Lecture 09

Introduction to Earthquake Resistant Design of RC Structures

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- Earthquakes and Their Effects on Buildings
- Seismic Loading Criteria
- Load Combinations
- Gravity vs. Earthquake Loading
- Seismic Design Requirements for RC Buildings
- Introduction to BCP 2021
- References
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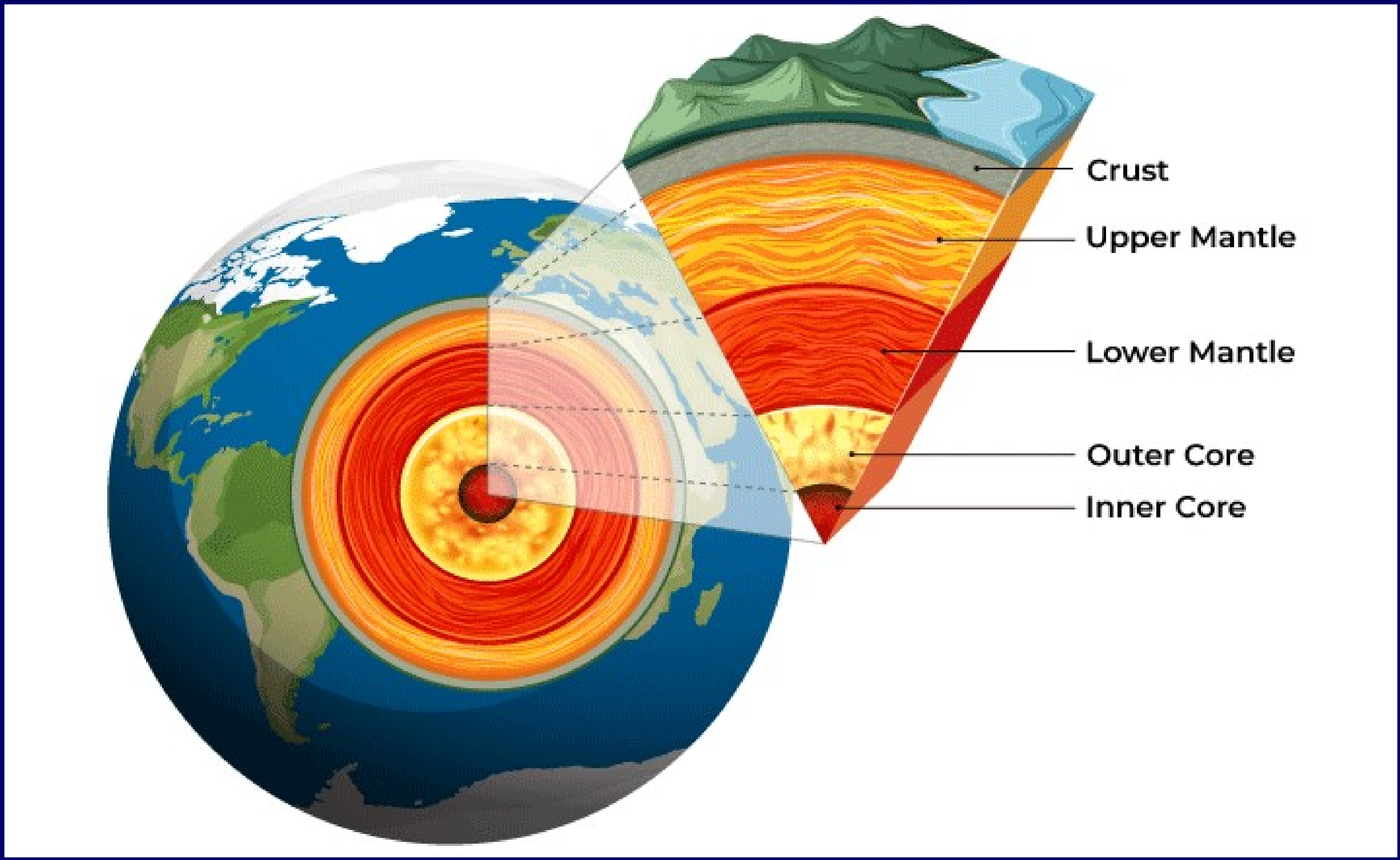
Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Describe*** the impact of earthquake loading on buildings, earthquake design philosophy and seismic loading criteria.
  - ***Calculate*** base shear using static lateral force procedures.
  - ***Analyze*** RC frames for seismic loads using the portal frame method.
  - ***Apply*** load combinations for the design of RC buildings.
  - ***Understand*** how seismic zones influence a structure's behavior.

Earthquakes and Their Effects on Buildings

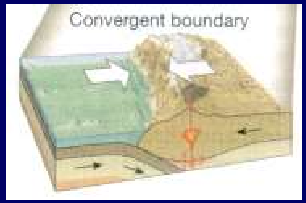
❑ The Earth's Interior

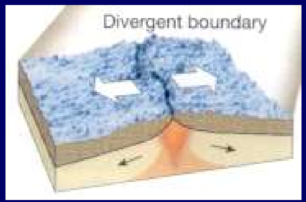


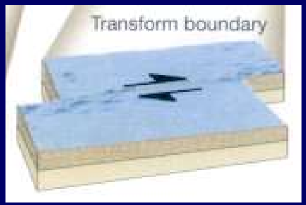
Earthquakes and Their Effects on Buildings

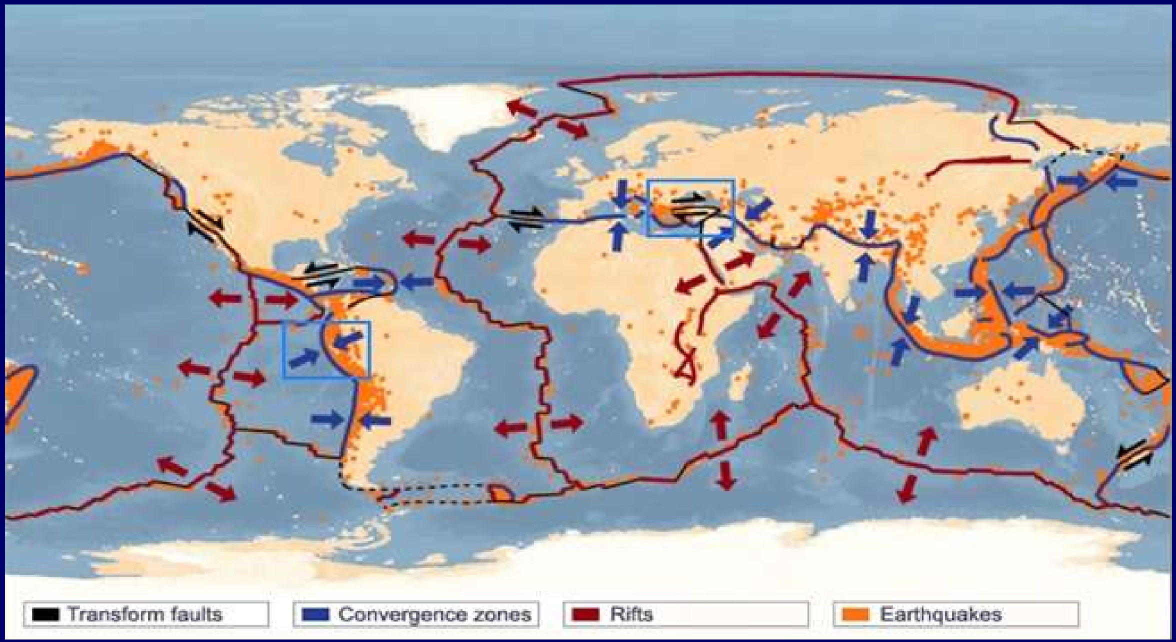
❑ The Earth's Interior

- Earthquake results from the sudden movement of the tectonic plates in the earth's crust.





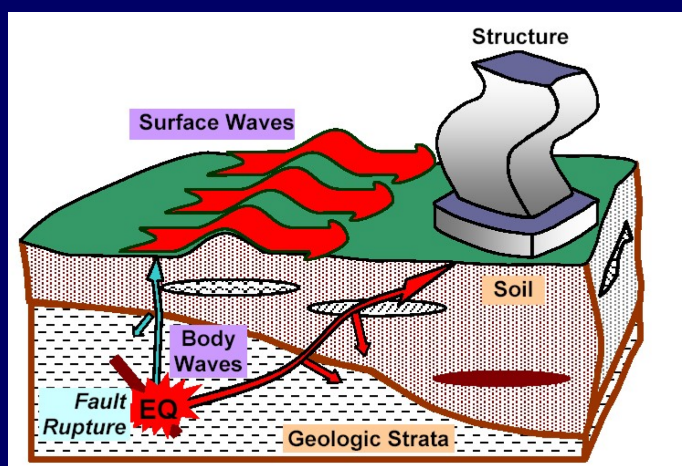


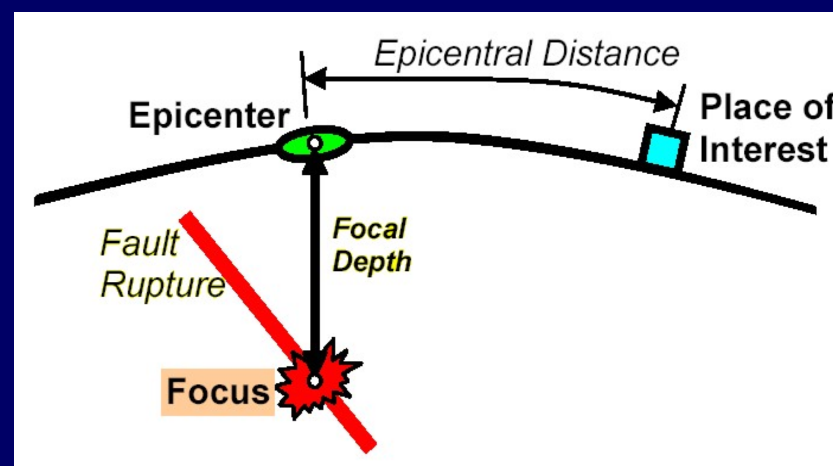


Earthquakes and Their Effects on Buildings

❑ Effect of Earthquake

- The movement, taking place at the fault lines, causes energy release which is transmitted through the earth in the form of waves.
- These waves reach the structure causing shaking.

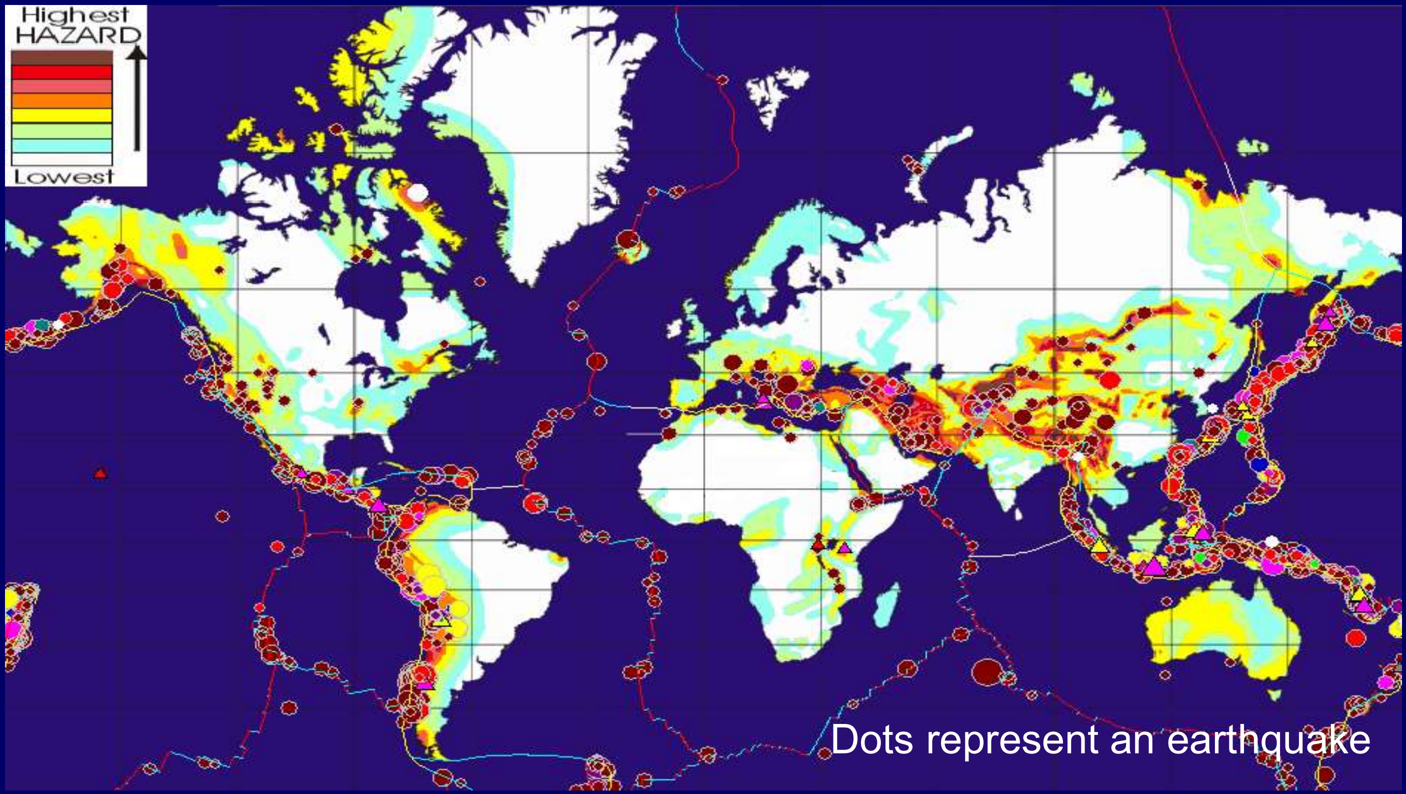




Earthquakes and Their Effects on Buildings

Seismic Events

- Seismic events around the globe are shown below
- These events mostly take place at boundaries of Tectonic plates



Earthquakes and Their Effects on Buildings

- Displacement due to Earthquake

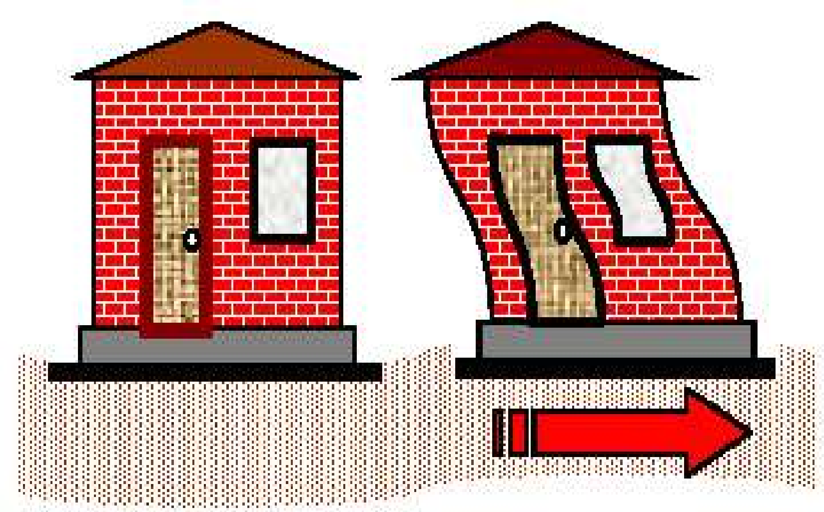


Figure 1: Effect of Inertia in a building when shaken at its base

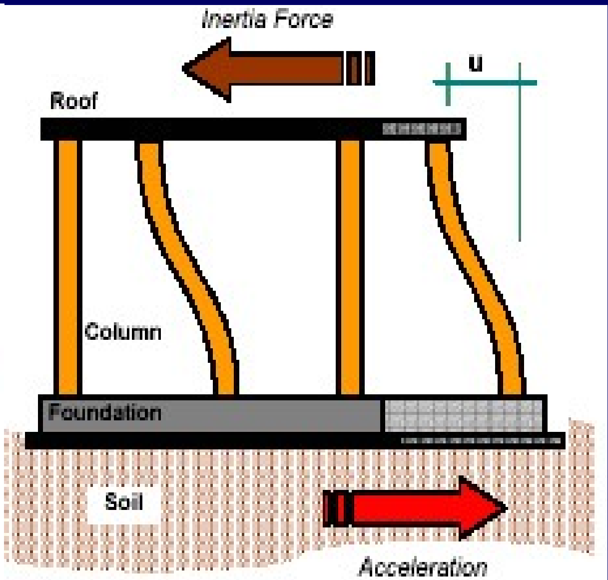


Figure 2: Inertia force and relative motion within a building

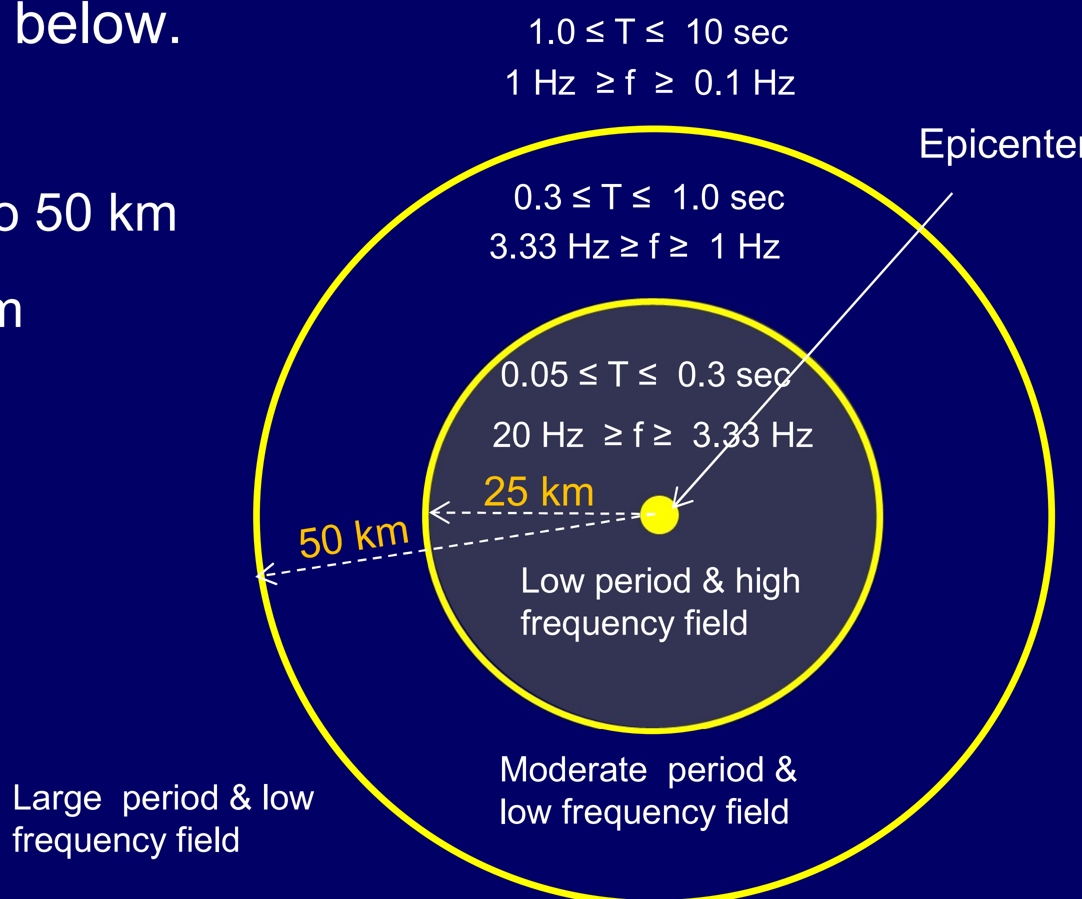
Earthquakes and Their Effects on Buildings

Horizontal and Vertical Shaking

- Earthquake causes shaking of the ground in all three directions.
- The structures designed for gravity loading (DL+LL) will be normally safe against vertical component of ground shaking.
- The vertical acceleration during ground shaking either adds to or subtracts from the acceleration due to gravity.
- The structures are normally designed for horizontal shaking to minimize the effect of damages due to earthquakes.

Earthquakes and Their Effects on Buildings

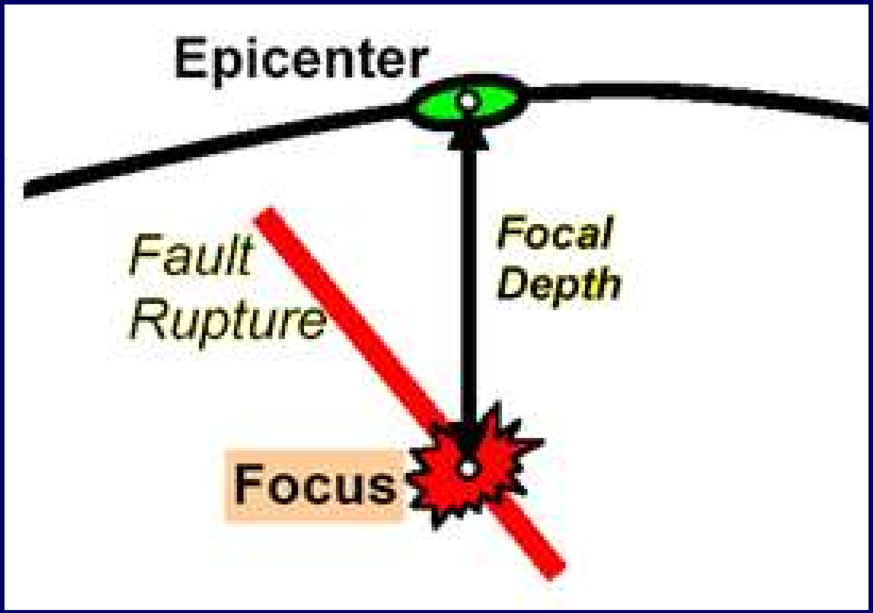
- **Earthquake characteristics**
- The characteristics of earthquake with respect to distance from the epicenter are shown below.
  1. Near Field: 0 to 25 km
  2. Intermediate Field: 25 to 50 km
  3. Far Field: Beyond 50 km



Earthquakes and Their Effects on Buildings

Types of earthquake based on focal depth

1. **Shallow earthquake:** Depth of focus varies between 0 and 70 km.
2. **Deep earthquake:** Depth of focus varies between 70 and 700 km.



Earthquakes and Their Effects on Buildings

Resonance risk for structures

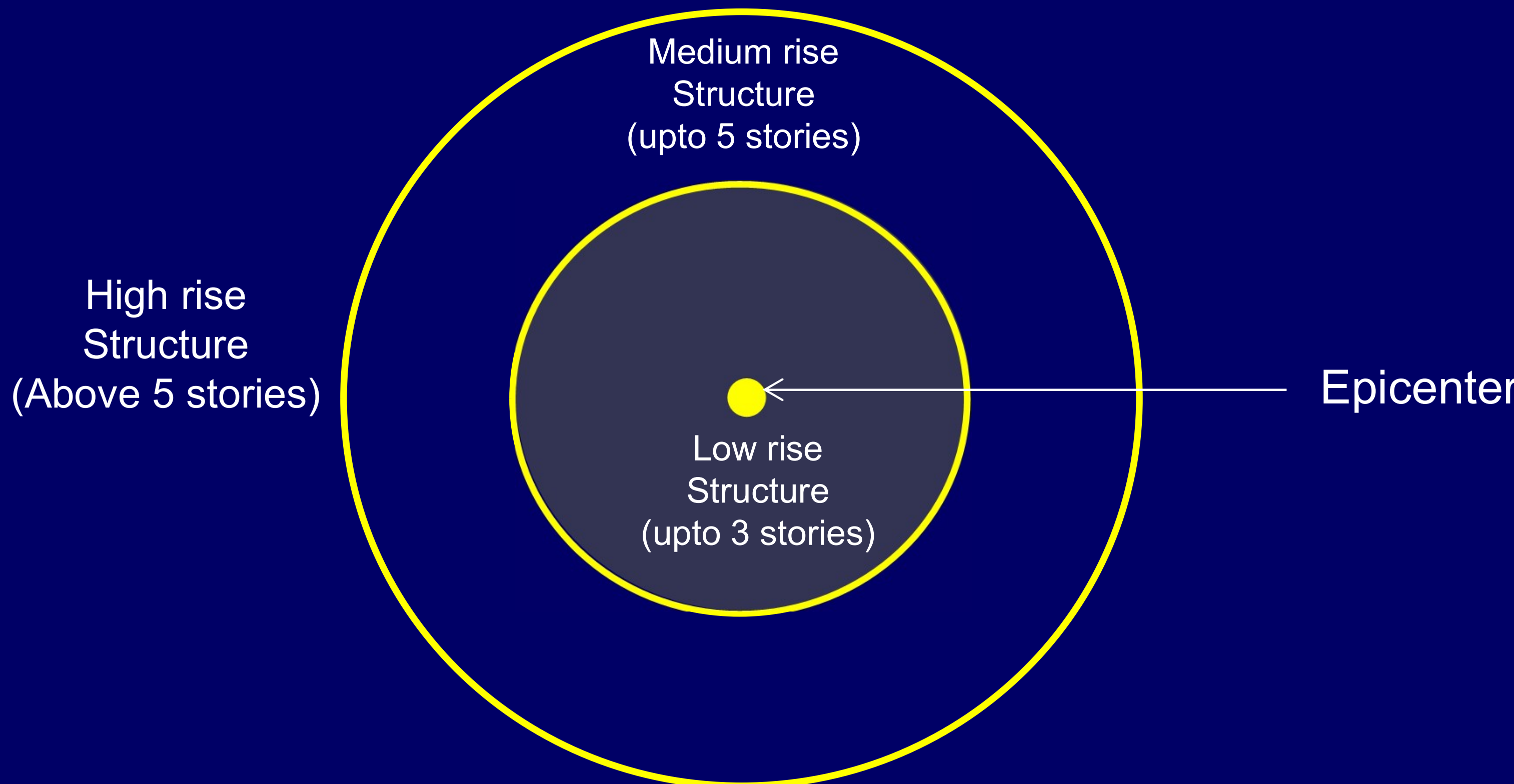
- The natural time period of a structure is its important characteristic to predict behavior during an earthquake of certain time period (Resonance phenomenon).
- For a particular structure, the natural time period is a function of mass and stiffness.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

- “T” can be roughly estimated from: T = 0.1 × number of stories

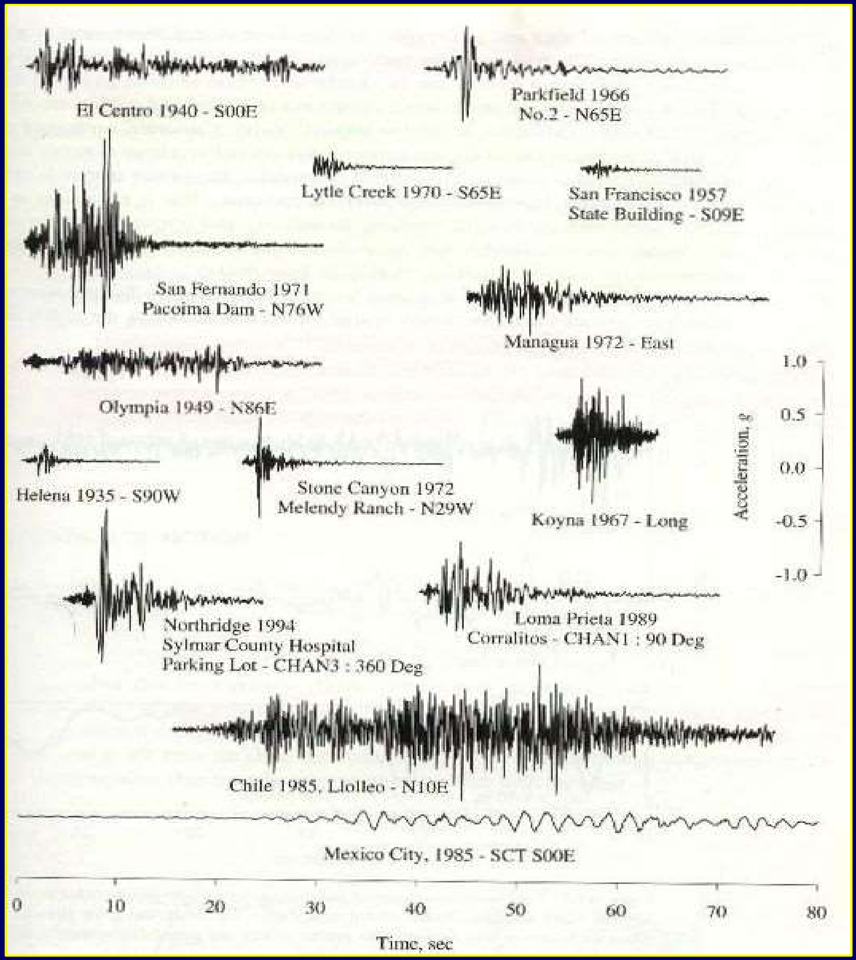
Earthquakes and Their Effects on Buildings

- **Resonance risk for structures near, intermediate and far field earthquakes**



Earthquakes and Their Effects on Buildings

- Earthquake Recording
  - Some Famous Earthquake Records



Earthquakes and Their Effects on Buildings

Importance of Architectural Features

- At the planning stage, architects and structural engineers must work together to ensure that the unfavorable features are avoided, and a good building configuration is chosen.

Earthquakes and Their Effects on Buildings

❑ Importance of Architectural Features

- The behavior of a building during earthquakes depend critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground.

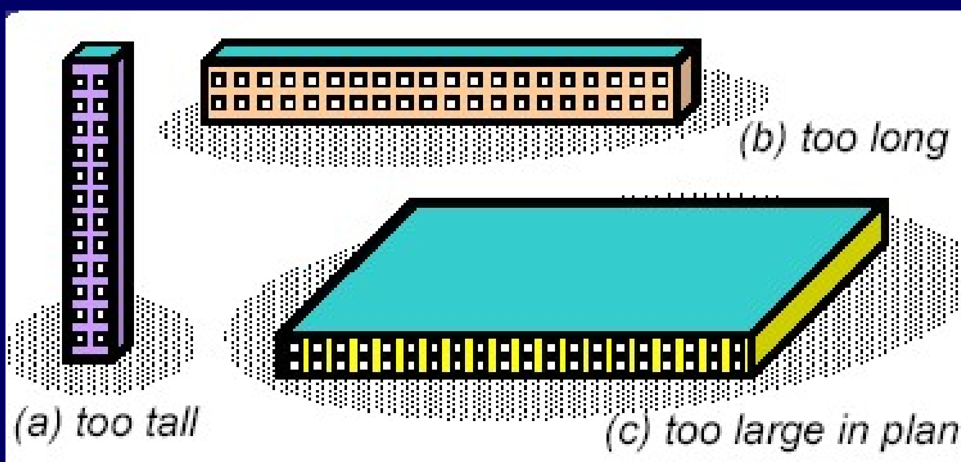


Figure 1: Buildings with one of their overall sizes much larger or much smaller than the other two, do not perform well during earthquakes.

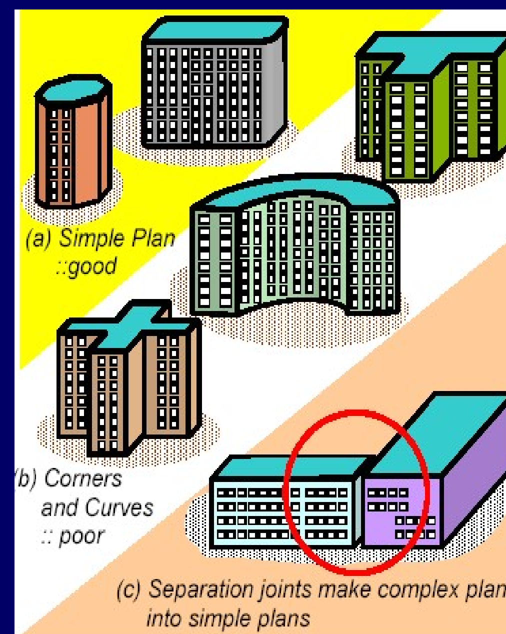
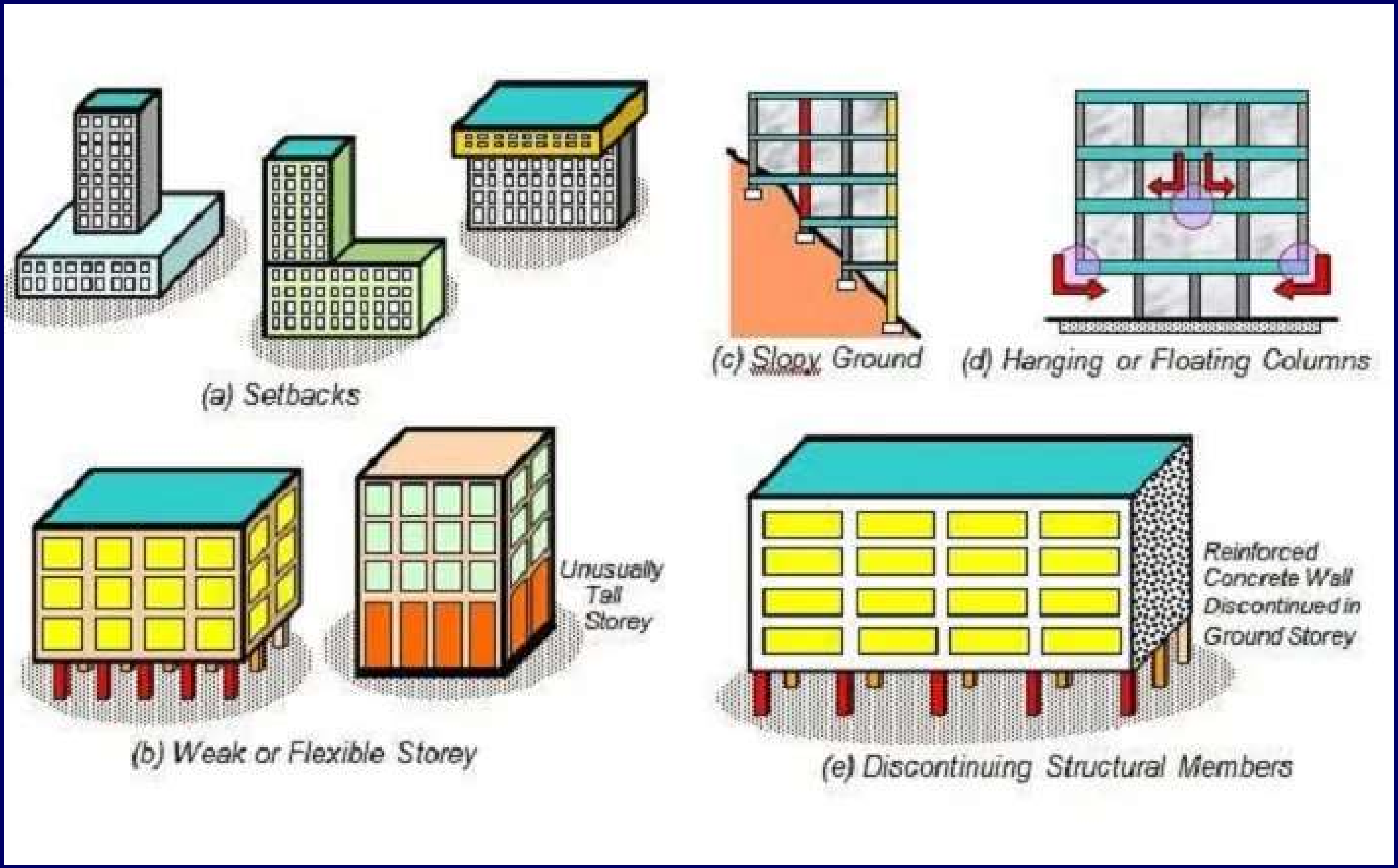


Figure 2: Simple plan shape buildings do well during earthquakes.

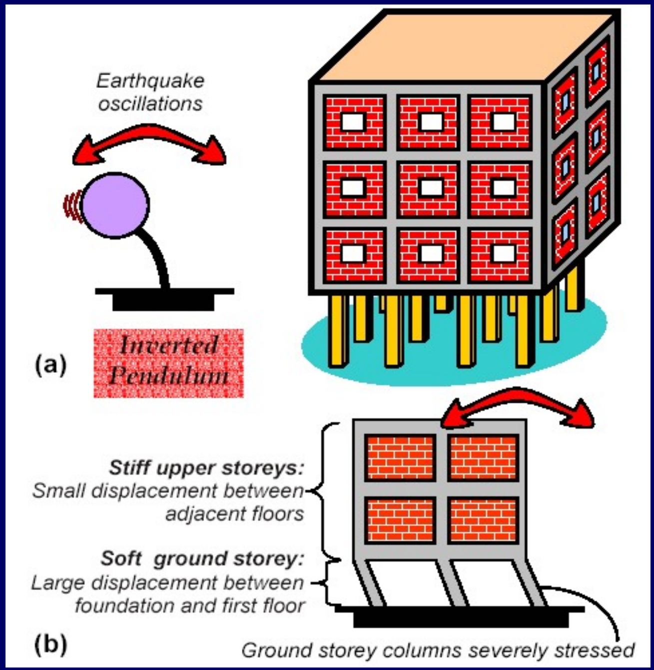
Earthquakes and Their Effects on Buildings

❑ Other Undesirable Scenarios



Earthquakes and Their Effects on Buildings

❑ Other Undesirable Scenarios



Earthquakes and Their Effects on Buildings

Earthquake Design Philosophy

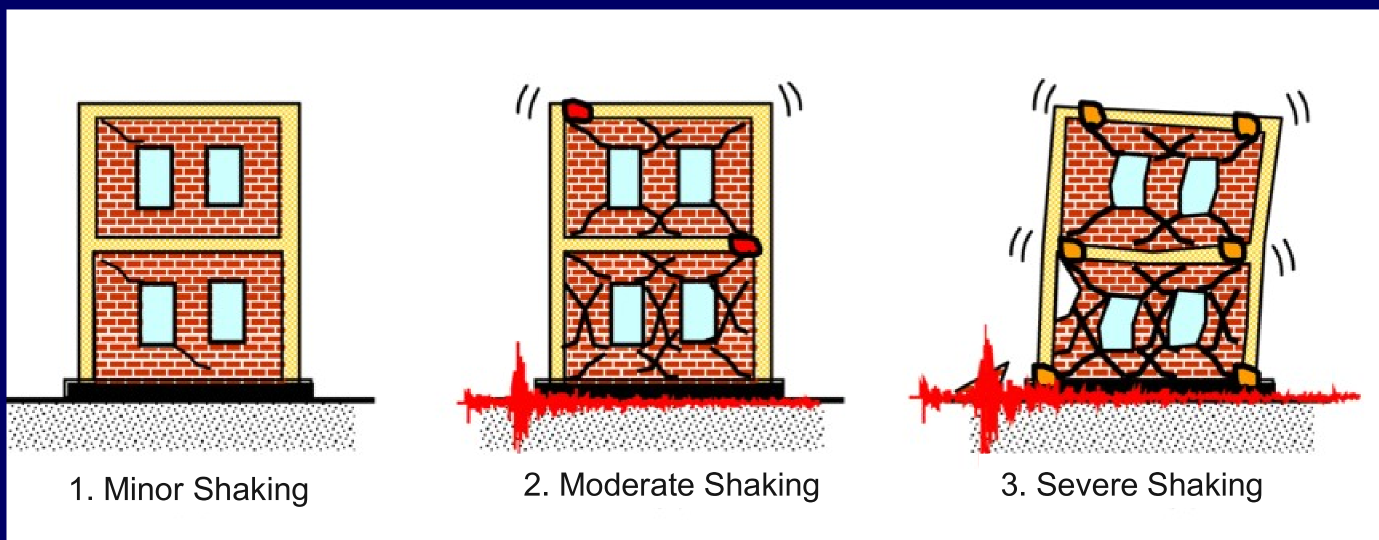
- Designing buildings to respond elastically to earthquakes without suffering any damage might be highly uneconomical.
- Hence, the design philosophy for earthquake resistant design is:

" To permit controlled damage in order to make the structure economically viable"

Earthquakes and Their Effects on Buildings

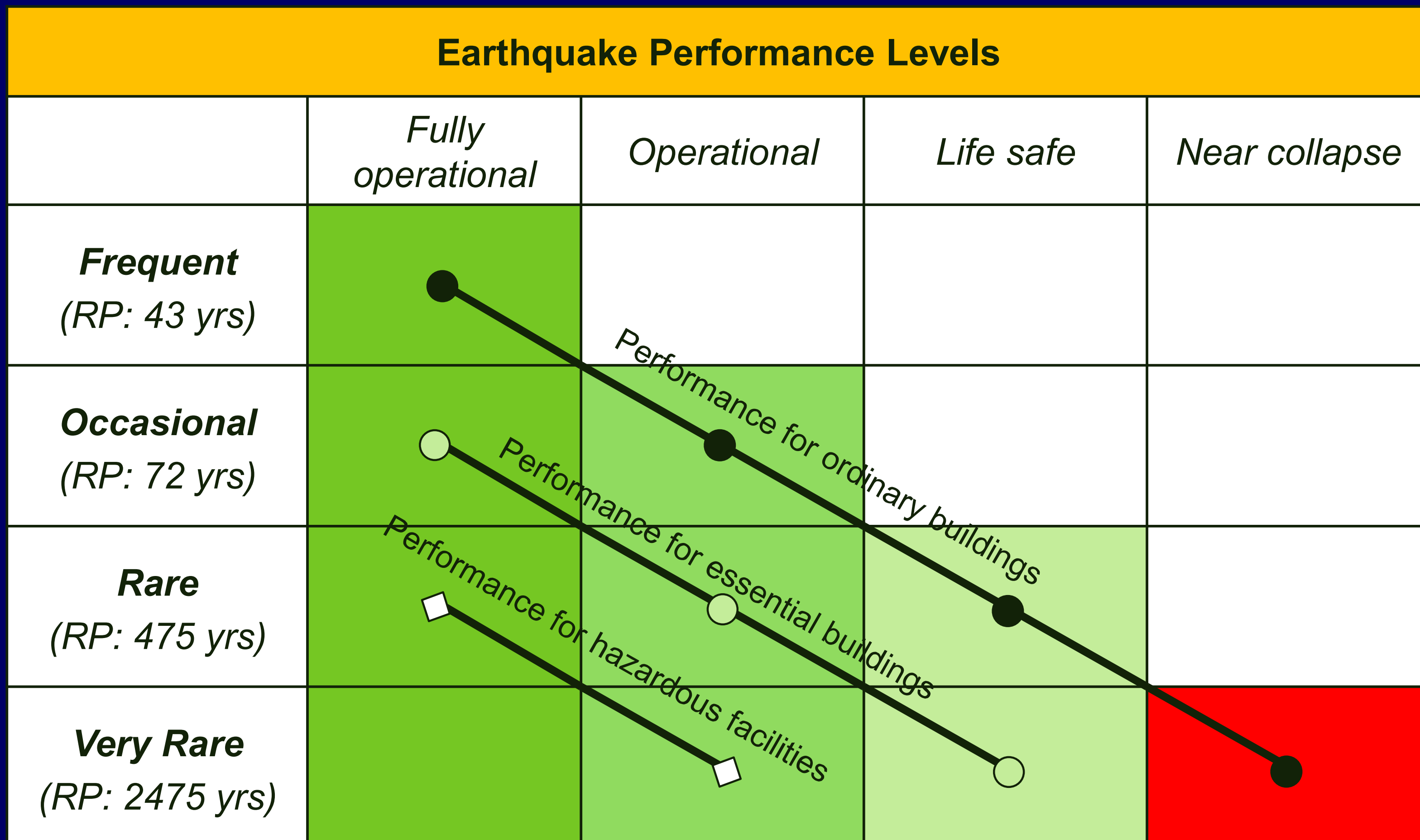
❑ Earthquake Design Philosophy

- Buildings should be able to resist;
  1. Minor Shaking with No/unnoticeable damage
  2. Moderate Shaking with Minor to moderate structural damage
  3. Severe Shaking with Structural damage, but no collapse



Earthquakes and Their Effects on Buildings

❑ Structural Performance Objectives



The description of each performance level is provided next

Earthquakes and Their Effects on Buildings

❑ Structural Performance Objectives

Performance Level	Description (as per Vision 2000)
Fully Functional	No significant damage has occurred to structural and non-structural components. Building is suitable for normal intended occupancy and use.
Operational	No significant damage has occurred to structure, which retains nearly all its pre-earthquake strength and stiffness. Nonstructural components are secure, and most would function, if utilities available. Building may be used for intended purpose, albeit in an impaired mode.
Life Safe	Significant damage to structural elements, with substantial reduction in stiffness, however, margin remains against collapse. Nonstructural elements are secured but may not function. Occupancy may be prevented until repairs can be instituted.
Near Collapse	Substantial structural and nonstructural damage. Structural strength and stiffness substantially degraded. Little margin against collapse. Some falling debris hazards may have occurred.

Seismic Loading Criteria

Building Code of Pakistan

- Following the 2005 earthquake in Pakistan, the initial Building Code, BCP SP 2007, was developed, mostly adopting the Uniform Building Code 1997 (UBC 97) except for its seismic maps.
- Recently, this code has undergone a revision to BCP 2021, shifting from its previous alignment with UBC 97 to embracing the International Building Code 2021 (IBC 2021)
- We will proceed with BCP SP 2007 for now. Later, a brief introduction to BCP 2021 will be provided..

Seismic Loading Criteria

Seismic Loading Criteria in BCP SP 2007

Seismic Zones

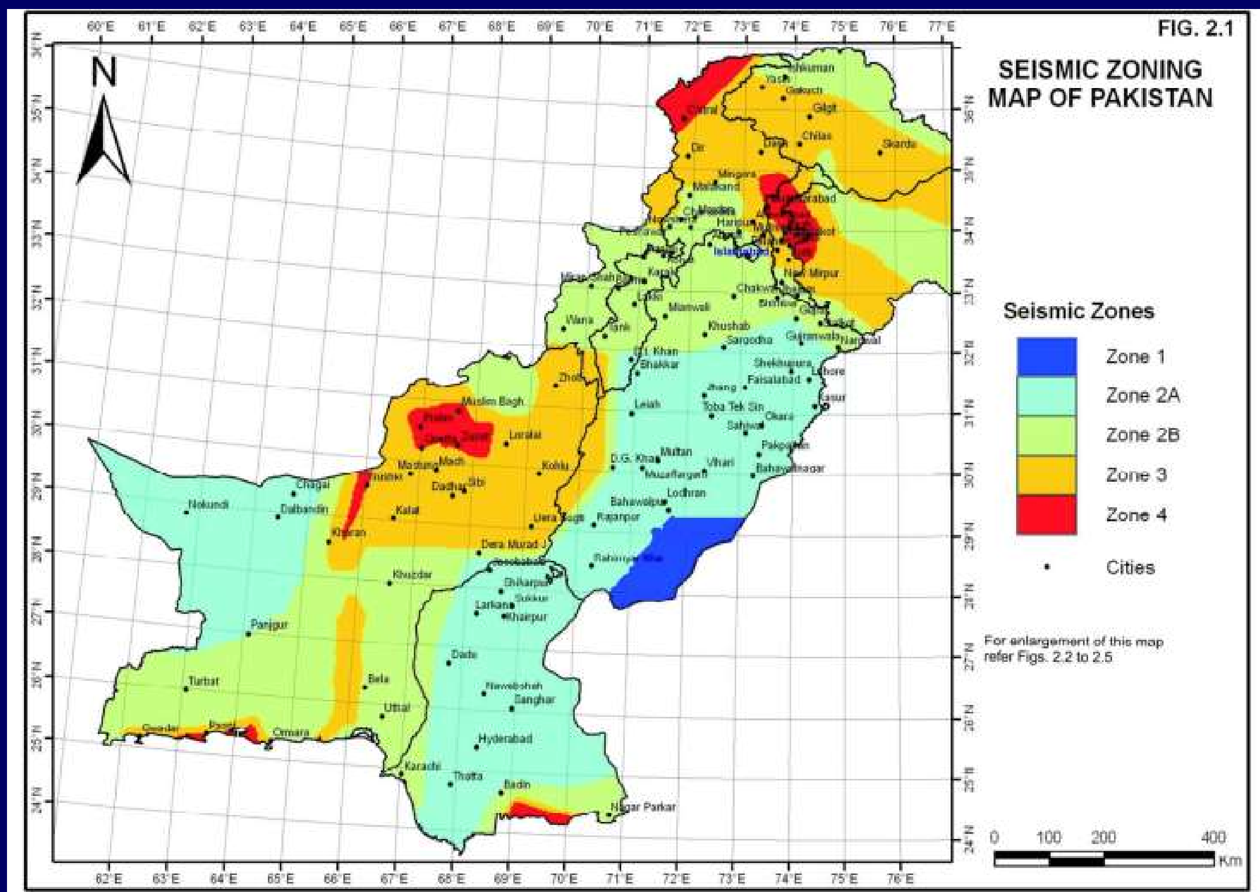
- According to BCP-SP 2007, Pakistan has been divided into five seismic zones. These zones are based on the peak ground acceleration ranges summarized in Table below.

S. No	Seismic Zones	Peak Horizontal Ground Acceleration
1	1	0.05 to 0.08g
2	2A	0.08 to 0.16g
3	2B	0.16 to 0.24g
4	3	0.24 to 0.32g
5	4	>0.32g

Where; g is the acceleration due to gravity

Seismic Loading Criteria

- ❑ **Seismic Loading Criteria in BCP SP 2007**
  - ❖ **Seismic Zones**



Seismic Loading Criteria

Seismic Loading Criteria in BCP SP 2007

Determination of Lateral Force

- The total design seismic force imposed by an earthquake on the structure at its base is referred to as base shear "V" .
- The design seismic force can be determined based on:

1. Dynamic Lateral Force Procedure (Sec. 5.31, BCP-2007)
   i. Time History Analysis.
   ii. Response Spectrum Analysis.
2. Equivalent Lateral Static Force Procedure (Sec. 5.30.2, BCP-2007)

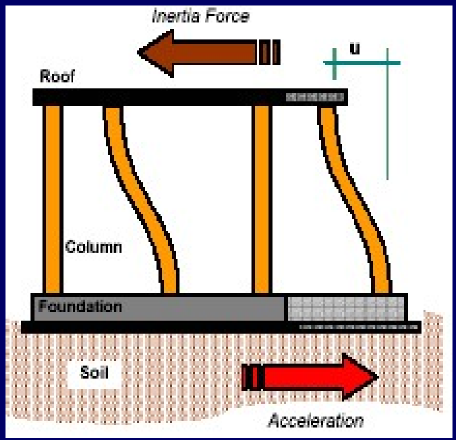
Seismic Loading Criteria

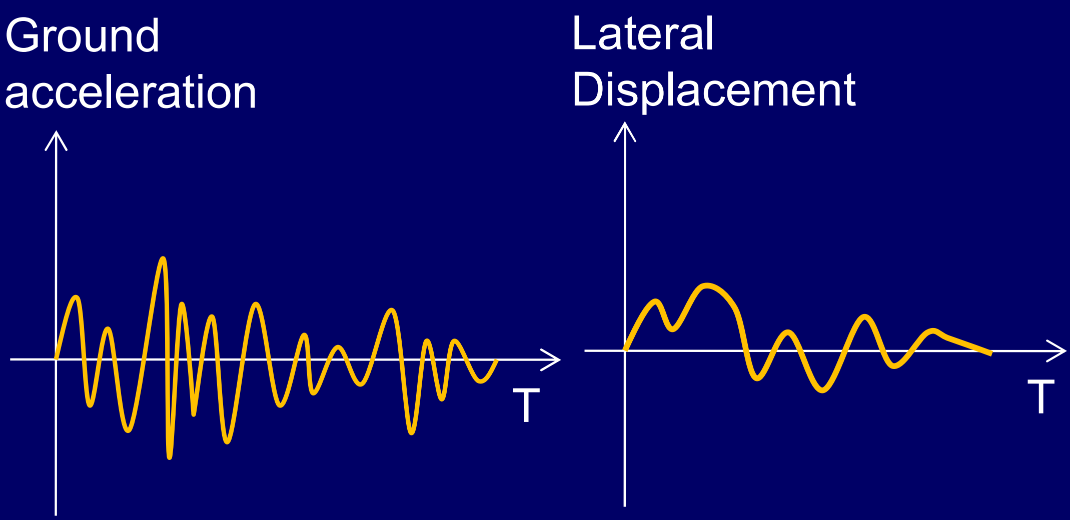
❑ Seismic Loading Criteria in BCP SP 2007

1. Dynamic Lateral Force Procedure

i. Time History Analysis

- It is the analysis of the dynamic response of a structure at each increment of time when the base is subjected to a specific ground motion time history



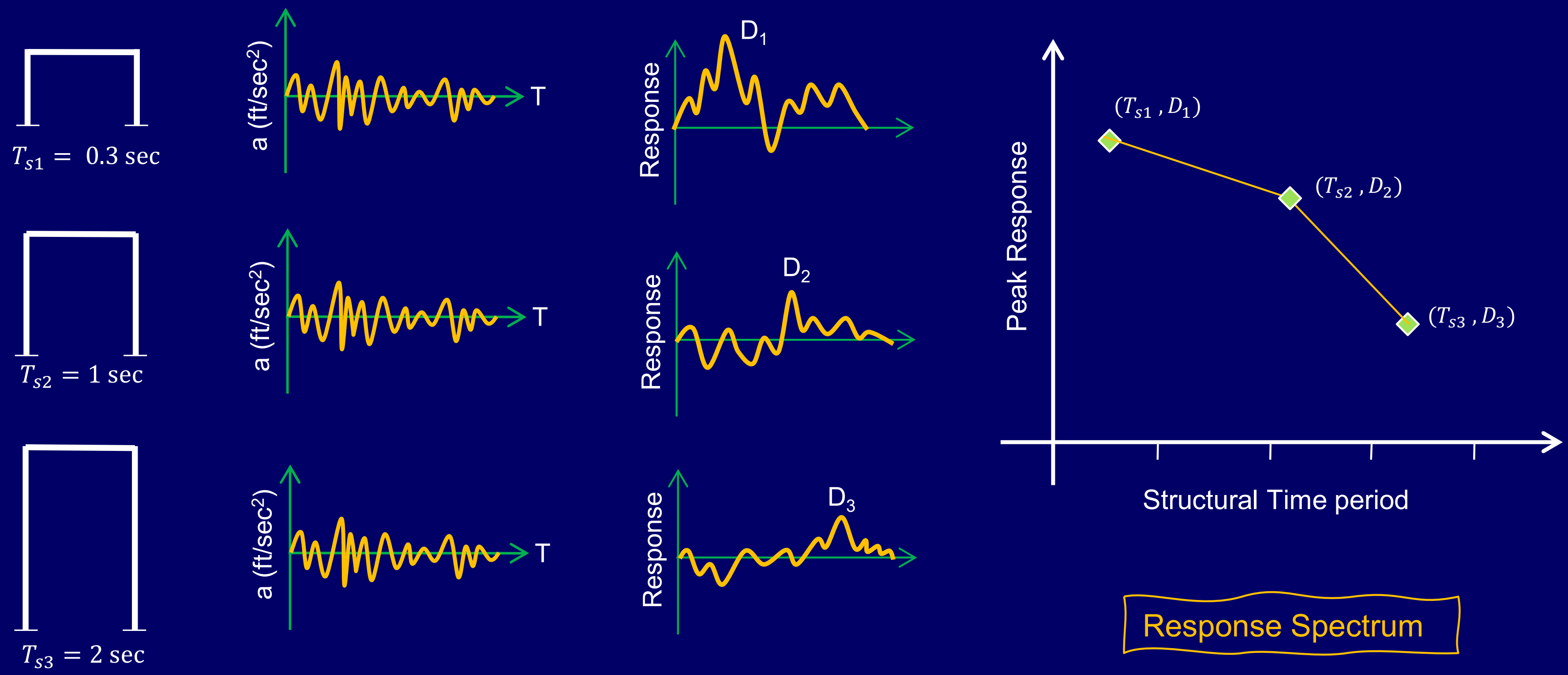


Seismic Loading Criteria

❑ Seismic Loading Criteria in BCP SP 2007

1. Dynamic Lateral Force Procedure

ii. Response Spectrum Analysis

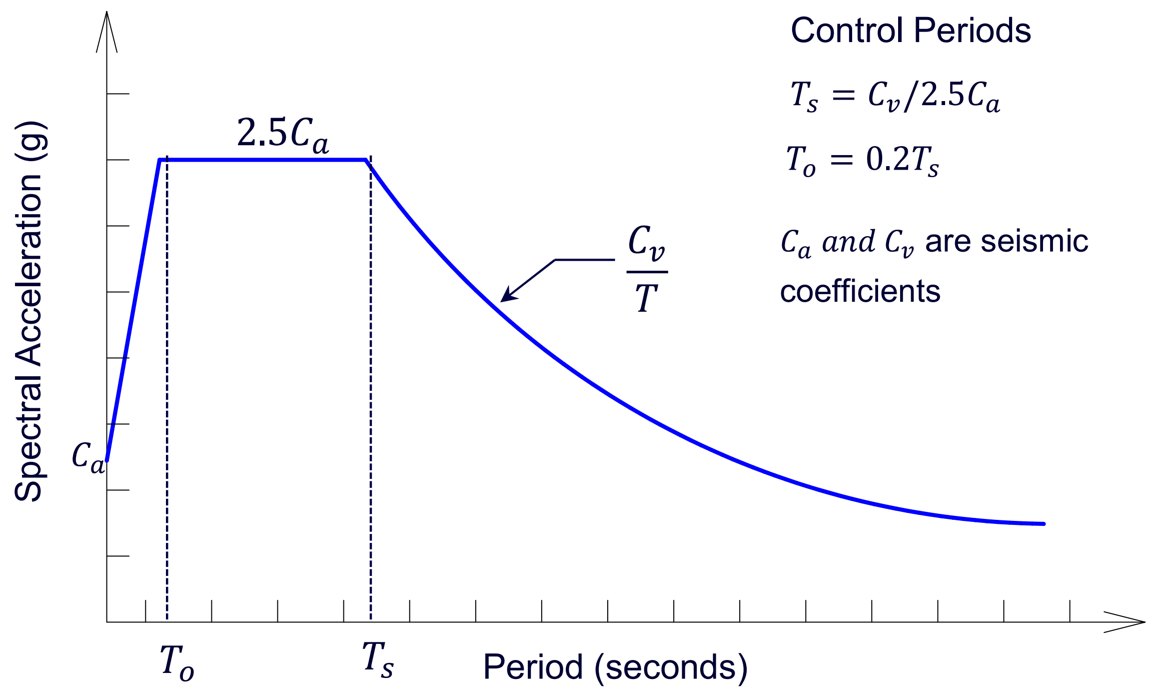


Seismic Loading Criteria

❑ Seismic Loading Criteria in BCP SP 2007

1. Dynamic Lateral Force Procedure

ii. Response Spectrum Analysis



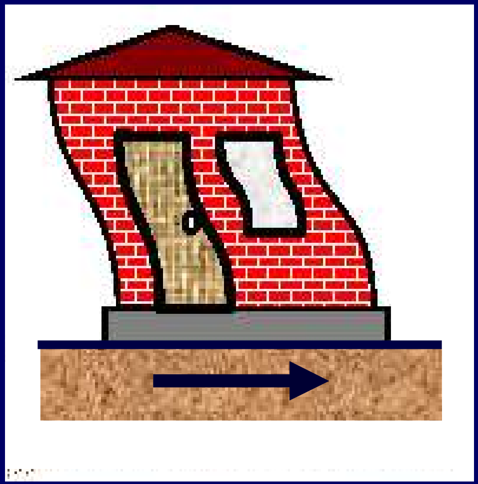
Response Spectra (BCP SP-2007)

Seismic Loading Criteria

❑ Seismic Loading Criteria in BCP SP 2007

2. Equivalent Lateral Static Force Procedure (5.30.2)

- The equivalent static lateral force method is a simplified technique to transform the effect of dynamic loading of an expected earthquake by a static force.



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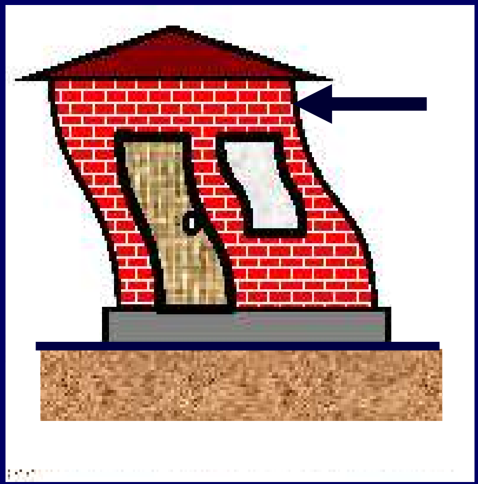


Seismic Loading Criteria

Seismic Loading Criteria in BCP SP 2007

Determination of Lateral Force (5.30.2)

- **Determination of Design Base Shear:** The total design base shear (V) can be determined from the following formula;

$$V = \frac{C_v I}{RT} W$$

Where;

These Tables are provided in Appendix

C_v = seismic coefficient (Table 5.16)

I = seismic importance factor (Table 5.10)

R = numerical coefficient representative of inherent over strength and global ductility capacity of lateral force-resisting systems (Table 5.13).

W = the total seismic dead load defined in Section 5.30.1.1

T = period of structure, can be determined in accordance with section 5.30.2.2

Seismic Loading Criteria

Seismic Loading Criteria in BCP SP 2007

Determination of Lateral Force (5.30.2)

- **Base Shear Limits**

$$V_{min} = 0.11 C_a I W$$

$$V_{max} = \frac{2.5 C_a I}{R} W$$

In addition, for seismic zone 4, the total base shear shall also not be less than ; $V = (0.8 Z N_v I / R) W$

Where; N_v = near source factor (Table 5.19)

Z = Seismic zone factor (Table 5.9)

Seismic Loading Criteria

❑ Seismic Loading Criteria in BCP SP 2007

❖ Determination of Lateral Force (5.30.2)

- **Vertical Distribution of Base Shear**

The force at a particular story level x of the structure is given by

$$F_x = (V - F_t)\frac{W_x h_x}{\sum W_i h_i}$$

Where;

- $F_t = 0.07\mathrm{TV} \leq 0.25V$ (may be considered as zero where $T < 0.7sec$)

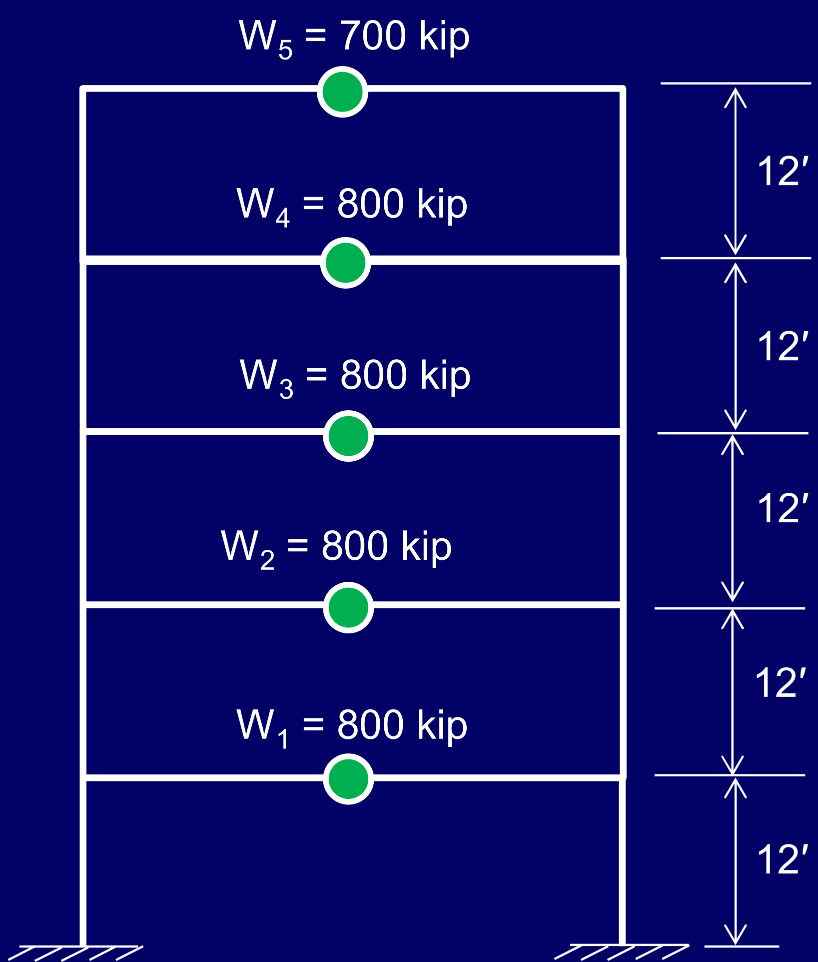
F_t is an additional concentrated force that is applied to the top level (i.e., the roof) in addition to the F_x force at that level.

Seismic Loading Criteria

Example 9.1

Given Data

- Structural system: SMF (concrete)
- Occupancy: Residential
- Site: Abbottabad, KP
- Soil Profile Type: S_D
- Number of stories: 5
- Story height: 12 ft. each



Required Data

a. Base Shear V as per BCP SP 2007

b. Story Forces, F_x

Seismic Loading Criteria

❑ Solution

❖ Determination of Base Shear

Using the relevant tables from the Appendix;

$Z = 0.3,$ soil: S_D , C_a = 0.36, C_v = 0.54, I = 1 and R = 8.5

$T_n = C_t(h_n)^{3/4} = 0.030(60)^{3/4}$ = 0.647 sec

$$V = \frac{C_v I}{RT} W = \frac{0.54 \times 1}{8.5 \times 0.647}(3900) = \mathbf{382.94}\ \text{kip}$$

$$V_{min} = 0.11 C_a I W = 0.11 \times 0.36 \times 1 \times 3900 = 154.44\ \text{kip}$$

$$V_{max} = \frac{2.5 C_a I W}{R} = \frac{2.5 \times 0.36 \times 1 \times 3900}{8.5} = 412.94\ \text{kip}$$

Seismic Loading Criteria

❑ Solution

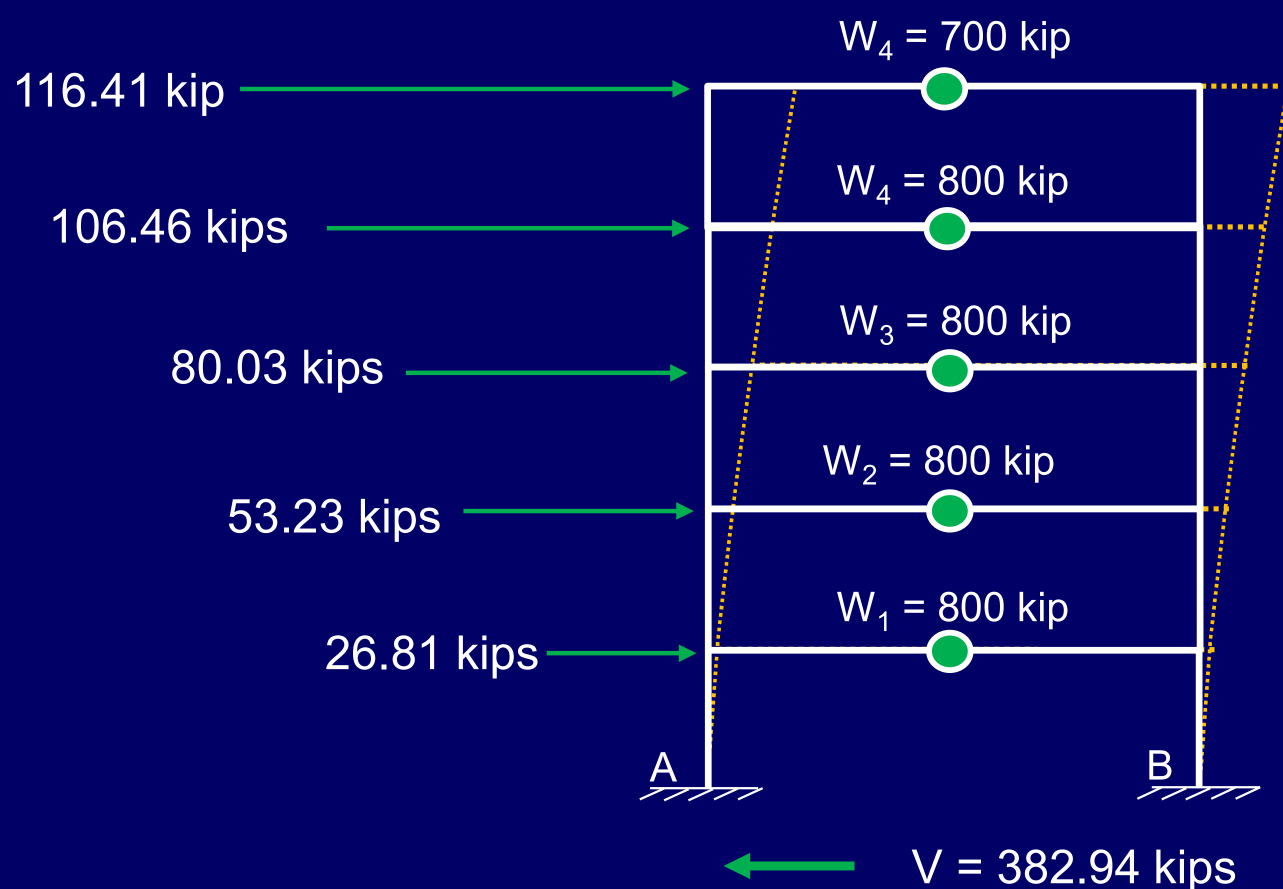
❖ Vertical Distribution of Base Shear

$Levels$	h_x (ft)	W_x (kips)	$W_x h_x$	$\frac{W_x h_x}{\sum W_i h_i}$	V (kips)	$F_x = V \frac{W_x h_x}{\sum W_i h_i} (kips)$
1	12	800.00	9600	0.070	382.94	26.81
2	24	800.00	19200	0.139	382.94	53.23
3	36	800.00	28800	0.209	382.94	80.03
4	48	800.00	38400	0.278	382.94	106.46
5	60	700.00	42000	0.304	382.94	116.41
		$\sum W_i h_i =$	**138000**	Check: $\sum F_x = V$; $382.94 = 382.94 \rightarrow OK!$		

Seismic Loading Criteria

❑ Solution

❖ Vertical Distribution of Base Shear



Load Combinations

Load Combinations in UBC 97 (16.12.2.1)

- UBC-97 adopts load combinations and strength reductions factors of ACI 318-99.

Load Combinations

- 1.4D
- 1.4D + 1.7L
- 1.1(1.2D + 0.5L+E)
- 1.1(0.9D + E)

Strength Reduction Factors

- Flexure: 0.9
- Shear: 0.85
- Compression:

  0.7 for tied and 0.75 for spiral

Where;

U = factored load , D = dead load, L = live load and

E = earthquake load (defined next).

Load Combinations

Load Combinations in UBC 97 (16.12.2.1)

Definition of E

- According to section 1630.1.1 of UBC-97 (section 5.30.1.1 of BCP SP-2007), *E* is given as:

$$E = \rho E_h + E_v$$

  - E_h = horizontal component of the earthquake load (story force)
  - E_v = vertical component of the earthquake ground motion = $0.5C_aID$
  - ρ = redundancy factor(defined in section 1630.1). In most cases, $\rho \approx 1$

- Putting the values of E_v and ρ , we get

$$E = E_h + 0.5C_aID$$

Load Combinations

Load Combinations in UBC 97 (16.12.2.1)

Definition of E

- Substituting value of E, the seismic load combinations become:

$$U = 1.1[1.2D + 0.5L \pm (E_h + 0.5C_a ID)] \quad \text{-------- (i)}$$

$$U = 1.1[0.9D + 0.5L \pm (E_h + 0.5C_a ID)] \quad \text{-------- (ii)}$$

- As the equations contain the C_a term that depends upon both seismic zone and soil type, unique load combinations will be produced for various seismic zones and various soil types within the same zone.

Load Combinations

- **Load Combinations in UBC 97 (16.12.2.1)**
  - **Seismic Load Combo Set**
    - For a given seismic zone, occupancy category, and soil type, each equation produces eight unique load combinations, resulting in a set comprising a total of 16 combinations as illustrated next.

Load Combinations

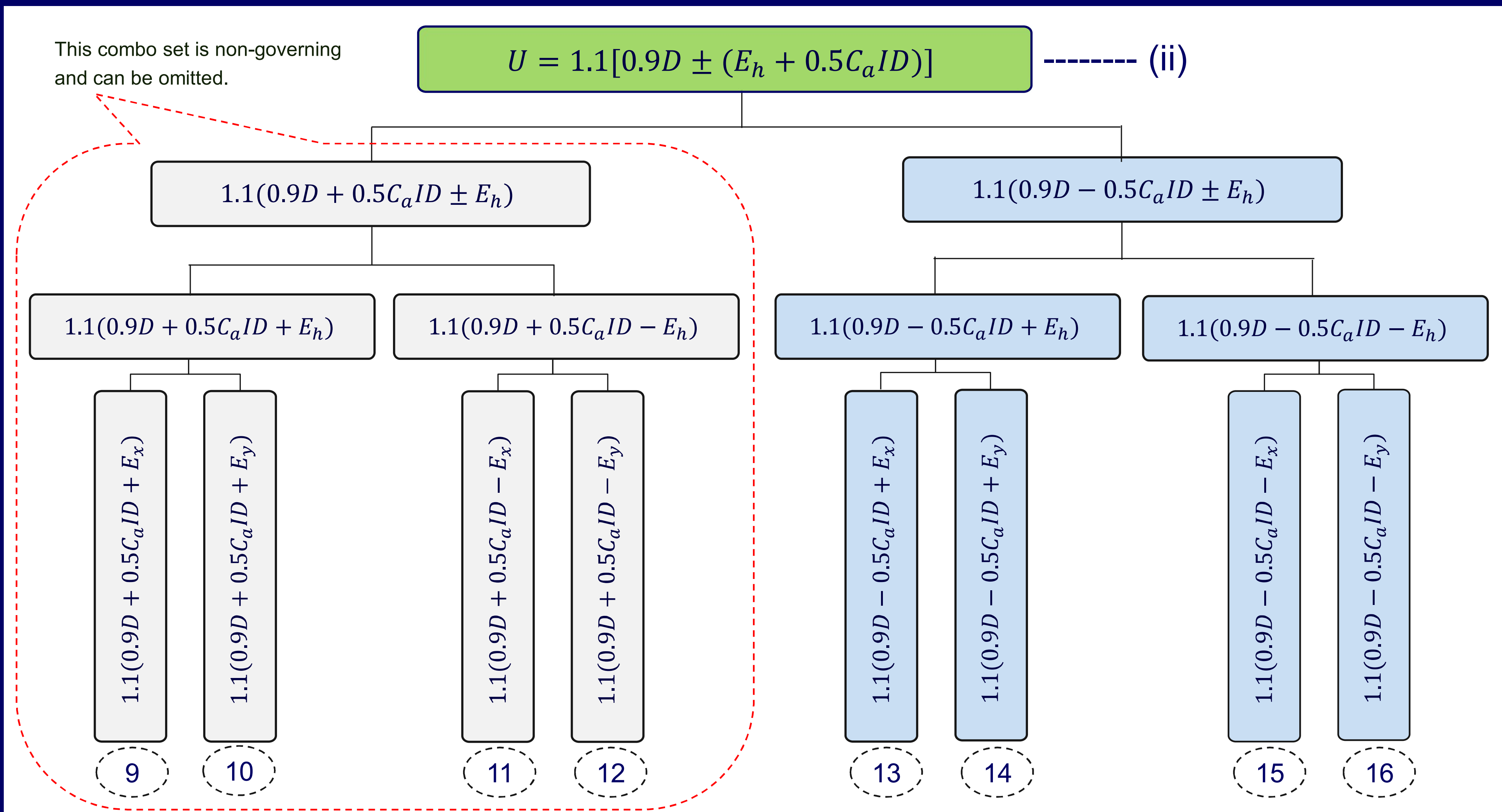
❑ Load Combinations in UBC 97 – Seismic Load Combo Set

$$U = 1.1[1.2D + 0.5L \pm (E_h + 0.5C_aID)]$$ -------- (i)

- $1.1(1.2D + 0.5C_aID + 0.5L \pm E_h)$
  - $1.1(1.2D + 0.5C_aID + 0.5L + E_h)$
    - (1) $1.1(1.2D + 0.5C_aID + 0.5L + E_x)$
    - (2) $1.1(1.2D + 0.5C_aID + 0.5L + E_y)$
  - $1.1(1.2D + 0.5C_aID + 0.5L - E_h)$
    - (3) $1.1(1.2D + 0.5C_aID + 0.5L - E_x)$
    - (4) $1.1(1.2D + 0.5C_aID + 0.5L - E_y)$
- $1.1(1.2D - 0.5C_aID + 0.5L \pm E_h)$
  - $1.1(1.2D - 0.5C_aID + 0.5L + E_h)$
    - (5) $1.1(1.2D - 0.5C_aID + 0.5L + E_x)$
    - (6) $1.1(1.2D - 0.5C_aID + 0.5L + E_y)$
  - $1.1(1.2D - 0.5C_aID + 0.5L - E_h)$
    - (7) $1.1(1.2D - 0.5C_aID + 0.5L - E_x)$
    - (8) $1.1(1.2D - 0.5C_aID + 0.5L - E_y)$

Load Combinations

❑ Load Combinations in UBC 97 – Seismic Load Combo Set



Load Combinations

Example 9.2

- ***Produce*** seismic load combinations for a residential building located in Peshawar having foundation on a hard soil.

Table 5.16 —Seismic Coefficients C_a

Soil Profile Type	Seismic Zone Factor, Z				
	Z = 0.075	*Z = 0.15*	*Z = 0.20*	*Z = 0.3*	*Z = 0.4*
S_A	0.06	0.12	0.16	0.24	$0.32N_a$
S_B	0.08	0.15	0.20	0.30	$0.40N_a$
S_C	0.09	0.18	0.24	0.33	$0.40N_a$
S_D	0.12	0.22	0.28	0.36	$0.44N_a$
S_E	0.19	0.30	0.34	0.36	$0.36N_a$
S_F	See Footnote 1				

Load Combinations

❑ Solution

For Peshawar which lies in zone 2B, Z = 0.20

Soil type : S_D (hard/stiff soil)

$C_a = 0.28$ (from Table 5.16 against Z = 0.20)

Seismic importance factor, $I = 1$ (for residential building)

Upon substituting the values of I and C_a, the resulting seismic load combinations are presented in the following slides.

Load Combinations

Solution

S. No.	$U = 1.1[1.2D + 0.5L \pm (E_h + 0.5C_aID)]$	
1	$1.1(1.2D + 0.5C_aID + 0.5L + E_x)$	$1.474D + 0.55L + 1.1E_x$
2	$1.1(1.2D + 0.5C_aID + 0.5L + E_y)$	$1.474D + 0.55L + 1.1E_y$
3	$1.1(1.2D + 0.5C_aID + 0.5L - E_x)$	$1.474D + 0.55L - 1.1E_x$
4	$1.1(1.2D + 0.5C_aID + 0.5L - E_y)$	$1.474D + 0.55L - 1.1E_y$
5	$1.1(1.2D - 0.5C_aID + 0.5L + E_x)$	$1.166D + 0.55L + 1.1E_x$
6	$1.1(1.2D - 0.5C_aID + 0.5L + E_y)$	$1.166D + 0.55L + 1.1E_y$
7	$1.1(1.2D - 0.5C_aID + 0.5L - E_x)$	$1.166D + 0.55L - 1.1E_x$
8	$1.1(1.2D - 0.5C_aID + 0.5L - E_y)$	$1.166D + 0.55L - 1.1E_y$

Load Combinations

❑ Solution

S. No.	$U = 1.1[0.9D \pm (E_h + 0.5C_aID)]$	
9	$1.1(0.9D + 0.5C_aID + E_x)$	$1.144D + 1.1E_x$
10	$1.1(0.9D + 0.5C_aID + E_y)$	$1.144D + 1.1E_y$
11	$1.1(0.9D + 0.5C_aID - E_x)$	$1.144D - 1.1E_x$
12	$1.1(0.9D + 0.5C_aID - E_y)$	$1.144D - 1.1E_y$
13	$1.1(0.9D - 0.5C_aID + E_x)$	$0.836D + 1.1E_x$
14	$1.1(0.9D - 0.5C_aID + E_y)$	$0.836D + 1.1E_y$
15	$1.1(0.9D - 0.5C_aID - E_x)$	$0.836D - 1.1E_x$
16	$1.1(0.9D - 0.5C_aID - E_y)$	$0.836D - 1.1E_y$

Load Combinations

Load Combinations in Other Codes

BCP SP 2007

- Same as that of UBC 97

ACI 318-19

- U = 1.4D
- U = 1.2D+1.6L
- U = 1.2D + 1.0L ± 1.0E
- U = 0.9D ± 1.0E

BCP 2021

- Same as that of ACI 318-19

NOTE:

It is important to note that "E" in these load combinations is not as defined in UBC 97. It must be calculated in accordance with International Building Code (IBC). (ASCE 7 12.4.2.2)

Load Combinations

Compatibility of BCP SP 2007 (UBC) and ACI Code

- Chapter 7 of BCP SP 2007 can be used for earthquake resistant design of RC structures using load combination and Strength Reduction Factors of chapter 5 of BCP (UBC 97 load combinations).

- To maintain compatibility in the usage of BCP code, analysis is done using load combinations of UBC 97. Design can be done using:

  1. UBC 97 design procedure of chapter 19 which is ACI 318-99
  2. ACI 318-19 using load combinations and strength reduction factors of UBC 97.

Load Combinations

Applications of Load Combinations

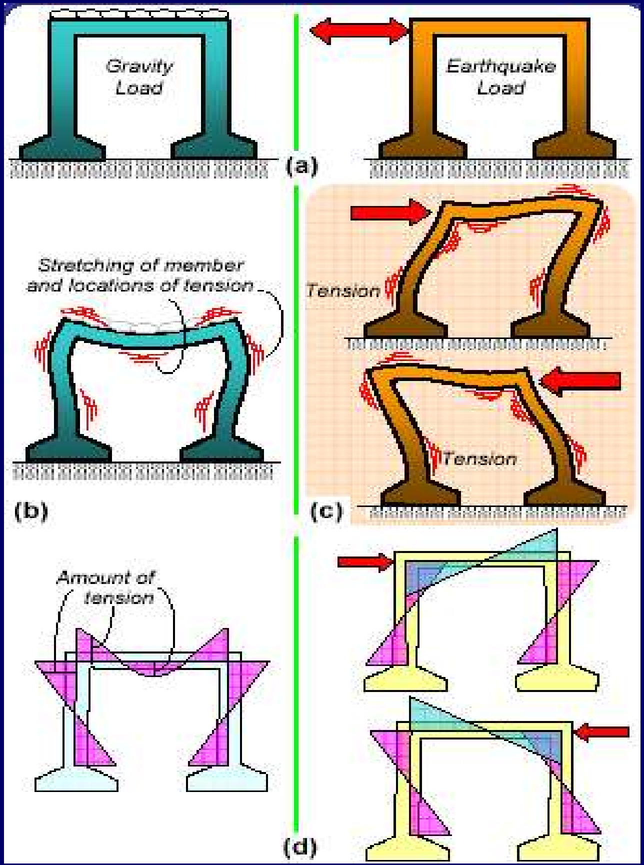
- Following steps are followed to apply load combinations:

1. The structure is analyzed for unamplified load cases separately e.g.,
    - Analysis for unamplified dead load (1.0D)
    - Analysis for unamplified live load (1.0L)
    - Analysis for unamplified lateral story load cases ($1.0E_h$)
2. Load effects obtained for each load case are multiplied with amplification factors and combined as per code load combination requirements.
3. With this approach, the structure has to be analyzed only for each load case. After analysis, any load combinations can be performed with load cases.

Gravity vs. Earthquake Loading

❑ Gravity loading vs Earthquake loading in RC buildings

- Under gravity loads, tension in the beams is at bottom midspan and is at top at the ends.
- On the other hand, earthquake loading causes tension in the beam and column faces at locations different from those under gravity loading.
- Hence steel bars are required on both faces of beams to resist reversals of bending moment.



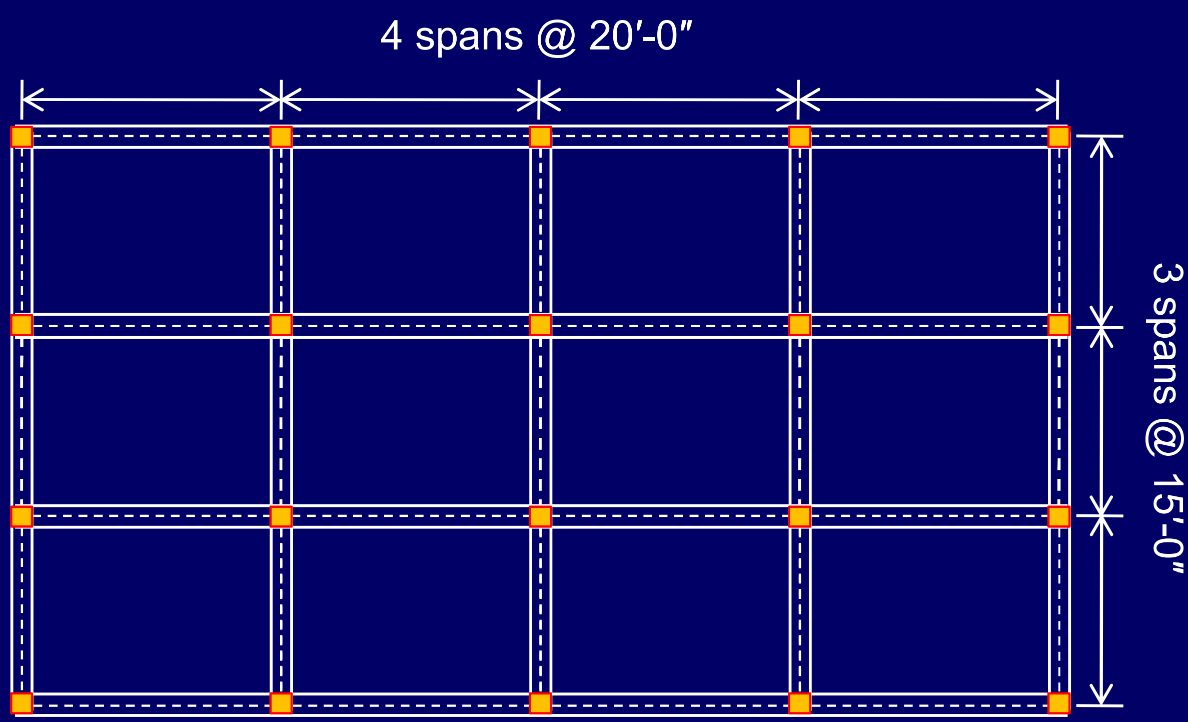
Case Study

Comparative Study of Gravity and Earthquake Load Analysis in Different Zones of a Given Structure using SAP2000

Gravity vs. Earthquake Loading

❑ Input Data

- The analysis was performed on a three-story building (shown below) using SAP2000, employing ACI 318-05 load combinations for all seismic zones.



Gravity vs. Earthquake Loading

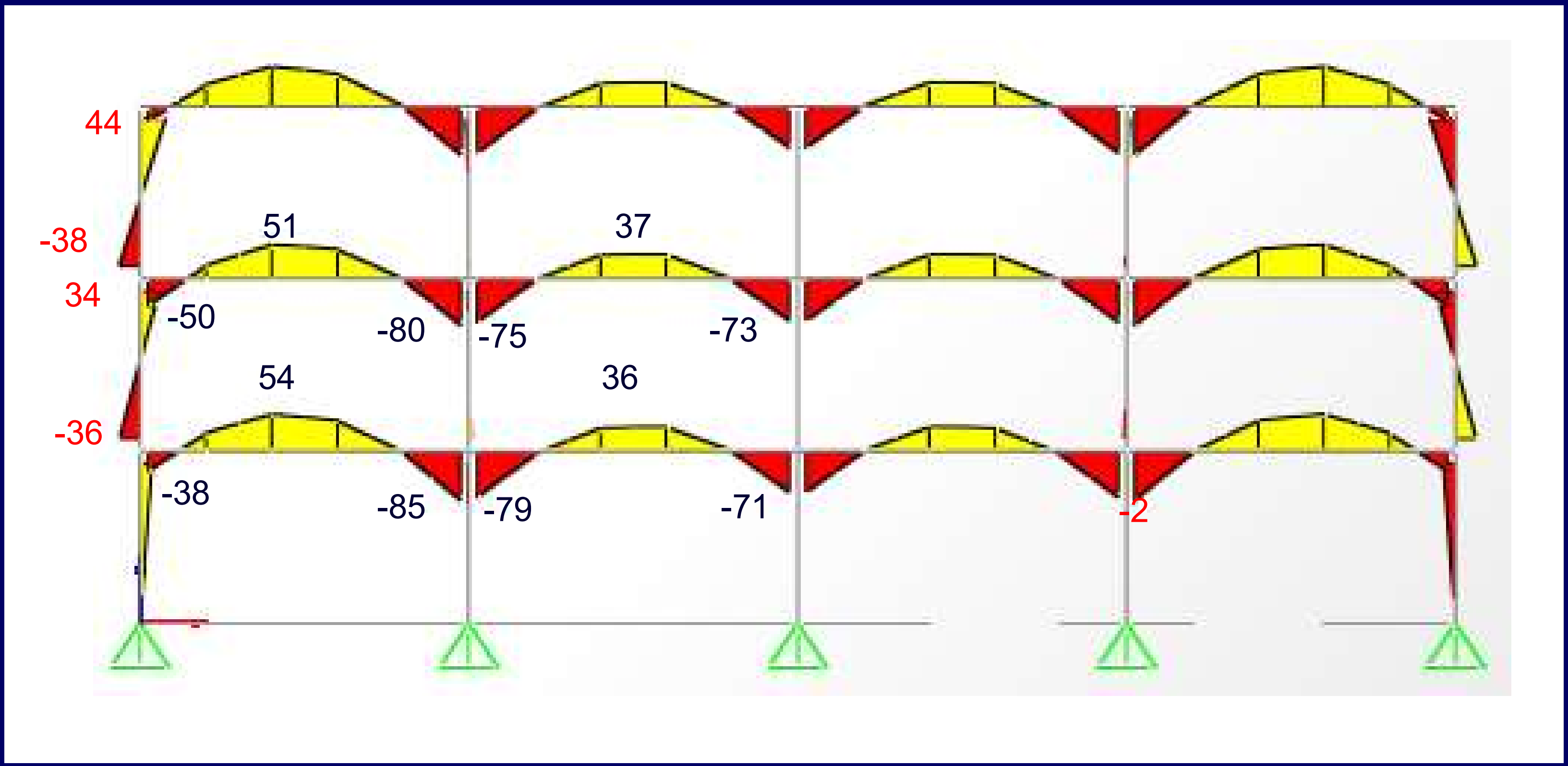
Objectives of the Study

- The study aims to:
  1. Determine the bending moments due to gravity loads
  2. Determine the bending moments due to earthquake loads in zones 1 to 4.
  3. Compare the variations in bending moments resulting from different loading conditions.
  4. Compare the reinforcement requirement due to change in loading.

Gravity vs. Earthquake Loading

❑ Gravity Load Analysis

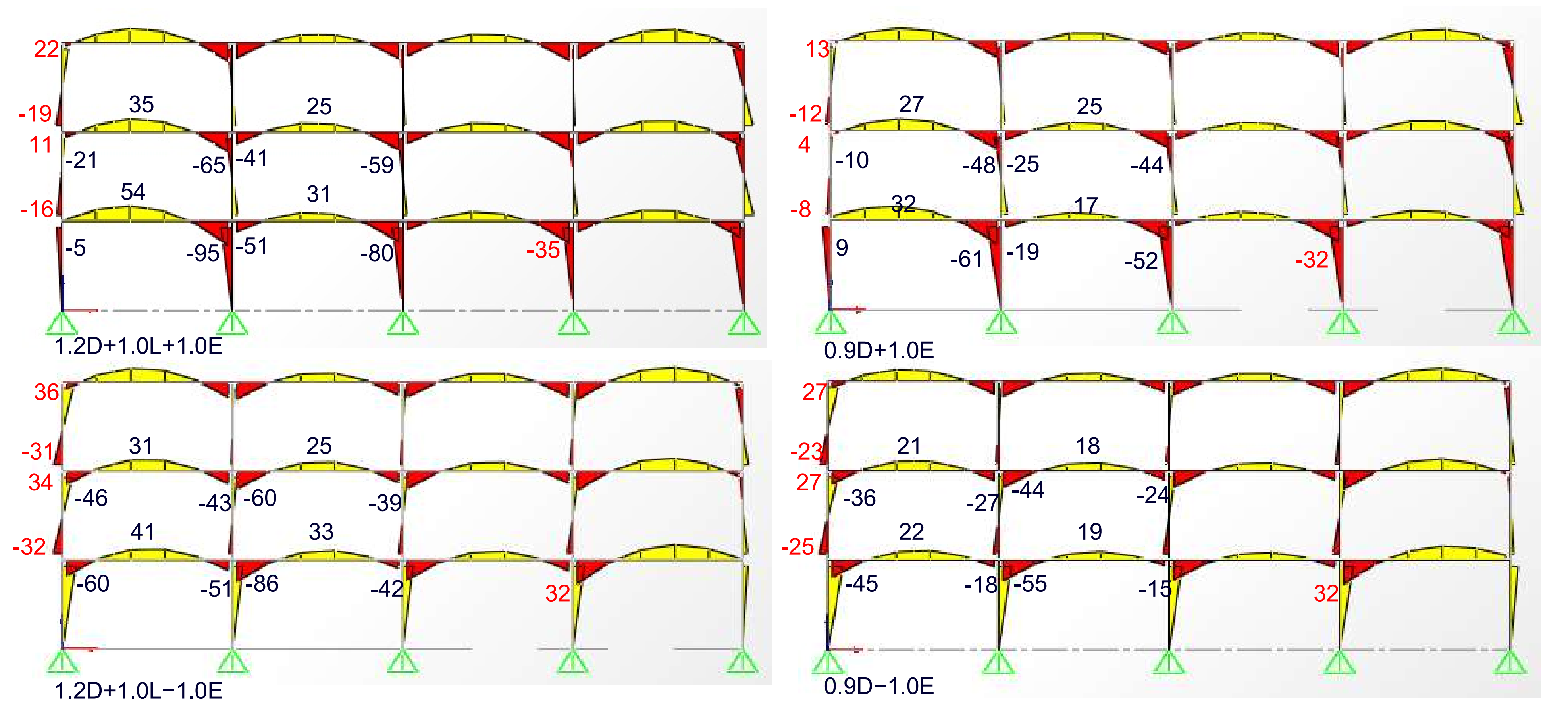
- The analysis results (bending moments) for all seismic zones corresponding to load combination 1.2D +1.6L are shown below.



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

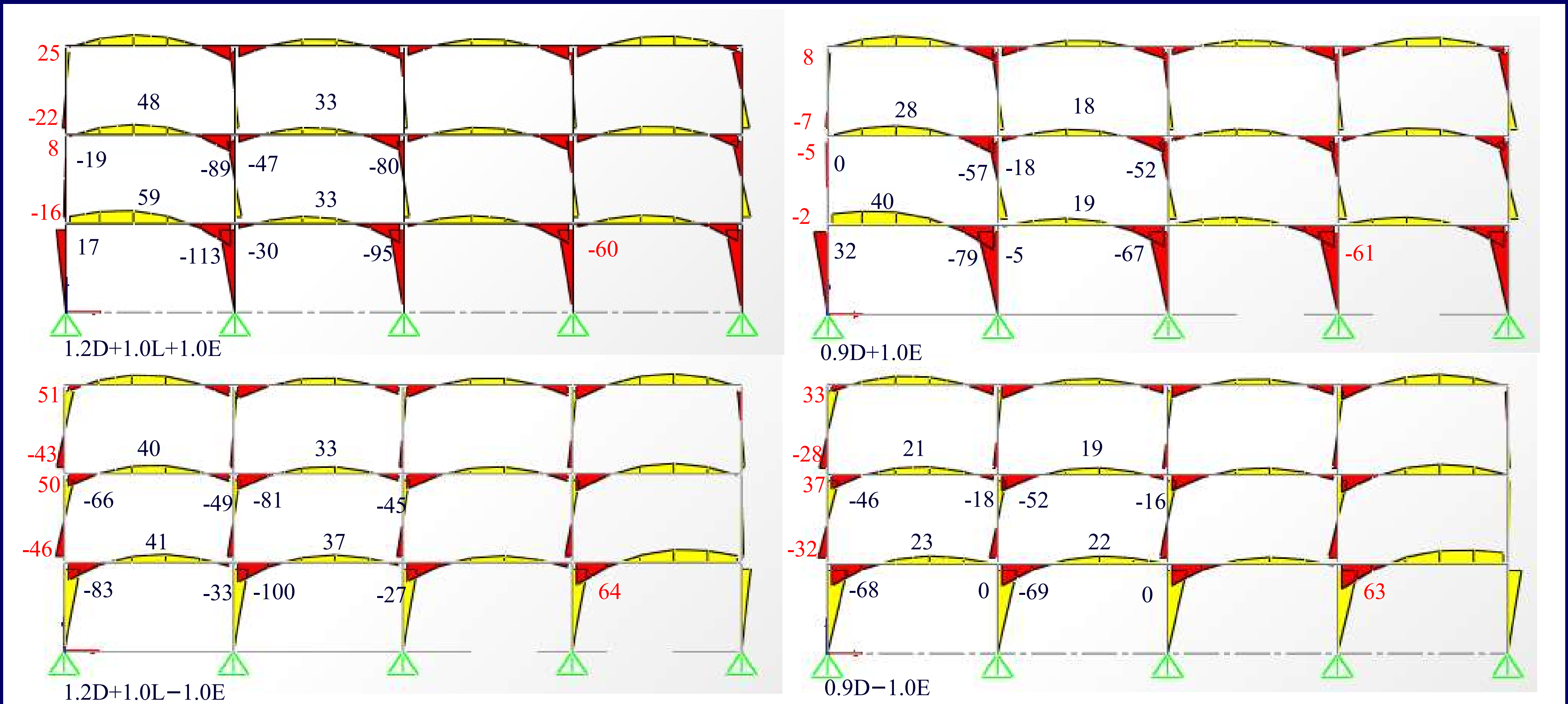
❖ Zone 1



Gravity vs. Earthquake Loading

Seismic Analysis Results

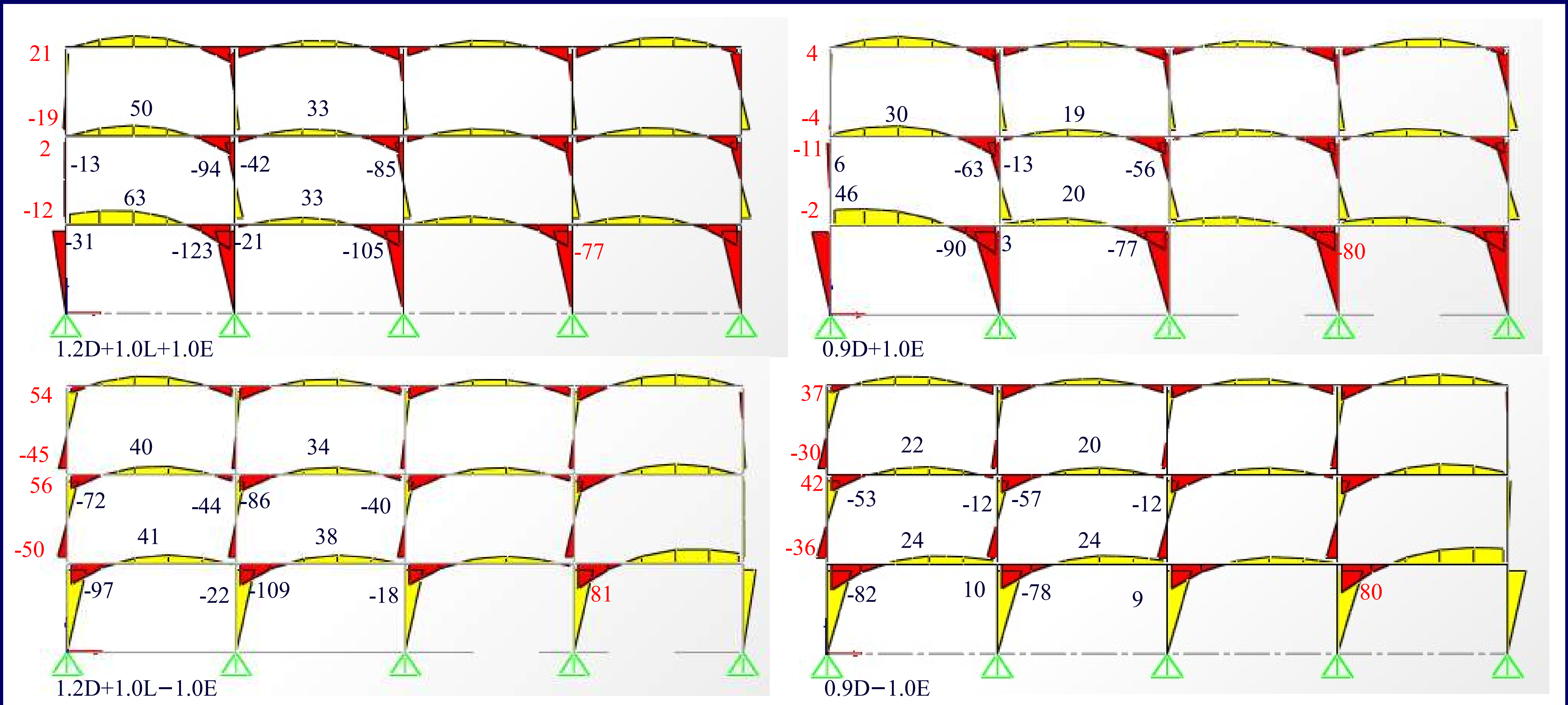
Zone 2A



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

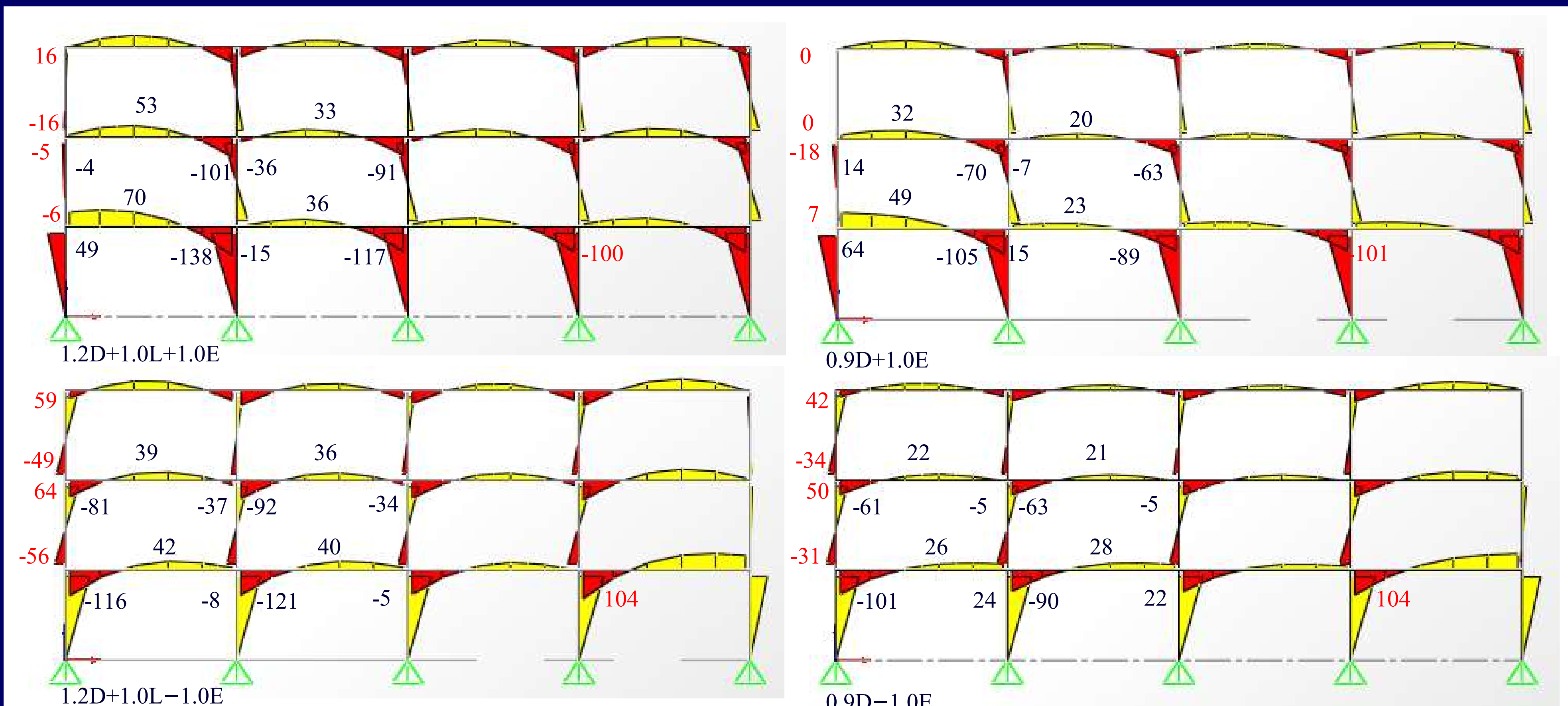
❖ Zone 2B



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

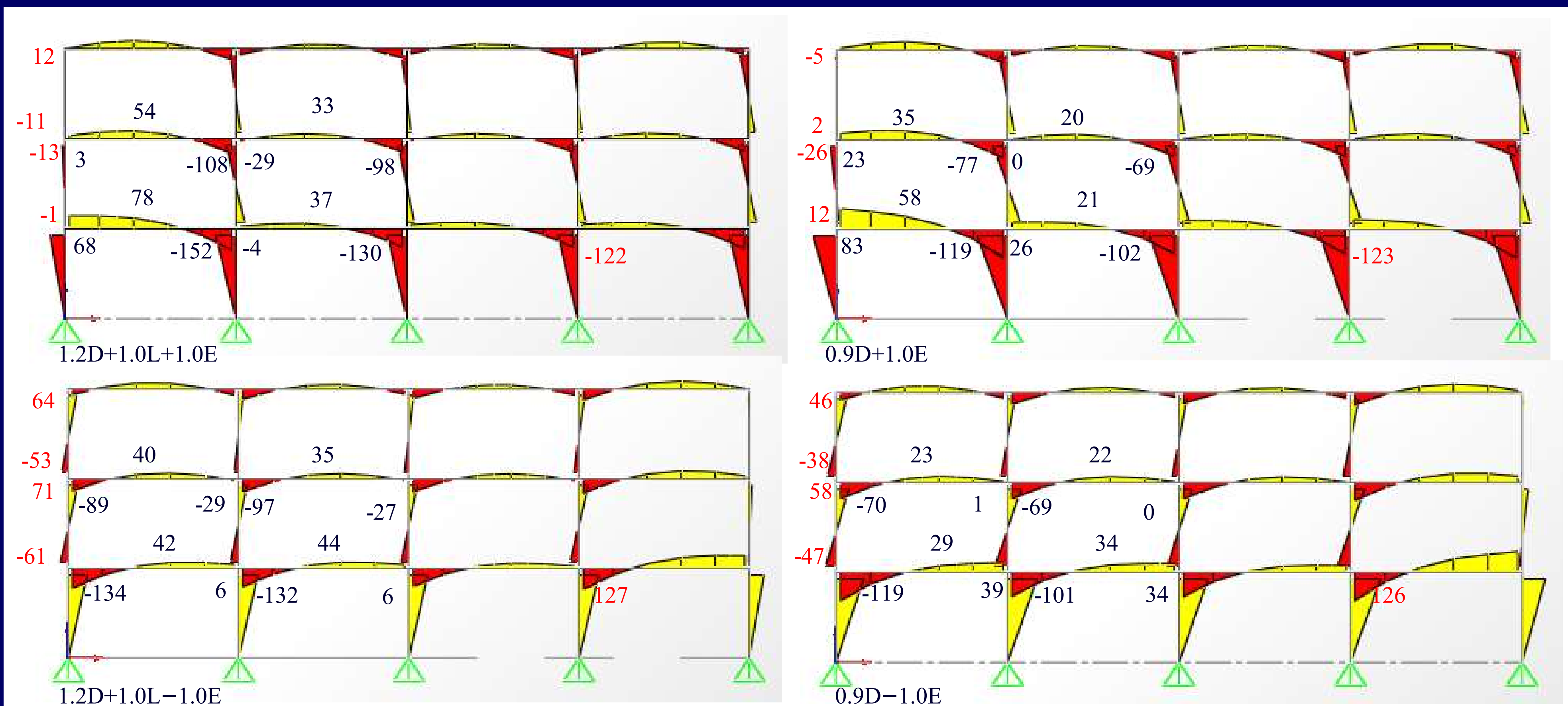
❖ Zone 3



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

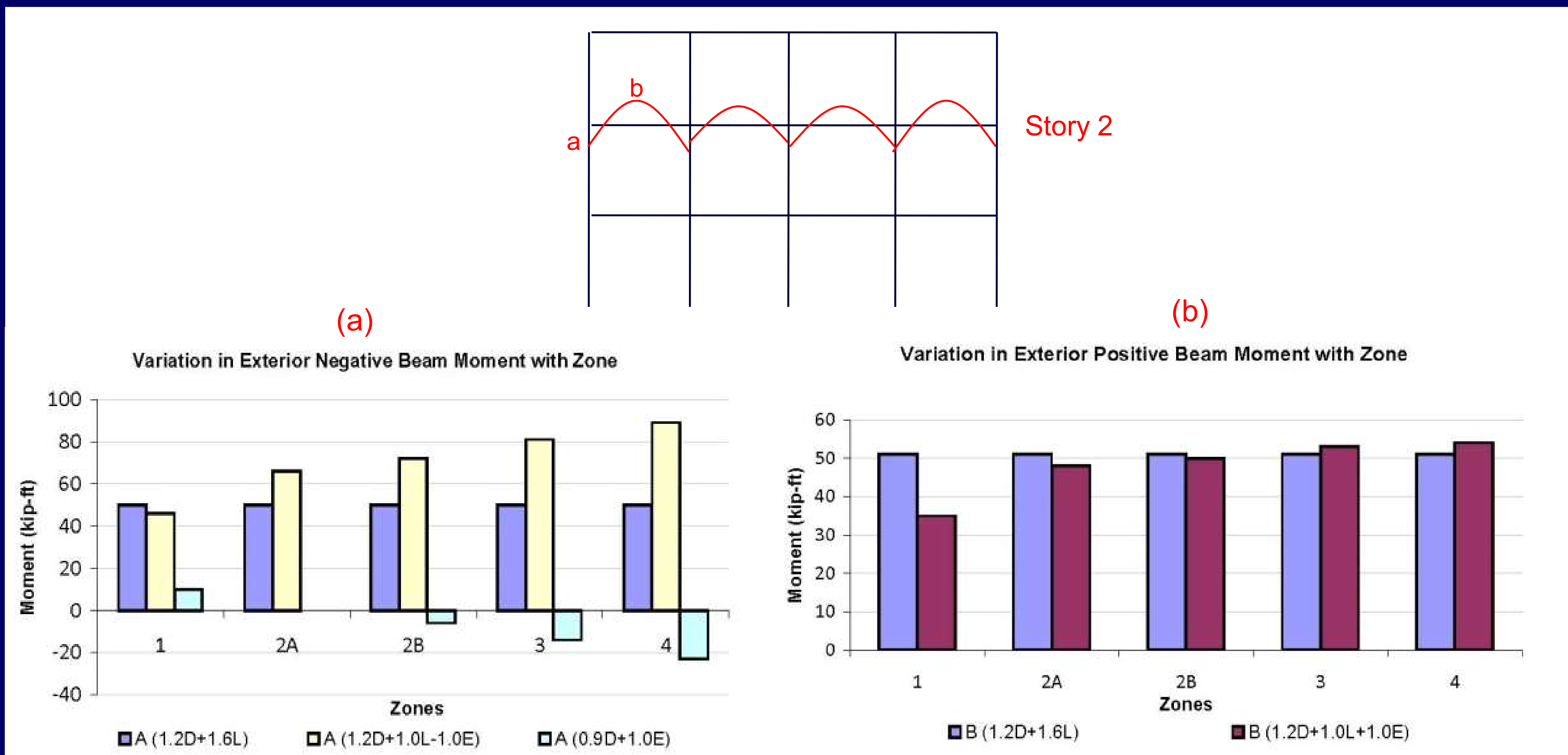
❖ Zone 4



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

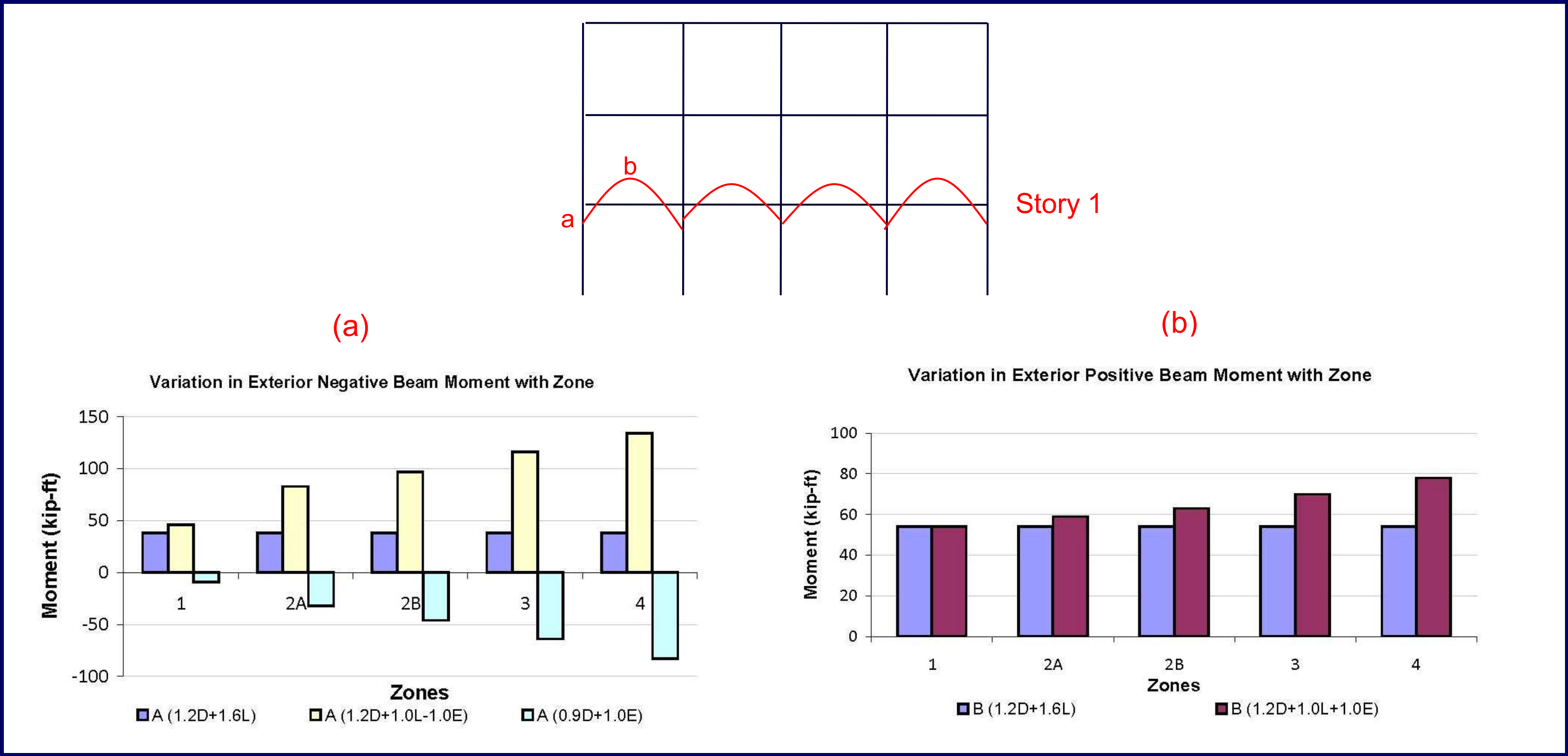
❖ Comparison of Beam Bending Moments



Gravity vs. Earthquake Loading

Seismic Analysis Results

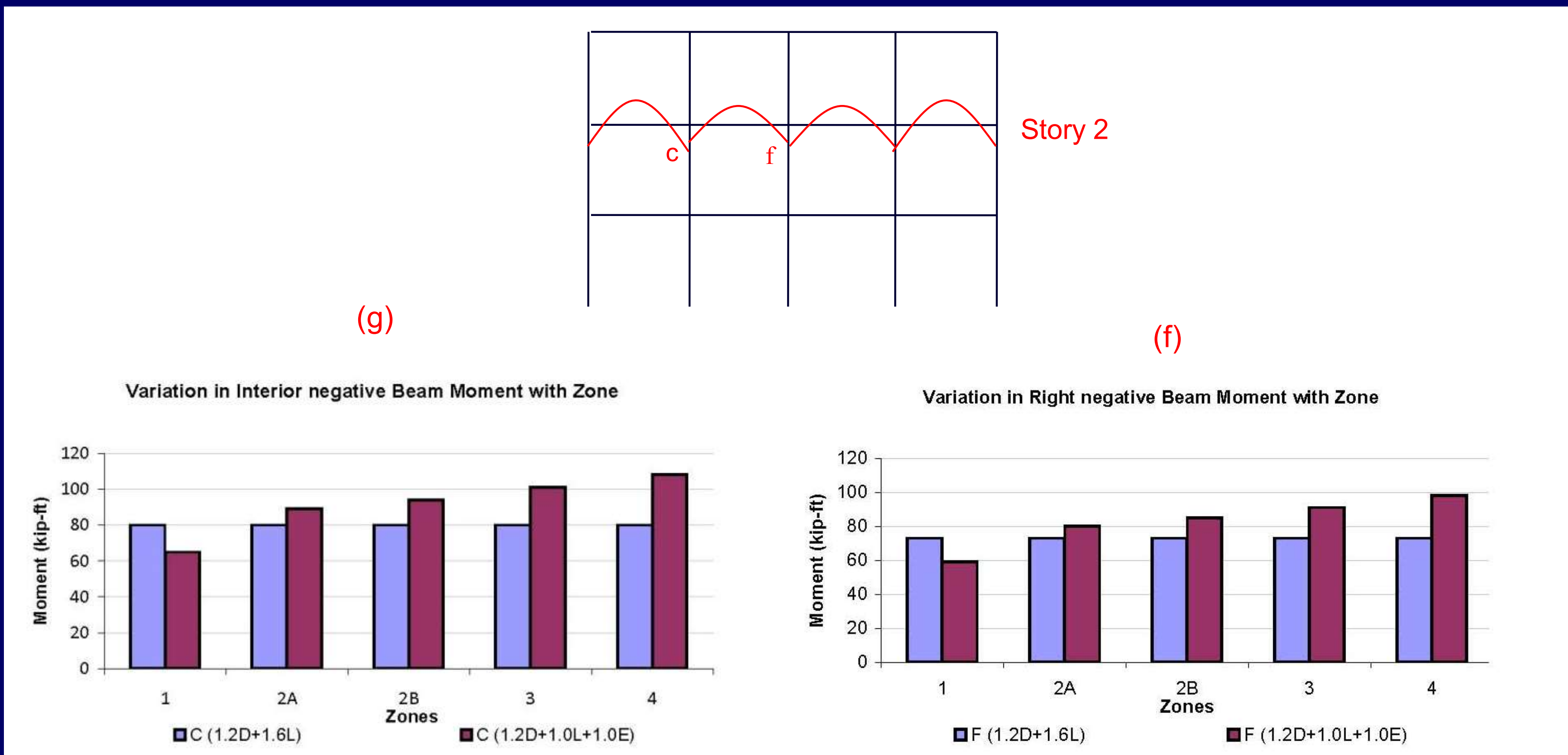
Comparison of Beam Bending Moments



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

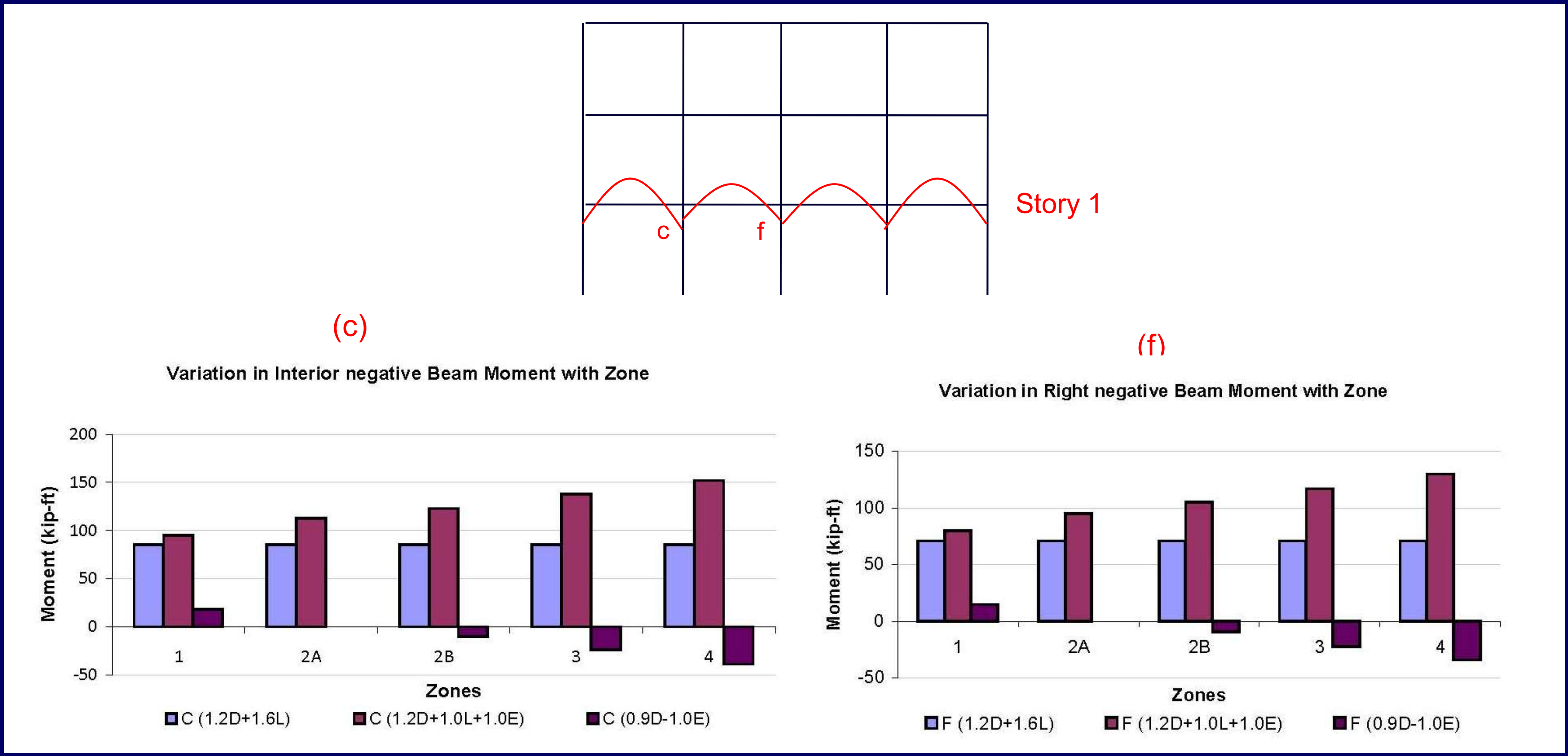
❖ Comparison of Beam Bending Moments



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

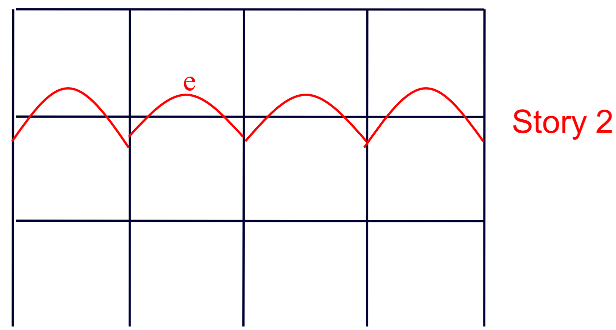
❖ Comparison of Beam Bending Moments



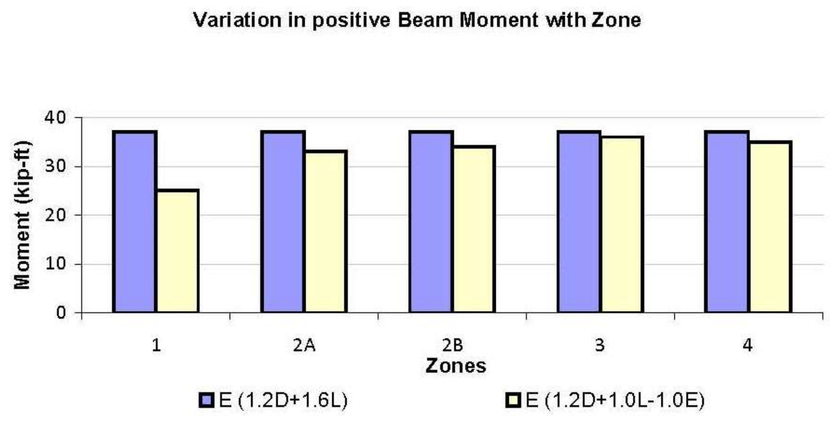
Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

❖ Comparison of Beam Bending Moments



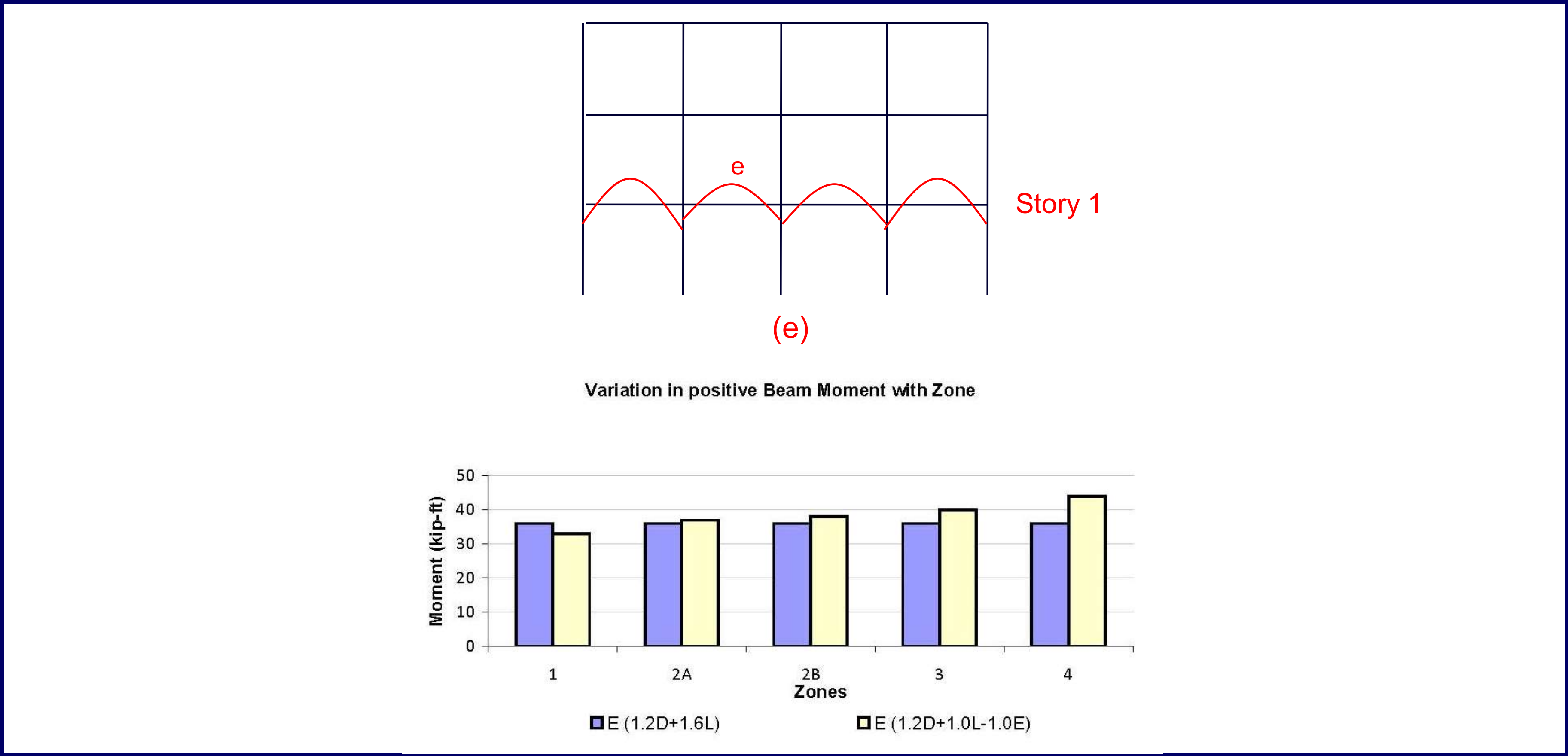
(e)



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

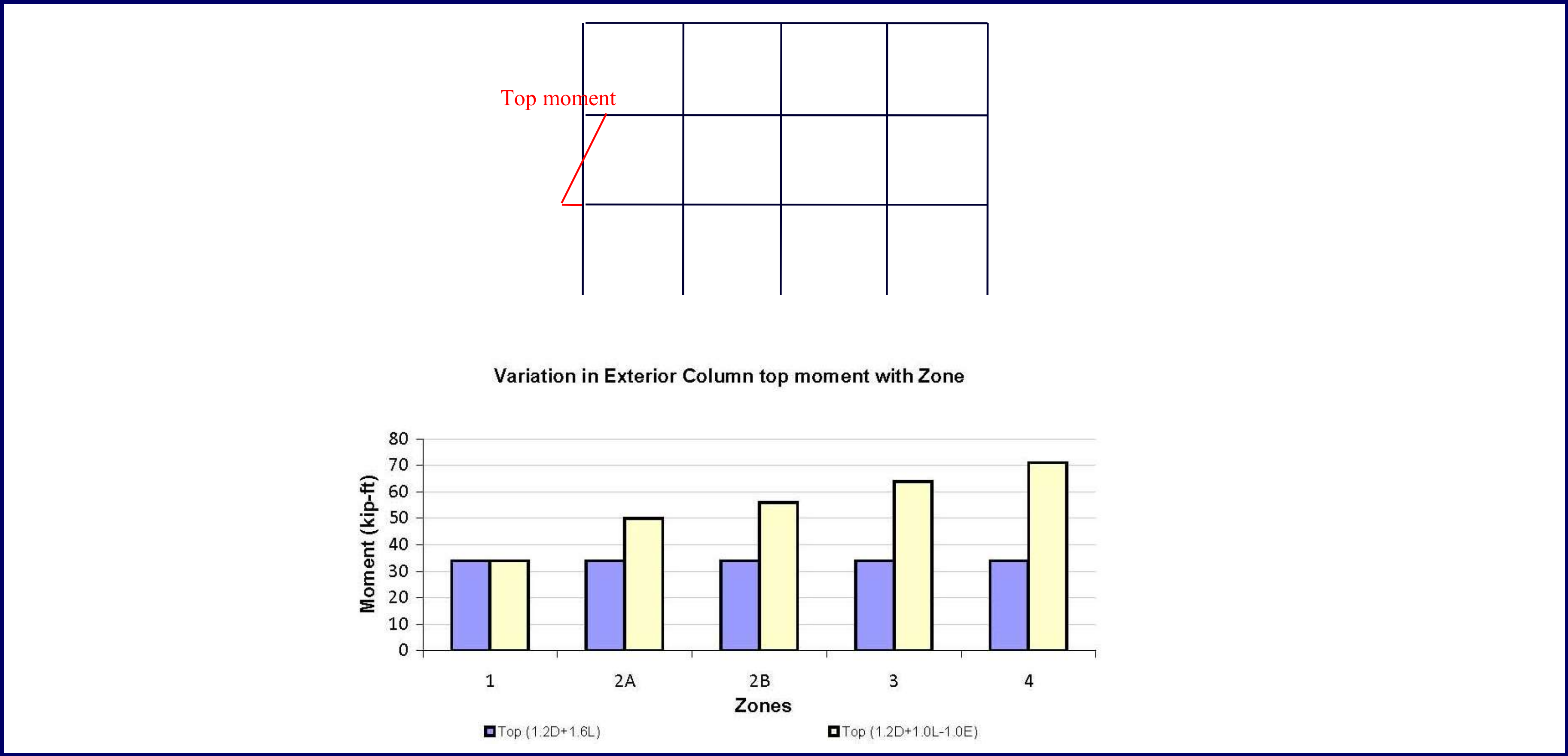
❖ Comparison of Beam Bending Moments



Gravity vs. Earthquake Loading

❑ Seismic Analysis Results

❖ Comparison of Column Bending Moments



Gravity vs. Earthquake Loading

Seismic Analysis Results

Conclusions

- The moments in almost all cases increase due to lateral loads in a progressive manner from top to bottom and from low to high zone.
- However, there is no significant change in beam mid span positive moments for all zones.
- Within a story, exterior negative moment in a beam increases more than that of interior negative moments in the same seismic zone.
- Positive end moments in beams, especially in lower stories, may become significant in higher seismic zones.

Seismic Design Requirements for RC Buildings

❑ Seismic-Force-Resisting Systems

- Several structural systems are employed in earthquake-resistant design. These encompass, but are not limited to, the following:
    1. Bearing Wall Systems
    2. Building Frame Systems
    3. Moment-Resisting Frame Systems
    4. Dual Systems
    5. Cantilever Column Systems
- Each chosen system must comply with structural limitations, height restrictions, and be designed and detailed according to the specific requirements of the code.

Seismic Design Requirements for RC Buildings

❑ Moment-Resisting Frame Systems

- Based on moment resisting capacity, there are three types of RC frames

  1. Special Moment Frame (SMF)
  2. Intermediate Moment Frame (IMF)
  3. Ordinary Moment Frame (OMF)

- Chapter 18 of the ACI 318-19 contains the special provisions for moment-resisting systems.

- These provisions aim to ensure adequate toughness during earthquake-induced inelastic displacement reversals. This goal can be achieved this by mandating sufficient concrete confinement.

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Moment-Resisting Frame Systems

- The ACI special Provisions for SMF and IMF have been covered at BSc. Level. Please download **Lecture 05 (Part II) of RCD - II** from the website for further study.
- However, a quick revision of some ACI provisions for SMF are provided next.

Seismic Design Requirements for RC Buildings

General Provisions

- We will start by outlining a few provisions that apply to all frames in general.

Material Properties

- Specified compressive strength of concrete in members resisting earthquake induced forces, shall not be less than 3000 psi (cylinder strength) as per Table 19.2.1.1.
- There is no limit on the maximum value of f_c' for normal weight concrete.

Seismic Design Requirements for RC Buildings

General Provisions

Material Properties

- Specified compressive strength of concrete in members resisting earthquake induced forces, shall not be less than 3000 psi (cylinder strength) as per Table 19.2.1.1.
- There is no limit on the maximum value of f_c' for normal weight concrete.

Seismic Design Requirements for RC Buildings

General Provisions

Material Properties (20.2.2.5)

- Deformed longitudinal reinforcement resisting earthquake-induced moment shall be in accordance with (a) or (b)

a) ASTM A706 (low alloy steel): Grade 60 and 80

b) ASTM A615 (Billet steel):

  - Grade 80 is not permitted
  - Grade 60 with certain conditions listed below.

Seismic Design Requirements for RC Buildings

General Provisions

Material Properties (20.2.2.5)

a) ASTM A615 (Billet steel):

i. Actual f_y − specified $f_y \leq 18ksi$

ii. Ratio of actual ultimate tensile strength to actual yield strength shall be at least 1.25

iii. Minimum elongation in 8 inches long bar shall be at least

- 14% for #3 to #6
- 12% for #7 to #11
- 10% for #14 and #18

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Beams (18.6.2)

i. **Dimensional Limits (18.6.2.1)**

a. Ratio of clear span l_n to the effective depth d shall be at least 4 ($l_n/d \geq 4$)

e.g., for L_n = 15 ft, d = 16″, L_n/d = 15 × 12/16 = 11.25 > 4, O.K.

b. Ratio of width b_w to depth h shall be at least 0.3 ($b_w/h \geq 0.3$)

e.g., for width, b = 12″ and depth, h = 18″, b/h = 12/18 = 0.67 > 0.3, O.K.

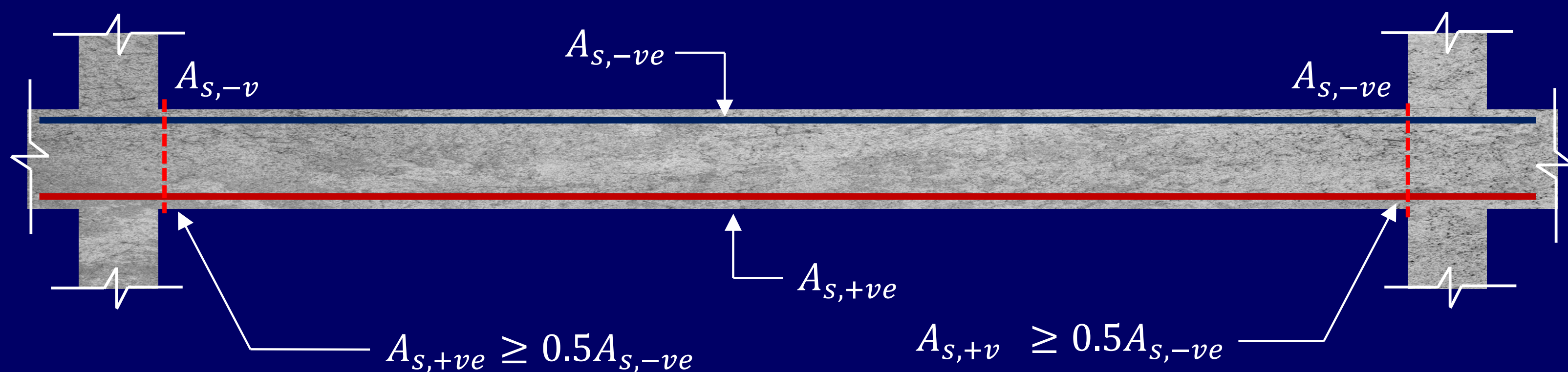
c. Minimum width b_w shall not be less than 10″

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Beams (18.6.2)

ii. Flexural reinforcement (18.6.3)



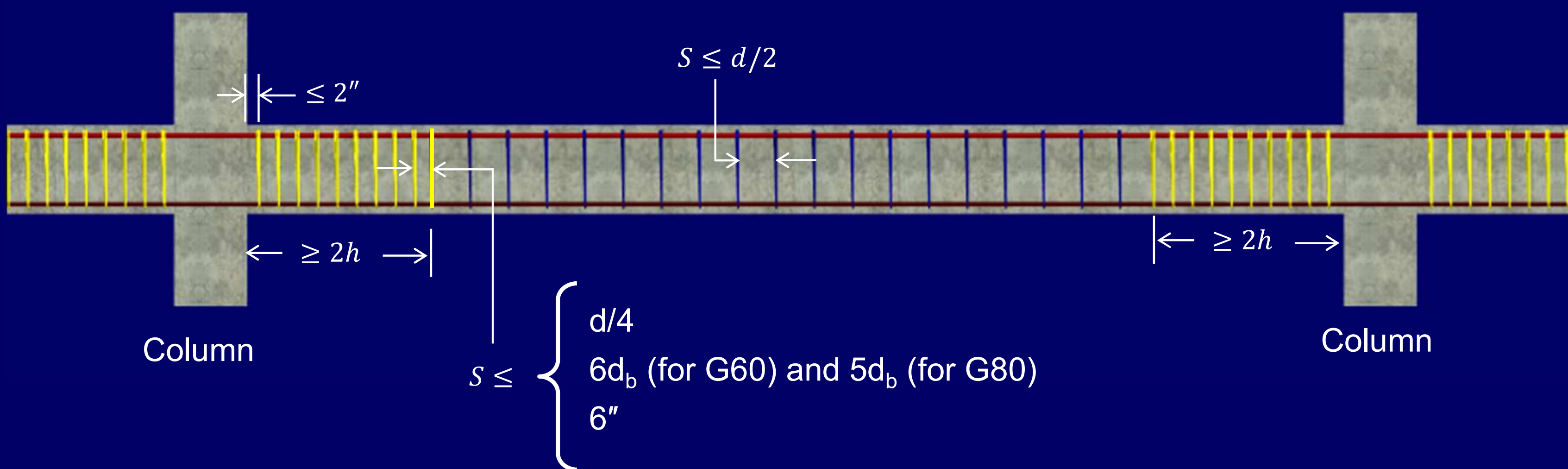
1. *Minimum 2 bars continous at all locations*
2. *At ends of beams;* $A_{s,+ve} \geq 0.5A_{s,-ve}$
3. $A_{s,min} = larger\ of \left(\frac{3\sqrt{f_c'}}{f_y}, \frac{200}{f_y}\right) bd\ (at\ critical\ locations)$ and $A_{s,max} = 0.025bd\ (for\ Grade\ 60)$
4. $A_{s,-v}$ or $A_{s,+ve}$ (at all sections) ≥ (maximum of A_s at either joint)/4

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Beams (18.6.2)

ii. Transverse reinforcement (18.6.4)

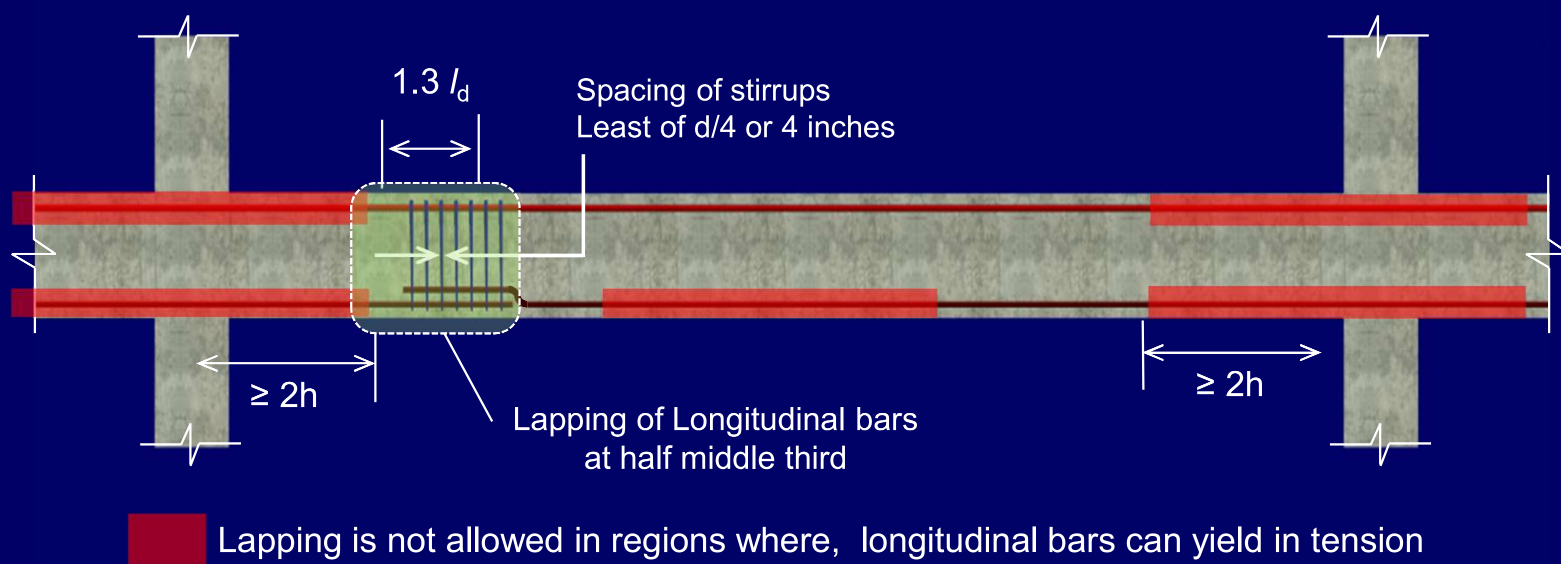


Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Beams (18.6.2)

iii. Splices (18.6.3.3)



Lap splice length =1.3 l_d = 1.3× 0.05 (f_y/ $\sqrt{f_c'}$)d_b

70 d_b for f_c' = 3 ksi and f_y = 60 ksi

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Beams (18.6.2)

iii. **Splices (18.6.3.3)**

- Mechanical (section 25.5.7) and welded splices (section 18.2.8) are permitted at the same half middle third location as shown on previous slide and should have strength of at least $1.25f_y$.

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Columns (18.7)

i. **Dimensional limits (18.7.2)**

a) The shortest cross-sectional dimension shall be at least 12″

b) The ratio of the shortest cross-sectional dimension to the perpendicular dimension shall be at least 0.4

For example; 12/12, 12/18, 12/24 OK; but 12/36 is not O.K

Seismic Design Requirements for RC Buildings

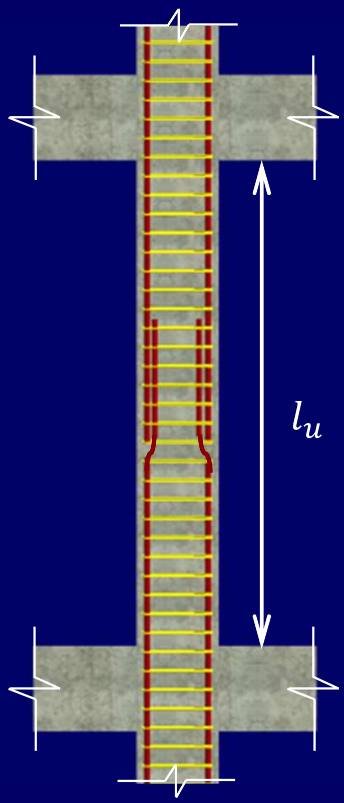
ACI Provisions for Special Moment Frames (SMF)

Provisions for Columns (18.7)

ii. Longitudinal reinforcement (18.7.4)

a) Minimum Area of longitudinal reinforcement, A_{st}, shall be at least $0.01A_g$

b) Maximum Area of longitudinal reinforcement, A_{st}, shall not exceed $0.06A_g$.



Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Columns (18.7)

iii. Transverse Reinforcement (18.7.5)

- Amount of transverse reinforcement A_{sh} shall be as per ACI Table 18.7.5.4.

<table>
<tr><th>Conditions</th><th colspan="3">A_{sh} (in²/in)
(For rectilinear hoops)</th></tr>
<tr><td>$P_u \leq 0.3A_g f_c'$ and
$f_c' \leq 10{,}000\ psi$</td><td>Greater of
(a) and (b)</td><td>$0.3\left(\frac{A_g}{A_{ch}} - 1\right)\frac{f_c'}{f_{yt}} s b_c$</td><td>(a)</td></tr>
<tr><td rowspan="3">$P_u > 0.3A_g f_c'$ or
$f_c' > 10{,}000\ psi$</td><td rowspan="3">Greatest of
(a),(b) and
(c)</td><td>$0.09\frac{f_c'}{f_{yt}} s b_c$</td><td>(b)</td></tr>
<tr><td>$\frac{0.2 k_f k_n P_u}{f_{yt} A_{ch}} s b_c$</td><td>(c)</td></tr>
<tr><td colspan="4">$k_f = \frac{f_c'}{25000} + 0.6 \geq 1.0 \quad and \quad k_n = \frac{n_l}{n_l - 2}$</td></tr>
</table>

Where;

$A_g = bh$; $A_{ch} = (b - 2c_c)(h - 2c_c)$

$b_c = b - 2c_c$

$s =$ vertical spacing of stirrups (c/c)

$f_c' =$ concrete compressive strength

$f_{yt} =$ yield tensile strength of transverse reinforcement.

$P_u =$ factored axial load on column

$k_f =$ concrete strength factor

$k_n =$ confinement effectiveness factor

$n_l =$ the number of longitudinal bars around the perimeter of a column core.

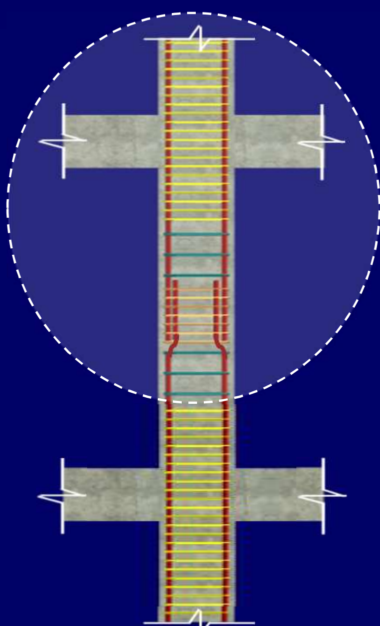
Seismic Design Requirements for RC Buildings

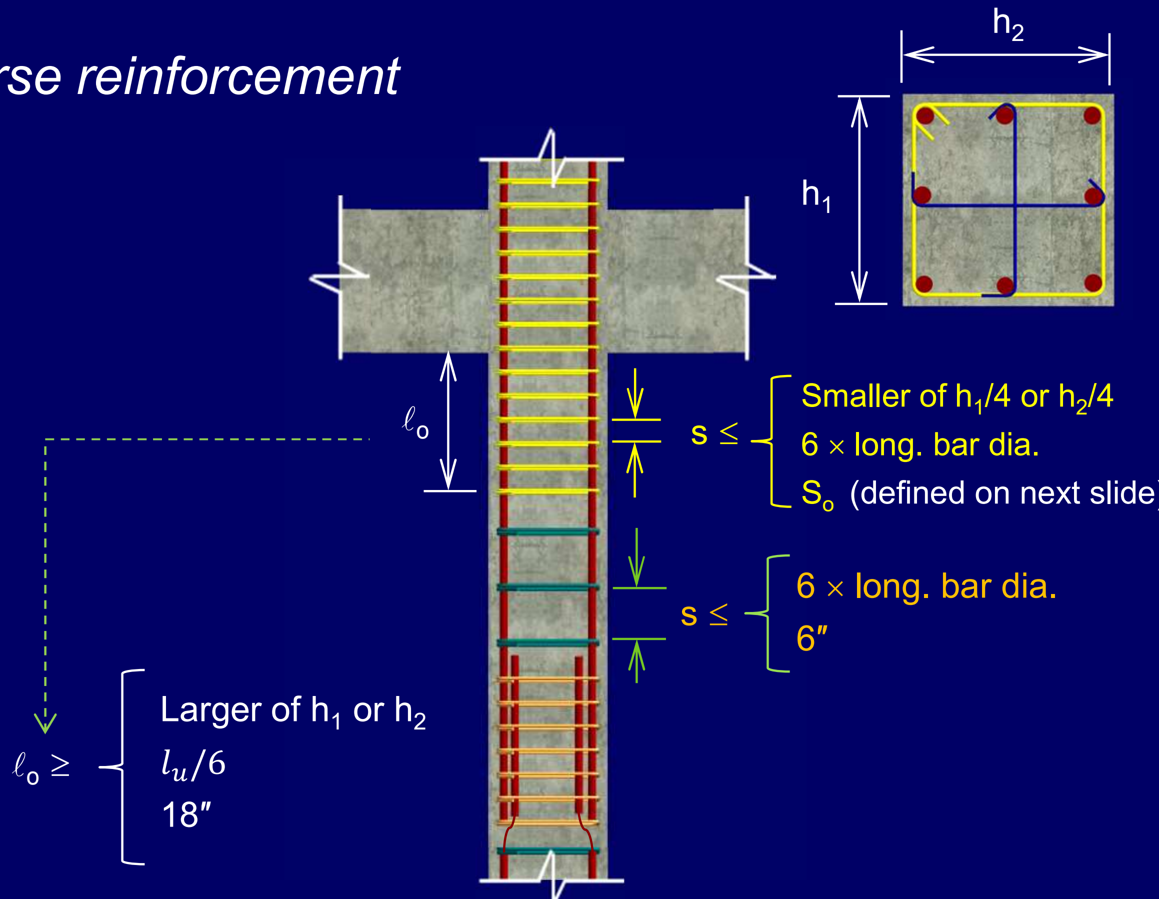
ACI Provisions for Special Moment Frames (SMF)

Provisions for Columns (18.7)

iii. Transverse Reinforcement (18.7.5)

- *Spacing of transverse reinforcement*



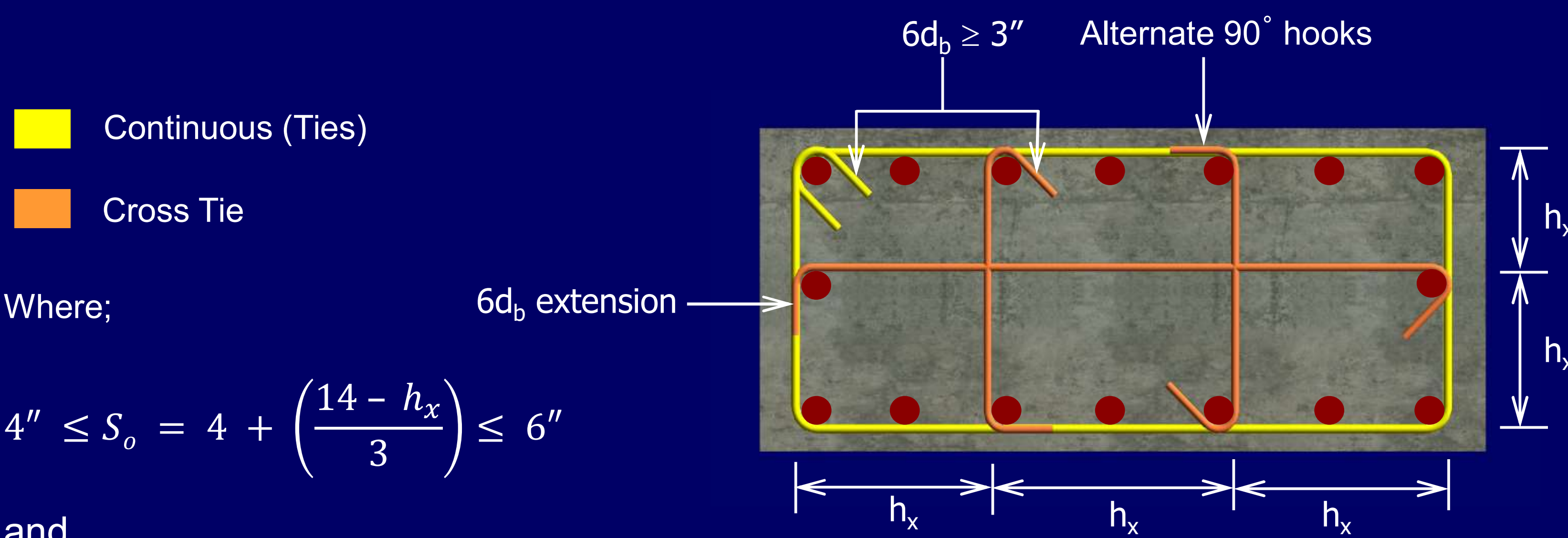


Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Columns (18.7)

iii. Transverse Reinforcement (18.7.5)



Where;

$$4'' \leq S_o = 4 + \left(\frac{14 - h_x}{3}\right) \leq 6''$$

and

h_x = max. value of h_x on all column faces

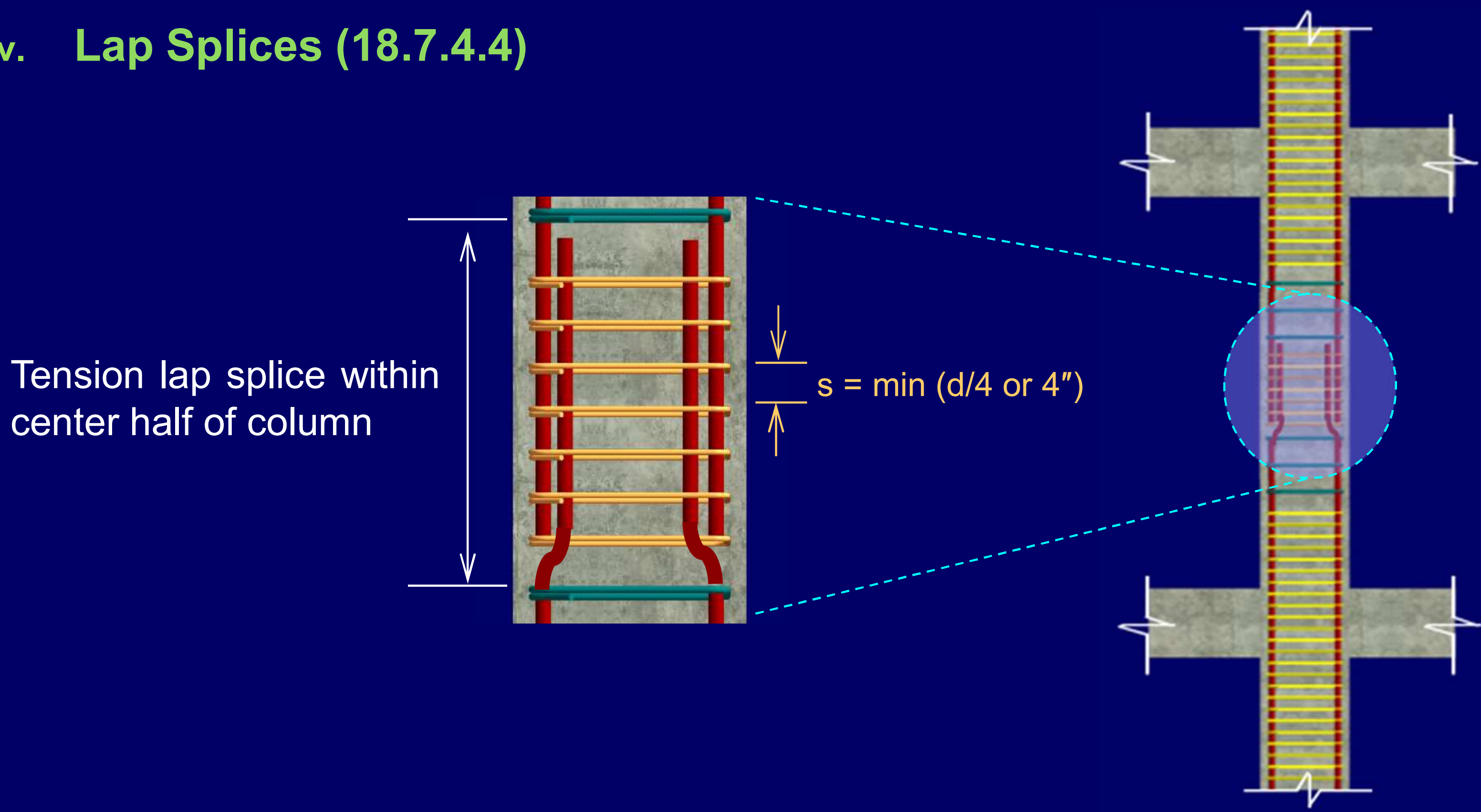
$h_x \leq 14''$

Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Special Moment Frames (SMF)

❖ Provisions for Columns (18.7)

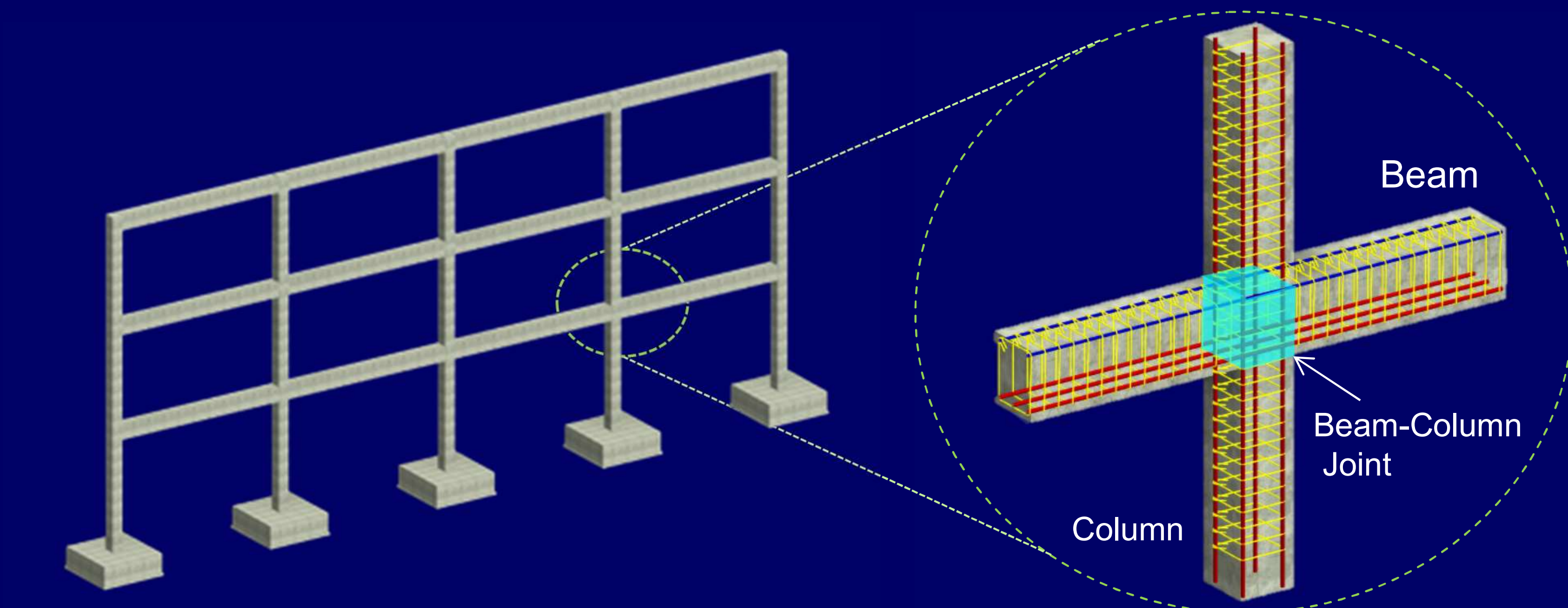
iv. Lap Splices (18.7.4.4)



Seismic Design Requirements for RC Buildings

❑ ACI Provisions for Joints and Connections

- ACI has provided specific provisions for joints and connections in its separated standard "ACI 352". These provisions will be discussed in **Lecture 10** of the course.

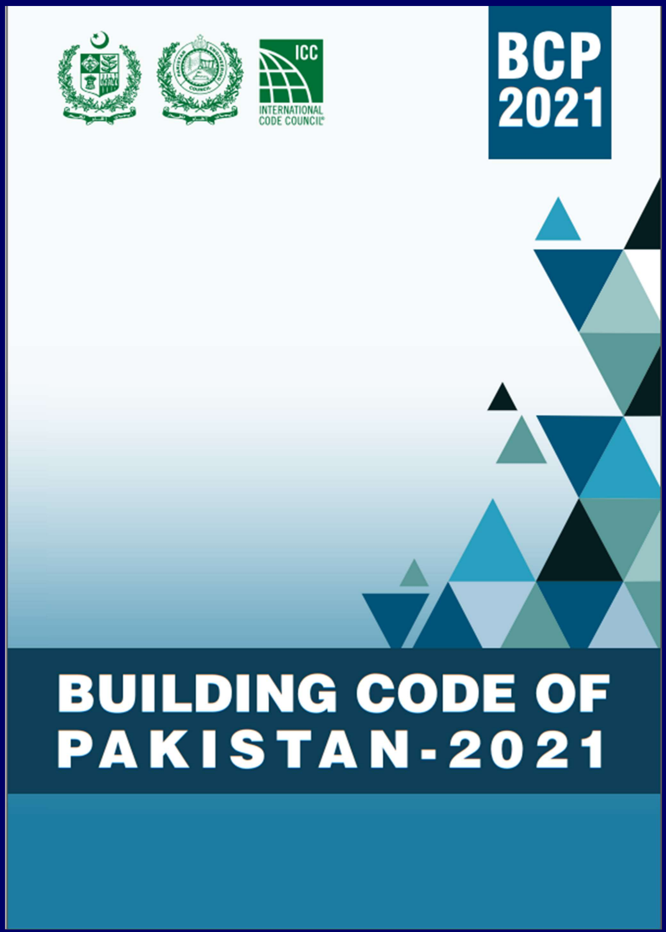


Introduction to BCP 2021

❑ BCP 2021

- The Building Code of Pakistan 2021 (BCP 2021), issued in 2022, adopts the International Building Code (IBC 2021) except for seismic maps.

- BCP 2021 integrates results from a recently updated probabilistic seismic hazard analysis (PSHA) carried out with cutting-edge methodologies and the latest data sources available.



Introduction to BCP 2021

❑ BCP 2021

- The following members from UET, Peshawar were part of the PEC Task Force Experts Working Group:

1. Engr. Dr. Prof. Qaisar Ali
2. Engr. Dr. Prof Irshad Ahmad
3. Engr. Dr. Prof Syed Muhammad Ali
4. Engr. Dr. Muhammad Waseem
5. Engr. Dr. Shahid Ullah

ACKNOWLEDGEMENTS

Pakistan Engineering Council acknowledges the significant role of all stakeholders, partners, especially International Code Council, World Bank, NED-UET other provincial and federal entities in development of *Building Code of Pakistan (2021)*. PEC admires vital role of Engr. Dr. Prof. Sarosh Hashmat Lodi, Convener, PEC Task Force/ Vice Chancellor, NED-UET, Karachi. The Task Force has performed dedicated hard work keeping in view various technical parameters, case studies, data sets and allied expertise regarding development of BCP (2021) *based on 2021 International Building Code*. In this regard, Mr. Mark Johnson, Executive Vice President/ Director of Business Development, ICC, USA and Mr. Faiz-ul-Sibtain, Project Coordinator, PEC, both contributed in an extraordinary way regarding finalizing of four ***"ICC Development License Agreements"*** inked by PEC and ICC from 2017 to 2021. PEC acknowledges the important role of Code Editorial Committee members including Engr. Dr. JPC Chair Prof. Shuaib H. Ahmad, Prof. Dr. Muhammad Masood Rafi, Dr. Ashfaq Ahmed Sheikh and others for consolidation and final editing of BCP (2021). The title page of BCP (2021) designed by Engr. Shuaib Ahmed, Assistant Prof. NED-UET, Karachi.

PEC Task Force Experts Working Group:

1.	Engr. Dr. Prof. Sarosh Hashmat Lodi Vice Chancellor, NED-University of Engineering and Technology, Karachi	Convener/ Task Force
2.	Dr. Prof. Muhammad Asif Khan Ex-Vice Chancellor, University of Peshawar, Peshawar	Group Lead/ Member
3.	Engr. Brig. (Retd.) Dr. Prof. Khaliq-ur-Rashid Kayani CEO, Architectural and Civil Engineering Services, Rawalpindi	Group Lead/ Member
4.	Dr. Tariq Hassan Advocate Supreme Court of Pakistan/ Ex-Chairman, SECP, Islamabad	Group Lead/ Member
5.	Engr. Khurram Khaliq Khan General Manager, NDRMF, Islamabad	Group Lead/ Member
6.	Engr. Dr. Prof. Muhammad Masood Rafi Chairman, Department of Earthquake Engineering, NED-UET, Karachi	Member
7.	Engr. Dr. JPC Chair Prof. Shuaib H. Ahmad Department of Civil Engineering, NED-UET, Karachi	Member
8.	Engr. Dr. Prof. Brig. Shahid Iqbal Director (Research & Support), Engineer-in-Chief Branch, GHQ, Rawalpindi	Member
9.	Engr. Dr. Prof. Qaisar Ali Dean, Faculty of Civil, Agricultural and Mining Engg. Deptt. UET, Peshawar	Member
10.	Engr. Dr. Prof. Irshad Ahmad Chairman, Department of Civil Engineering, UET, Peshawar	Member
11.	Engr. Dr. Syed Muhammad Ali Shah Director, Centre for Earthquake Studies, PAEC, Islamabad	Member
12.	Engr. Dr. Prof. Syed Muhammad Ali Director, Earthquake Engineering Center, UET, Peshawar	Member
13.	Engr. Dr. Prof. Syed Muhammad Jamil Dean, School of Civil and Environmental Engineering, NUST, Islamabad	Member
14.	Engr. Dr. Prof. Asad Ullah Qazi Head of Structural Division, Department of Civil Engineering, UET, Lahore	Member
15.	Engr. Dr. Wasim Khaliq Associate Prof. NUST Institute of Civil Engineering, Islamabad	Member
16.	Engr. Dr. Muhammad Wasim Associate Prof. Department of Civil Engineering, UET, Peshawar	Member
17.	Engr. Dr. Fawad Ahmed Najam Associate Prof. NUST Institute of Civil Engineering, Islamabad	Member
18.	Engr. Dr. Shahid Ullah Assistant Prof. Earthquake Engineering Centre, UET, Peshawar	Member

Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

- In BCP 2021, the seismic analysis is based on the Maximum Considered Earthquake (MCE), which is a very rare type of earthquake with a 2% probability of exceedance in 50 years.
- In contrast to BCP-SP 2007, which relied on a singular Peak Ground Acceleration (PGA) across all time period values, BCP-2021 introduces two distinct spectral accelerations at specified time periods.
    1. Short Period Spectral Acceleration (S_s) → T = 0.2 sec
    2. Long Period spectral Acceleration (S_1) → T = 1.0 sec

Introduction to BCP 2021

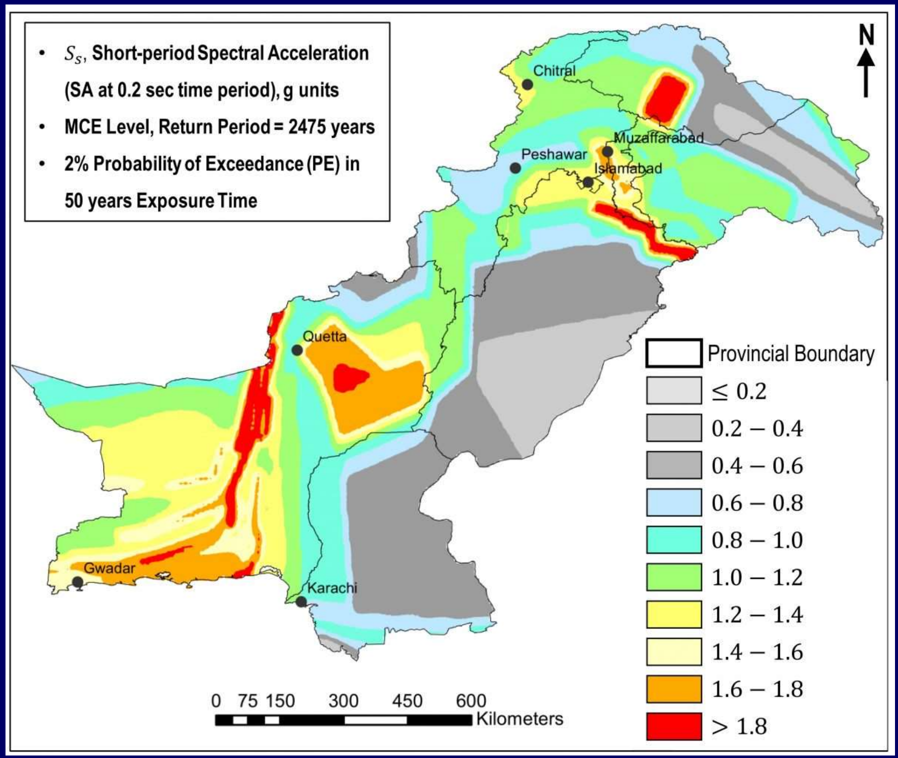
Seismic Loading Criteria in BCP 2021

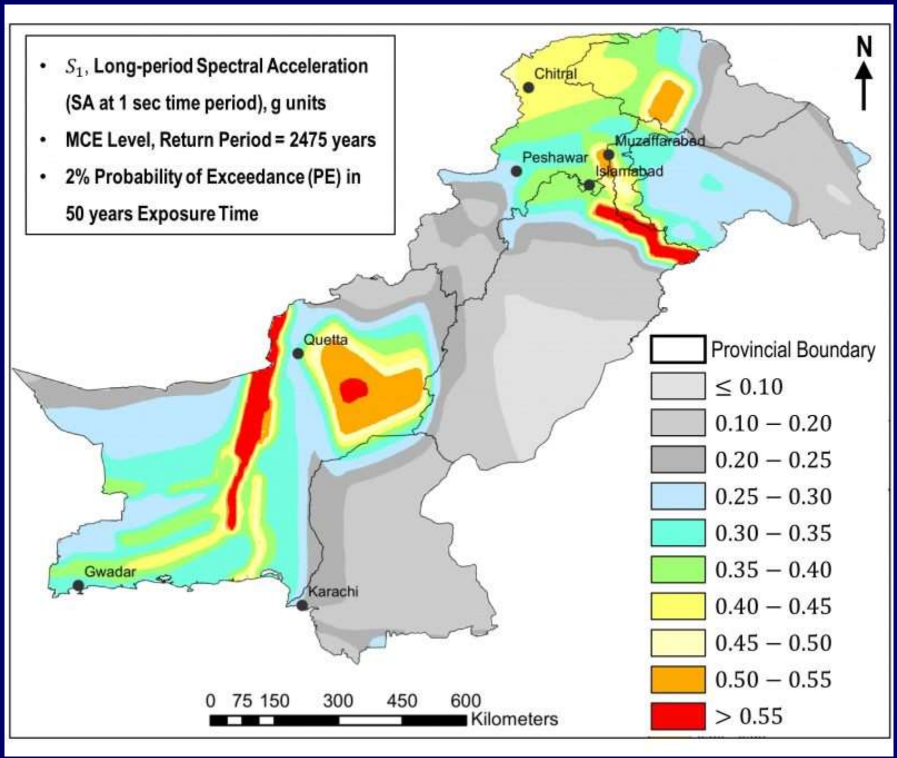
- The parameters S_s and S_1 values are selected from the relevant Seismic hazard map of country.
- For Pakistan, these values are provided in figures 1613.2.1(1) and 1613.2.1(2) of BCP-2021 as shown next.

Introduction to BCP 2021

Seismic Loading Criteria in BCP 2021

Seismic Map of Pakistan





Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

❖ Adjusted MCE Level Spectral Acceleration Parameters

- It should be noted that the S_s and S_1 correspond to MCE level, excluding local site conditions.

- To account for the local site effects, the parameters shall be adjusted as follows;

$$S_{MS} = F_a \times S_s$$

$$S_{M1} = F_v \times S_1$$

Where;

F_a and F_v which are site coefficients provided in Tables 1613.2.2(1) and 1613.2.2(2) of BCP-2021 (shown next)

Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

❖ Adjusted MCE Level Spectral Acceleration Parameters

- Site Coefficients F_a and F_v

TABLE 1613.2.3(1)
VALUES OF SITE COEFFICIENT F_a[a]

SITE CLASS	MAPPED RISK TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) SPECTRAL RESPONSE ACCELERATION PARAMETER AT SHORT PERIOD					
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s = 1.25$	$S_s \ge 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	Note b	Note b	Note b
F	Note b	Note b	Note b	Note b	Note b	Note b

TABLE 1613.2.3(2)
VALUES OF SITE COEFFICIENT F_V[a]

SITE CLASS	MAPPED RISK TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) SPECTRAL RESPONSE ACCELERATION PARAMETER AT 1-SECOND PERIOD					
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 = 0.5$	$S_1 \ge 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2[c]	2.0[c]	1.9[c]	1.8[c]	1.7[c]
E	4.2	3.3[c]	2.8[c]	2.4[c]	2.2[c]	2.0[c]
F	Note b	Note b	Note b	Note b	Note b	Note b

Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

❖ Design Response Spectral Acceleration Parameters

- The five-percent damped design response spectral acceleration at short-period S_{DS} and at long period S_{D1} shall be determined from the following equations:

$$S_{DS} = \frac{2}{3} S_{MS} \quad \text{and} \quad S_{D1} = \frac{2}{3} S_{M1}$$

Hence,

$$S_{DS} = \frac{2}{3} S_S \times F_a$$

$$S_{D1} = \frac{2}{3} S_1 \times F_v$$

Introduction to BCP 2021

Seismic Loading Criteria in BCP 2021

Seismic Design Category (SDC)

- Contrary to BCP SP 2007, which used seismic zoning (from zone 1 to zone 4) to denote earthquake severity, the revised code now categorizes severity based on design category.
- The Seismic Design Category (SDC) is allocated to a structure depending on its occupancy category and the intensity of the design earthquake ground motion at the site.
- SDCs A, B, and C indicate lower hazard sites, whereas D, E, and F signify regions facing higher seismic risks.

Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

❖ Seismic Design Category (SDC)

- SDC is determined using Tables 1613.2.5(1) and 1613.2.5(2) of BCP-2021 (shown next) based on the design response spectral acceleration parameters (S_{DS} and S_s) and the risk category of the structure.

- The risk category for buildings and other structures can be obtained Table 1604.5 of BCP-2021.

Introduction to BCP 2021

Seismic Loading Criteria in BCP 2021

Seismic Design Category (SDC)

TABLE 1613.2.5(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD (0.2 second) RESPONSE ACCELERATION

VALUE OF S_{DS}	RISK CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D	D	D

TABLE 1613.2.5(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

VALUE OF S_{D1}	RISK CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D	D	D

Introduction to BCP 2021

❑ Seismic Loading Criteria in BCP 2021

❖ Seismic Design Category (SDC)

- Seismic design categories of some districts for Site class D and Seismic Risk Category III are provided below.

District	MCE RSA parameters		Site Coefficients		Adjusted MCE RSA parameters		DBE Parameters		SDC
	S_s	S_1	F_a	F_v	S_{MS}	S_{M1}	S_{DS}	S_{D1}	
Peshawar	0.84	0.29	1.164	2.02	0.98	0.59	0.65	0.39	D
Islamabad	1.3	0.38	1	1.92	1.30	0.73	0.87	0.49	D
Mansehra	1.17	0.36	1.032	1.94	1.21	0.70	0.80	0.47	D
Swat	1.06	0.40	1.076	1.9	1.14	0.76	0.76	0.51	D
Hangu	0.76	0.21	1.196	2.18	0.91	0.46	0.61	0.31	D
Mardan	0.76	0.32	1.196	1.98	0.91	0.63	0.61	0.42	D

Introduction to BCP 2021

Determination of Lateral Force

Equivalent Lateral Force Procedure

- BCP 2021 refers to ASCE 7-16 Section 12.8 for determination of total design base shear force in a given direction.

$$V = C_s W$$

Where;

C_s = seismic response coefficient $= \frac{S_{DS} I_e}{R}$

- S_{DS} = design response spectral acceleration parameter at short period
- I_e = seismic importance factor, obtained from Table (1.5-2 of ASCE 7)
- R = response modification factor, obtained from Table (12-2.1 of ASCE 7)

W = effective seismic weight

Introduction to BCP 2021

Determination of Lateral Force

Equivalent Lateral Force Procedure

- **Seismic Coefficient Limits**

The value of C_s shall not exceed $C_{s,max}$

$$C_{s,max} \begin{cases} \dfrac{S_{D1} I_e}{RT} & \text{for } T \le T_L \\ \dfrac{S_{D1} I_e T_L}{RT^2} & \text{for } T > T_L \end{cases}$$

Where;

S_{D1} = design response spectral acceleration parameter at long period

T = structure′s period (defined next)

T_L = long-period transition period(s) determined from seismic maps (typically T_L = 8 sec)

Introduction to BCP 2021

Determination of Lateral Force

Equivalent Lateral Force Procedure

- **Seismic Coefficient Limits**

Similarly, The value of C_s shall not be less than $C_{s,min}$

$$C_{s,min} = 0.044 S_{DS} I_e \geq 0.01$$

In addition, for structures located where S_1 is equal to or greater than 0.6g, C_s shall not be less than

$$C_{s,min} = \frac{0.5 S_1 I_e}{R}$$

Introduction to BCP 2021

Determination of Lateral Force

Equivalent Lateral Force Procedure

- **Structure's Period**

- The approximate fundamental period (T_a), in seconds, shall be determined in accordance with ASCE 7, 12.8.2.1.

$$T_a = C_t (h_n)^x$$

Where;

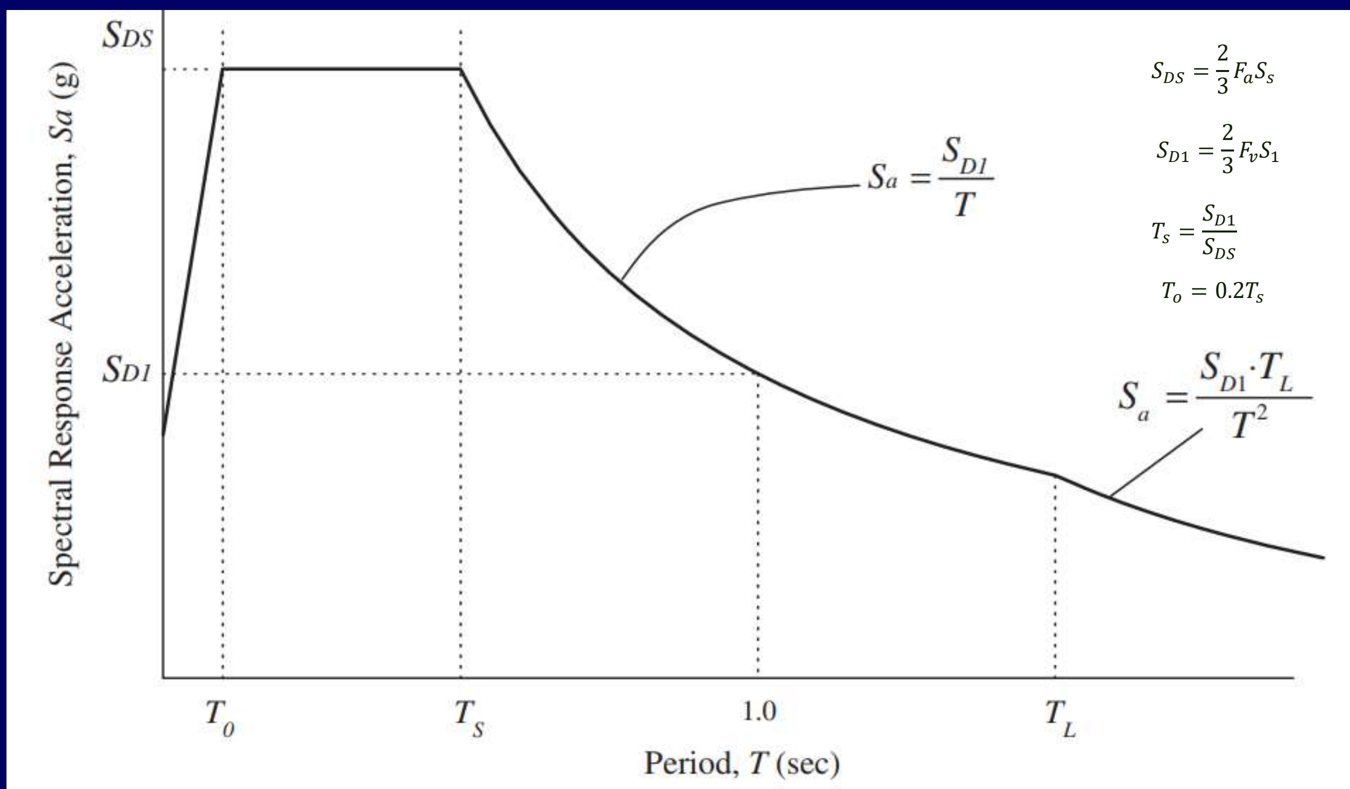
- h_n = structural height (from base level to top)
- $C_t = 0.028$ and $x = 0.8$ (for steel moment-resisting frames)
- $C_t = 0.016$ and $x = 0.9$ (for concrete moment-resisting frames)

Introduction to BCP 2021

Determination of Lateral Force

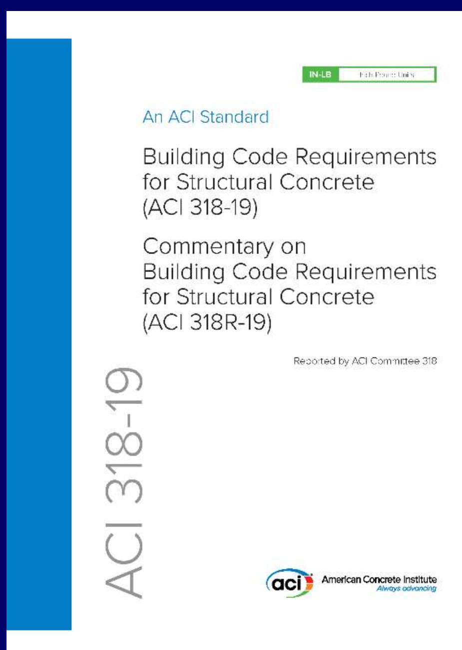
Dynamic Lateral Force Procedure

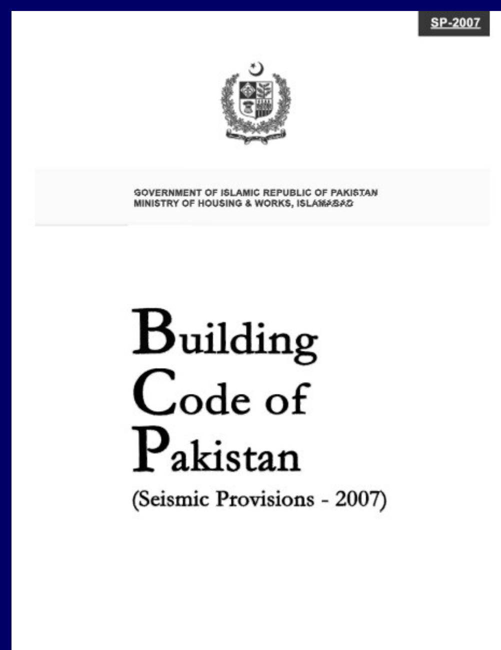
- Response Spectrum Analysis

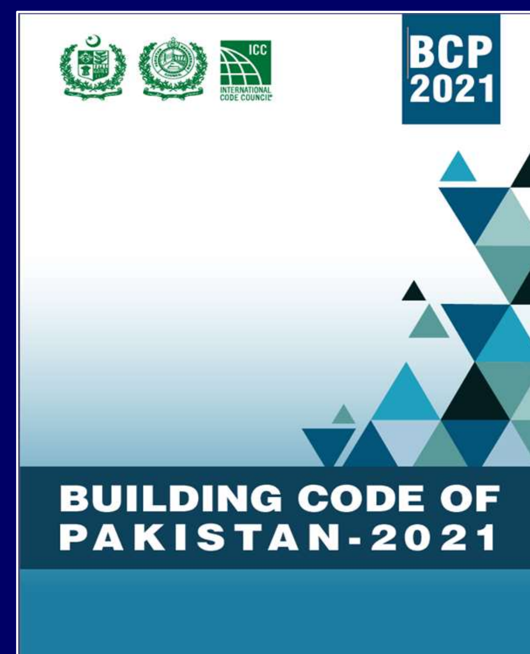


References

- Building Code Requirements for Structural Concrete (ACI 318-19)
- Building Code of Pakistan Seismic Provisions 2007 / UBC-97 Volume 2
- Building Code of Pakistan 2021







Appendix

❑ Seismic Tables of UBC-97

Table 4.1 — Seismic Zone Factor Z				
Soil Profile Type	Generic Description	Average Soil Properties for Top 100ft of Soil Profile		
		Shear wave velocity (ft/s)	SPT N(blows/ft)	Undrained Shear Strength (psf)
S_A	Hard rock	> 4920	---	---
S_B	Rock	2460 to 4920		
S_C	Very dense Soil & soft Rock	1150 to 2460	> 50	> 2000
S_D	Stiff soil Profile	575 to 1150	15 to 50	1000 to 2000
S_E	Soft soil	< 575	< 15	< 1000
S_F	Soil requiring site-specific Evaluation			

Appendix

❑ Seismic Tables of UBC-97

Table 5.20 —Seismic Source Type			
Seismic Source Type	**Seismic Source Description**	**Maximum moment Magnitude**	**Slip Rate (mm/yr)**
A	Faults that can produce large magnitude events and that have high rate of seismic activity	$M \geq 7.0$	$SR \geq 5$
B	All faults other than Types A and C	$M \geq 7.0$ $M < 7.0$ $M \geq 6.5$	$SR < 5$ $SR > 5$ $SR < 5$
C	Faults that are not capable of producing large magnitude events and that have relatively low rate of seismic activity	$M < 6.5$	$SR \leq 2$

Appendix

❑ Seismic Tables of UBC-97

Table 5.16 —Seismic Coefficients C_a					
Soil Profile Type	Seismic Zone Factor, Z				
	Z = 0.075	Z = 0.15	Z = 0.20	Z = 0.3	Z = 0.4
S_A	0.06	0.12	0.16	0.24	$0.32N_a$
S_B	0.08	0.15	0.20	0.30	$0.40N_a$
S_C	0.09	0.18	0.24	0.33	$0.40N_a$
S_D	0.12	0.22	0.28	0.36	$0.44N_a$
S_E	0.19	0.30	0.34	0.36	$0.36N_a$
S_F	See Footnote 1				

[1] Site-specific geotechnical investigation and dynamic site response analysis shall be performed to determine seismic coefficients for Soil Profile Type S_F.

Appendix

❑ Seismic Tables of UBC-97

Table 5.17 —Seismic Coefficients C_v					
Soil Profile Type	**Seismic Zone Factor, Z**				
	Z = 0.075	**Z = 0.15**	**Z = 0.20**	**Z = 0.3**	**Z = 0.4**
S_A	0.06	0.12	0.16	0.24	$0.32N_v$
S_B	0.08	0.15	0.20	0.30	$0.40N_v$
S_C	0.13	0.25	0.32	0.45	$0.56N_v$
S_D	0.18	0.32	0.40	0.54	$0.64N_v$
S_E	0.26	0.50	0.64	0.84	$0.96N_v$
S_F	See Footnote 1				

[1] Site-specific geotechnical investigation and dynamic site response analysis shall be performed to determine seismic coefficients for Soil Profile Type S_F.

Appendix

❑ Seismic Tables of UBC-97

Table 5.18 —Near Source Factor, N_a

Seismic Source Type	Closest Distance To Known Seismic Source		
	≤ 2 km	5 km	≥ 10 km
A	1.5	1.2	1.0
B	1.3	1.0	1.0
C	1.0	1.0	1.0

Table 5.19 —Near Source Factor, N_v

Seismic Source Type	Closest Distance To Known Seismic Source			
	≤ 2 km	5 km	10 km	≥ 15 km
A	2	1.6	1.2	1.0
B	1.6	1.2	1.0	1.0
C	1.0	1.0	1.0	1.0

Appendix

❑ Seismic Tables of UBC-97

Table 5.10 — Occupancy Category

Occupancy Category	Occupancy or Function of Structure	Seismic Importance factor, I
Essential facilities	• Group I, Division 1 Occupancies having surgery and emergency treatment areas • Fire and police stations • Garages and shelters for emergency vehicles and emergency aircraft Structures and shelters in emergency-preparedness centers • Aviation control towers • Structures and equipment in government communication centers and other facilities required for emergency response • Standby power-generating equipment for Category 1 facilities • Tanks or other structures containing housing or supporting water or other • fire-suppression material or equipment required for the protection of Category 1, 2 or 3 structures	1.25
Hazardous facilities	• Group H, Divisions 1, 2, 6 and 7 Occupancies and structures therein housing or supporting toxic or explosive chemicals or substances • Nonbuilding structures housing, supporting or containing quantities of toxic or explosive substances that, if contained within a building, would cause that building to be classified as a Group H, Division 1, 2 or 7 Occupancy	1.25

Appendix

❑ Seismic Tables of UBC-97

Table 5.10 — Occupancy Category

Occupancy Category	Occupancy or Function of Structure	Seismic Importance factor, I
Essential facilities	• Group I, Division 1 Occupancies having surgery and emergency treatment areas • Fire and police stations • Garages and shelters for emergency vehicles and emergency aircraft Structures and shelters in emergency-preparedness centers • Aviation control towers • Structures and equipment in government communication centers and other facilities required for emergency response • Standby power-generating equipment for Category 1 facilities • Tanks or other structures containing housing or supporting water or other • fire-suppression material or equipment required for the protection of Category 1, 2 or 3 structures	1.25
Hazardous facilities	• Group H, Divisions 1, 2, 6 and 7 Occupancies and structures therein housing or supporting toxic or explosive chemicals or substances • Nonbuilding structures housing, supporting or containing quantities of toxic or explosive substances that, if contained within a building, would cause that building to be classified as a Group H, Division 1, 2 or 7 Occupancy	1.25

Appendix

❑ Seismic Tables of UBC-97

Table 5.10 — Occupancy Category		
Occupancy Category	**Occupancy or Function of Structure**	**Seismic Importance factor, I**
Special Occupancy Category	• Group A, Divisions 1, 2 and 2.1 Occupancies • Buildings housing Group E, Divisions 1 and 3 Occupancies with a capacity greater than 300 students • Buildings housing Group B Occupancies used for college or adult education with a capacity greater than 500 students • Group I, Divisions 1 and 2 Occupancies with 50 or more resident incapacitated patients, but not included in Category 1 • Group I, Division 3 Occupancies • All structures with an occupancy greater than 5,000 persons • Structures and equipment in power-generating stations, and other public utility facilities not included in Category 1 or Category 2 above, and required for continued operation	1.00
Standard occupancy structures	• All structures housing occupancies or having functions not listed in Category 1, 2 or 3 and Group U Occupancy towers	1.00
Miscellaneous structures	Group U Occupancies except for towers	1.00

Appendix

❑ Seismic Tables of UBC-97

Table 5.13 – Structural Systems		
Basic Structural System	**Lateral Force resisting System Description**	***R***
1. Bearing wall system	**1. Light-framed walls with shear panels**	
	a. Wood structural panel walls for structures three stories or less	5.5
	b. All other light-framed walls	4.5
	2. Shear walls	
	a. Concrete	4.5
	b. Masonry	4.5
	3. Light steel-framed bearing walls with tension-only bracing	2.8
	4. Braced frames where bracing carries gravity load	
	a. Steel	4.4
	b. Concrete	2.8
	c. Heavy timber	2.8

Appendix

❑ Seismic Tables of UBC-97

Table 5.13 – Structural Systems		
Basic Structural System	**Lateral Force resisting System Description**	***R***
2. Building frame system	**1. Steel eccentrically braced frame (EBF)**	7
	2. Light-framed walls with shear panels	
	a. Wood structural panel walls for structures three stories or less	6.5
	b. b. All other light-framed walls	5
	3. Shear walls	
	a. Concrete	5.5
	b. Masonry	5.5
	4. Ordinary braced frames	
	a. Steel	5.6
	b. Concrete	5.6
	c. Heavy timber	5.6
	5. Special concentrically braced frames	6.4

Appendix

❑ Seismic Tables of UBC-97

Table 5.13 – Structural Systems		
Basic Structural System	**Lateral Force resisting System Description**	***R***
3. Moment-resisting frame system	**1. Special moment-resisting frame (SMRF)** a. Steel b. Concrete	 8.5 8.5
	2. Masonry moment-resisting wall frame (MMRWF)	6.5
	3. Concrete intermediate moment-resisting frame (IMRF)	5.5
	4. Ordinary moment-resisting frame (OMRF) a. Steel b. Concrete	 4.5 3.5
	5. Special truss moment frames of steel (STMF)	6.5

The Table additionally provides the R-Factor values for other structural systems such as Dual Systems, Cantilevered Column Building Systems, Shear Wall-Frame Interaction Systems, and Undefined Systems.