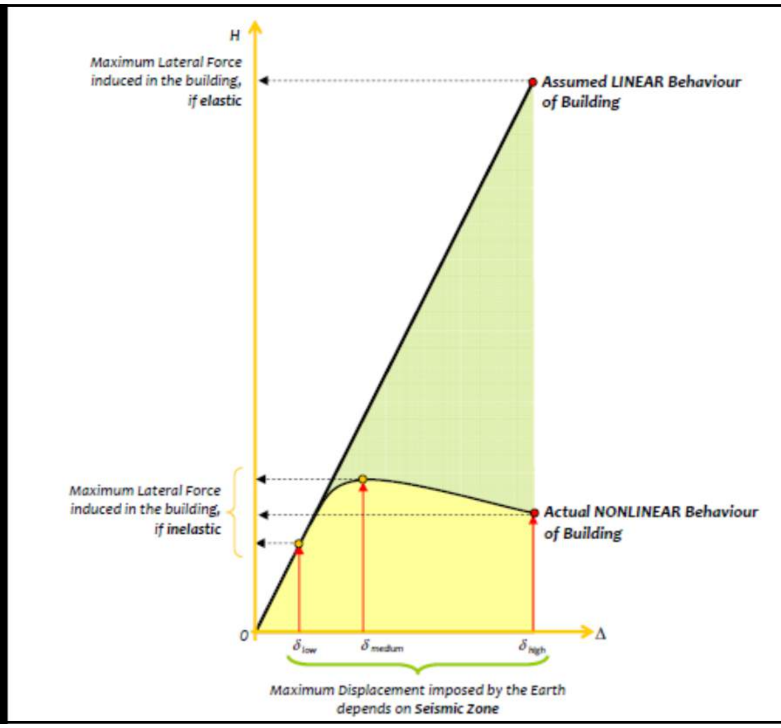
As a consequence, it may be necessary for the structure to undergo damage and thereby dissipate the energy input to it during the earthquake.

Thus the basic philosophy:

a) ***Minor (and frequent) shaking*** **with no damage to structural and non-structural elements;**

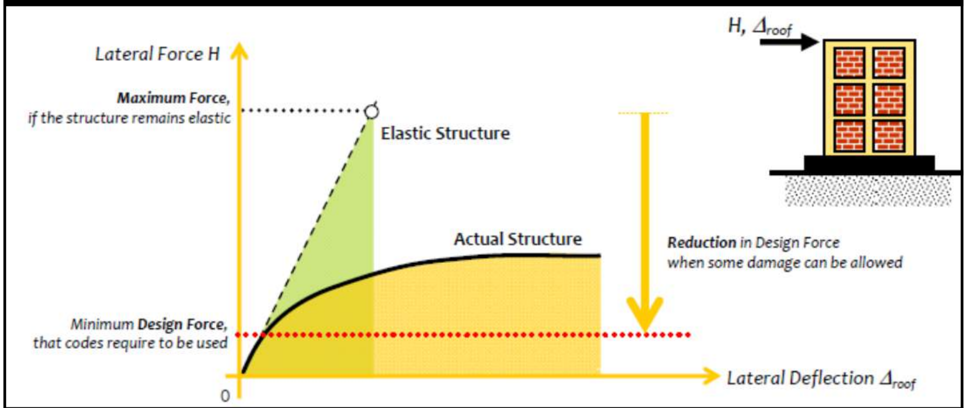
b) ***Moderate shaking*** **with minor damage to structural elements, and some damage to non-structural elements; and**

c) ***Severe (and infrequent) shaking*** **with damage to structural elements, but with NO collapse (to save life and property inside/adjoining the building).**



Buildings are designed only for a fraction (~8-26%) of the force that they would experience, if they were designed to remain elastic during the expected strong ground shaking, and thereby permitting damage. But, sufficient initial stiffness is required to be ensured to avoid structural damage under minor shaking.

Thus the basic philosophy:



The design for only a fraction of the elastic level of seismic forces is possible, only if the building can stably withstand large displacement demand through structural damage without collapse and undue loss of strength. (Ductility)

It is relatively simple to design structures to possess certain lateral strength and initial stiffness by appropriately proportioning the size and material of the members. But, achieving sufficient ductility is more involved and requires extensive laboratory tests on full-scale specimen to identify preferable methods of detailing.

Thus, seismic design balances reduced cost and acceptable damage, to make the project viable. This careful balance is arrived based on extensive research and detailed post-earthquake damage assessment studies.

design against earthquake effects is called as *earthquake-resistant design* and not *earthquake-proof design*.

- An earthquake-resistant building has four virtues
  - Good Seismic Configuration
  - Minimum Lateral Stiffness
  - Minimum Lateral Strength
  - Good Overall Ductility

Historical Development

An earthquake-induced *lateral force* was thought to be the root cause of the earthquake problem. Designers observed that buildings performed well, if they were designed for lateral forces. As a first measure of consciously designing for earthquake effects, designers took *10% of the weight of the building* and applied it as a lateral force on the building (distributed along the height). But, the 10% force was too penalizing for taller buildings.

Historical Development

Around that time, understanding grew on the ground motions, and it was learnt that different buildings respond differently to the same ground shaking. Thus, the design lateral force was now taken as *a function of the fundamental natural period of the building*. This was not sufficient either.

Historical Development

Many buildings showed brittle performance, *i.e.,* collapsed suddenly in low seismic regions. This was the beginning of understanding the *importance of introducing ductility* in buildings. But, the method of introducing ductility was prescriptive; it was based on limited laboratory tests performed on structural elements and sub-assemblages.

Historical Development

The above also was found insufficient, when buildings did not collapse, but were rendered not-usable after many strong earthquakes. *Performance of buildings* during and after the earthquake came into focus. Fresh thinking began towards *displacement-based design* of buildings. Then, it was clear that *imposed lateral displacement* was the root cause of the earthquake problem and not any *lateral force*. Thus, the present effort in the research community is to arrive at a *displacement based design with capability to quantitatively assess the ultimate deformation capacity of buildings at the design stage itself*.

Steps

- Configuration (simple geometry, plan aspect ratio, slenderness ration)
- Adopt a structural system that will resist the vertical and lateral loads offering direct load paths in both plan directions of the building
- Determine preliminary sizes of structural members
- Estimate design DL and LL loads (dead, imposed)

Steps

- Identify a desired collapse mechanism
- Prepare a basic structural analysis model of the building
- Select Analysis method and Estimate earthquake load As per Code
- Distribute it to the structural members - Apply the design seismic base shear V_B
- Perform seismic design of all structural elements

Steps

- Prepare the improved structural analysis model of the building
- Distribute it to the structural members - Apply the design seismic base shear V_B
- Verify, if the desired mechanism is generated in the building (push over/ time history)
- Detailing

Analysis Methods

Seismic Coefficient Method

- Simple regular configuration buildings, H < 40m

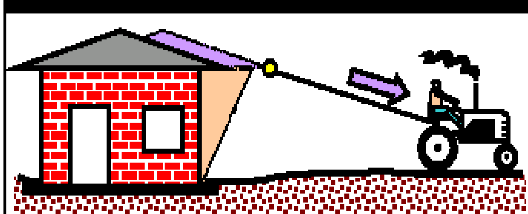
Response Spectrum Method

- Irregular buildings in plan and/ or elevation
- Buildings with abrupt change in strength and stiffness in plan and elevation
- Buildings with unusual shape, size, importance

Time History Method

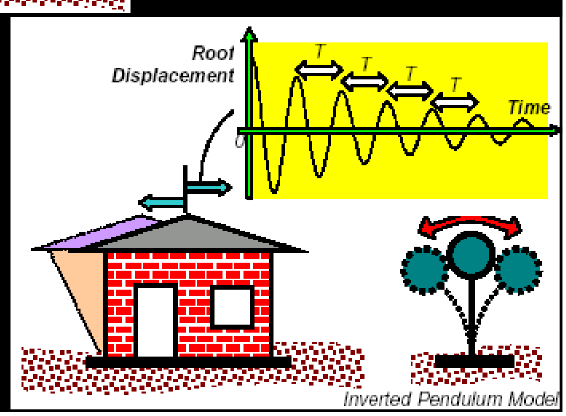
Seismic Coefficient Method is used for this course

Fundamental period of Building



Building pulled with a rope tied at its rope

Oscillation of building on cutting the rope



Free vibration response of a building (The back and forth motion is periodic)

$$\omega_n = \sqrt{k/m}$$

$$T_n = 2\pi / \omega_n$$

Fundamental Time Period

- The time taken (*in seconds*) for each complete cycle of oscillation (*i.e.,* one complete *back-and-forth* motion) is the same and is called *Fundamental Natural Period "T"* of the building.
- *"T"* depends on the building flexibility and mass.
- More the flexibility, the longer is the *T*, and more the mass, the longer is the *T*.
- In general, taller buildings are more flexible and have larger mass, and therefore have a longer *T*.
- On the contrary, low- to medium-rise buildings generally have shorter T.

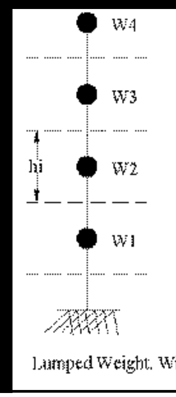
Equivalent Static Lateral Force

- Determine design base shear based on seismic hazard, building use group, total building mass, and building fundamental period
- Distribute base shear to building stories based on story masses and elevations
- Design for story forces applied in each orthogonal direction
- Also, ensure inelastic story drift does not exceed code requirement

Seismic Lump mass W_i

– Dead Load – preliminary member sizes, unit weights
– Live Load – Building occupancy
– Earthquake Load = Dead load + Appropriate imposed load

Design Live load	Percentage of Design Live load
Up to 3 KPa	25
Above 3 KPa	50
For roof	Nil



Design Earthquake Load

- Horizontal Base Shear

NBC 105	IS1893-2002
$V_s = C_d W_i$	$V_b = A_h W$

W_i = Seismic Weight of the Building
= Dead Load + Appropriate % of Live Load

- **The seismic weight at each level, W_i, shall be taken as the sum of the dead loads and the seismic live loads between the mid-heights of adjacent storeys**

Earthquake Load

NBC 105	IS1893-2002
$C_d = CZIK$	$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$

C_d = Design Horizontal Seismic Coefficient

C = Basic Seismic Coefficient

Z = Zone factor

I = Importance factor

K = Structural performance factor

A_h = Design Horizontal Seismic Coefficient

S_a/g = Average Response Acceleration Coefficient

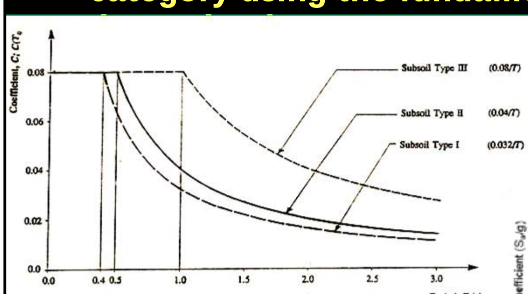
Z = Zone Factor

I = Importance factor

R = Response Reduction Factor

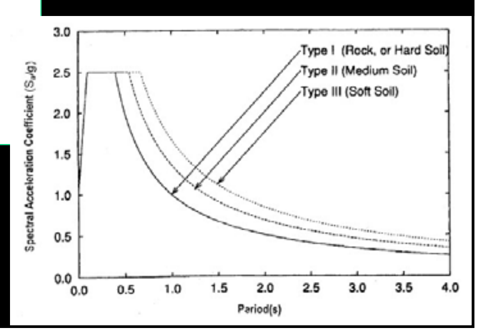
Basic Seismic Coefficient

- **The basic seismic coefficient, C & S_a/g, shall be determined from for the appropriate site subsoil category using the fundamental time period**



NBC 105

IS 1893: 2002



Period of Vibration NBC 105

- The periods of vibration, T_i, shall be established from properly substantiated data, or computation, or both
- Where the Seismic Coefficient Method is used, the fundamental translation period in the direction under consideration, T_1, shall be determined from
  - $T_1 = 2\pi \sqrt{(\Sigma W_i d_i^2 / g \Sigma F_i d_i)}$
- For the purposes of initial member sizing, the following approximate formulae for T_i may be used
  - $T_1 = 0.085\ H^{3/4}$ for steel frames
  - $T_1 = 0.06\ H^{3/4}$ for concrete frames
  - $T_1 = 0.09H / \sqrt{D}$ For other structures

If T_1 calculated using these equations is greater than 120 percent of that finally calculated using Equation, the seismic forces shall be re-assessed.

Period of Vibration IS1893

- **Approximate fundamental Natural Period T_a**
  - **$T_a = 0.075\ H^{0.75}$ for steel frames (NBC=0.085 $H^{3/4}$)**
  - **$T_a = 0.085\ H^{0.75}$ for concrete frames (NBC= 0.06 $H^{3/4}$)**
  - **$T_a = 0.09H / \sqrt{D}$ For other structures (NBC= 0.09H / $\sqrt{D}$)**

h = Height of building, in m. This excludes the basement story, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement story, when they are not so connected.

d= Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force

Site Subsoil Category

- Type I: Rock or Stiff Soil Sites
  - ✓ Sites with bedrock, including weathered rock with an unconfined compression strength greater than 500kPa, overlain by less than 20 m
  - ✓ very stiff cohesive material with an unconfined compression strength greater than 100 kPa, or
  - ✓ very dense cohesion less material with $N > 30$, where N is the standard penetration (SPT) value
  - ✓ Such sites will typically have a low amplitude natural period of less than 0.2 s

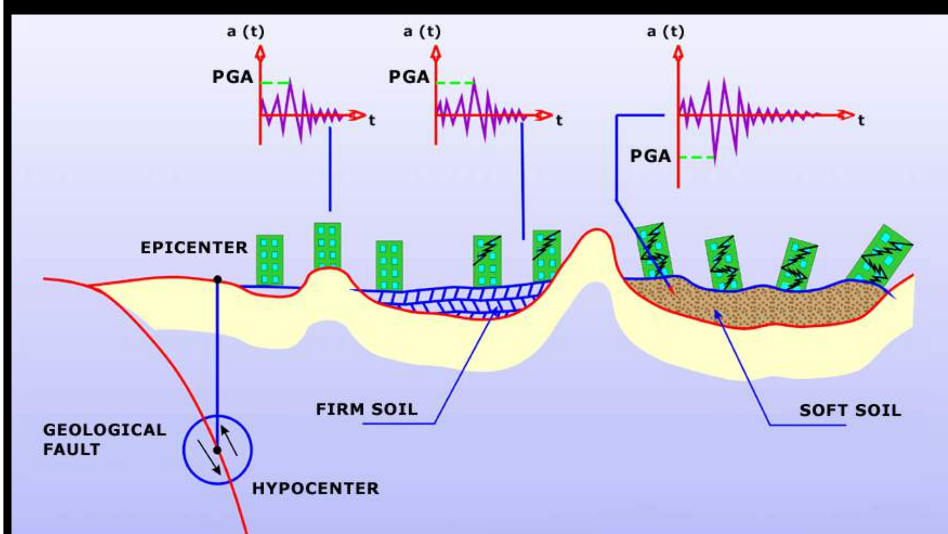
Site Subsoil Category

- Type II: Medium Soil Sites
  – Sites not described as either Type I or Type III

Site Subsoil Category

- Type III: Soft Soil Sites

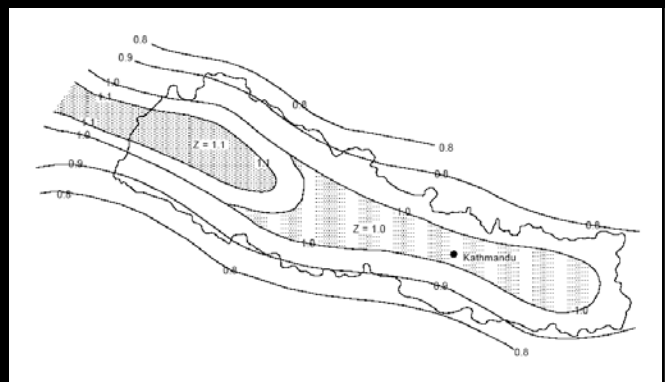
Cohesive Soil Classification	Representative undrained shear strength (kPa)	Minimum Depth of Soil (m)
Soft	12.5 - 25	20
Firm	25 - 50	25
Stiff	50 - 100	40
Very Stiff	100 - 200	60



Seismic Zoning Factor

- The seismic zoning factor, Z, shall be obtained from Figure for the appropriate location

NBC 105



IS 1893: 2002

Seismic Zone	II	III	IV	V
Z	0.10	0.16	0.24	0.36

Importance Factor (I)

NBC 105

Type of Building	Importance Factor
(a) Monumental Buildings	1.5
(b) Essential facilities that should remain functional after an earthquake	1.5
(c) Distribution facilities for gas or petroleum products in urban areas.	2.0
(d) Structures for the support or containment of dangerous substances (such as acids, toxic substances, etc.).	2.0
(e) Other structures	1.0

IS 1893: 2002

Type of Building	Importance Factor
Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
Other Buildings	1.0

Governing Factor for I

- Functional Use of Structure
- Hazardous consequence of its failure
- Post earthquake functional needs
- Historical Value
- Economic Importance

Structural Performance Factor

- **The minimum permissible value of the structural performance factor, K, and associated detailing requirements**

Item	Structural Type	Minimum Detailing Requirements	K
1.(a)	Ductile moment-resisting frame	Must comply with the detailing for ductility requirements of IS4326 and for steel frames, the additional requirements of NBC 111-94	1.00
(b)	Frame as in 1(a) with reinforced concrete shear walls	For frames : as for 1(a). Reinforced concrete shear walls must comply with appropriate3detailing for ductility requirements.	1.00
2.(a)	Frame as in 1(a) with either steel bracing members detailed for ductility or reinforced concrete infill panels	For frames : as for 1(a). Steel bracing members must comply with the detailing for ductility requirements NBC 111-94. Reinforced concrete infill panels must comply with the detailing requirements of NBC 109-94.	1.50

Structural Performance Factor

Item	Structural Type	Minimum Detailing Requirements	K
(b)	Frame as in 1(a) with masonry infills	Must comply with the detailing for ductility requirements of: IS 4326	2.00
3	Diagonally-braced steel frame with ductile bracing acting in tension only	Must comply with the detailing for ductility requirements of Nepal Steel Construction Standard	2.00
4	Cable-stayed chimneys	Appropriate materials Standard	3.00
5	Structures of minimal ductility including reinforced concrete frames not covered by 1 or 2 above, and masonry bearing wall structures.	Appropriate materials Standard	4.00

Response Reduction Factor

Building Frame Systems	**R**
Ordinary RC moment-resisting frame (OMRF)	3
Special RC moment-resisting frame (SMRF)	5
Steel frame with	
a) Concentric braces	4
b) Eccentric braces	5
Steel moment resisting frame designed as per SP 6	5
Load bearing masonry wall buildings)	
a) Unreinforced	1.5
b) Reinforced with horizontal RC bands	2.5
c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and jambs of openings	3
Ordinary reinforced concrete shear walls	3
Ductile shear walls	4
Ordinary shear wall with OMRF	3
Ordinary shear wall with SMRF	4
Ductile shear wall with OMRF	4.5
Ductile shear wall with SMRF	5

Governing Factor for K or R

- Over Strength
- Ductility
- Redundancy

Distribution of EQ Load

Distribution of Story Shears into different frames

- Frame forces proportional to the stiffness of the frames
- Additional forces due to torsional effects
  - Eccentricity – difference in center of mass and center of rigidity

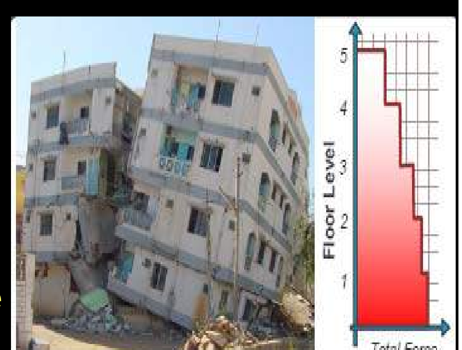


Figure 1: Total horizontal earthquake force in a building increases downwards along its height.

Distribution of Base Shear

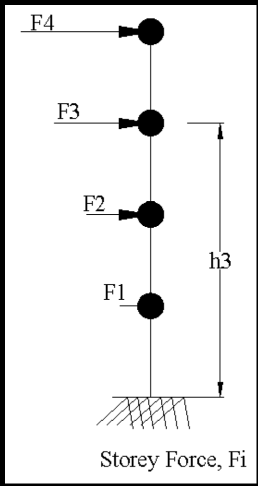
- Design Seismic Force at each level i

NBC 105

$$F_i = V \frac{W_i h_i}{\Sigma W_i h_i}$$

IS 1893: 2002

$$F_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}$$



Where h_i = floor height

Load Combination NBC105

Design Method	Combination
Working Stress Method	*DL + LL ± E* *0.7 DL ± E* *DL +SL ± E*
Limit State Method	*DL + 1.3 LL ± 1.25 E* *0.9 DL ± 1.25 E* *DL + 1.3 SL ± 1.25 E*

Load Combination IS1893

$1.5DL + 1.5\ LL$
$1.2DL + 1.2\ LL \pm 1.2\ E$
$1.5\ DL \pm 1.5\ E$
$0.9\ DL \pm 1.5\ E$

Thank You !!!