Lecture 05

Introduction to Earthquake Resistant Design of RC Structures (Part – I)

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Lecture Contents

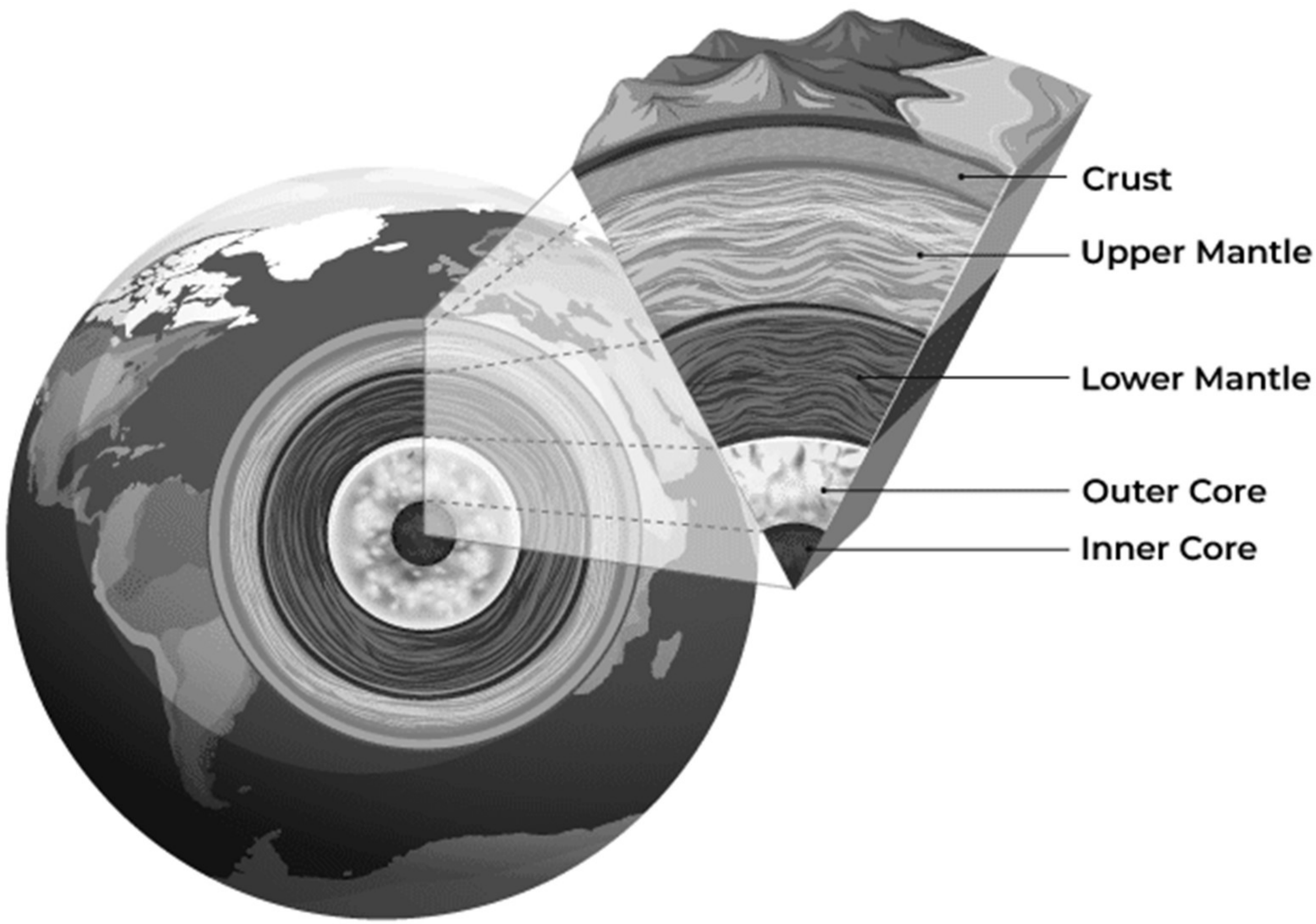
- Introduction to Earthquakes and Its Effects on Buildings
- Earthquake Design Philosophy
- Seismic Loading Criteria
- Static Lateral Force Procedure
- Design Examples
- References
- Appendix

Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Describe*** effects of earthquake loading on buildings
  - ***Explain*** earthquake *d*esign philosophy and seismic loading criteria
  - ***Calculate*** base shear using static lateral force procedures

Introduction to Earthquakes and Its Effects on Buildings

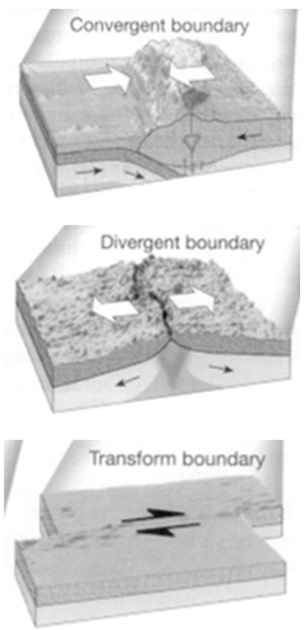
❑ The Earth's Interior

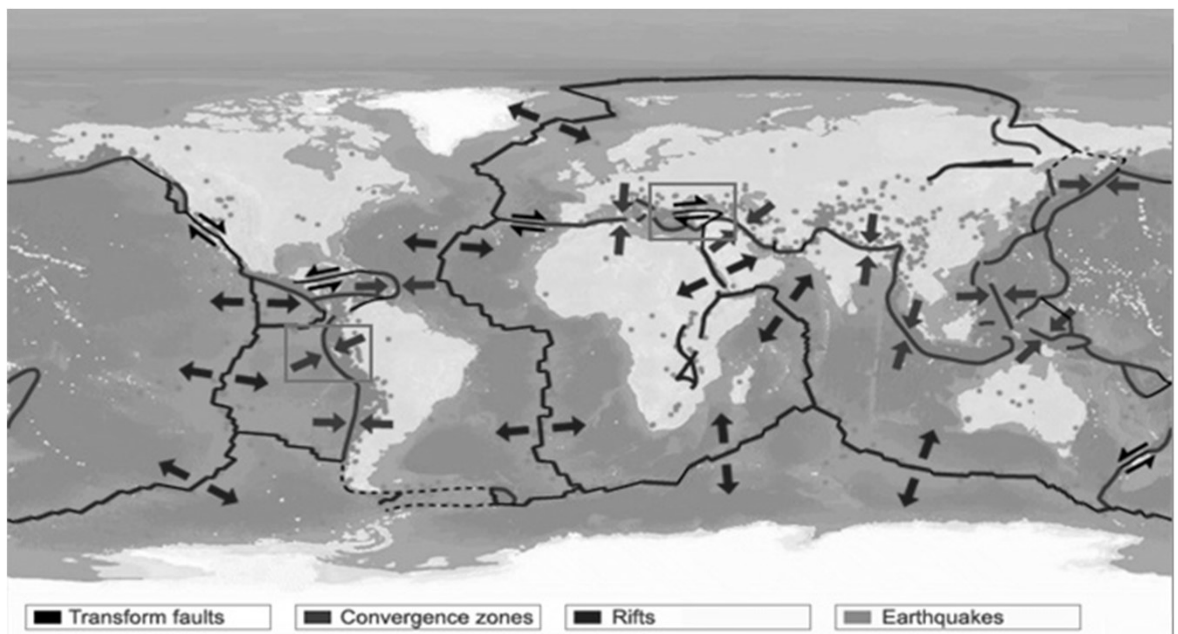


Introduction to Earthquakes and Its Effects on Buildings

❑ The Earth's Interior

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

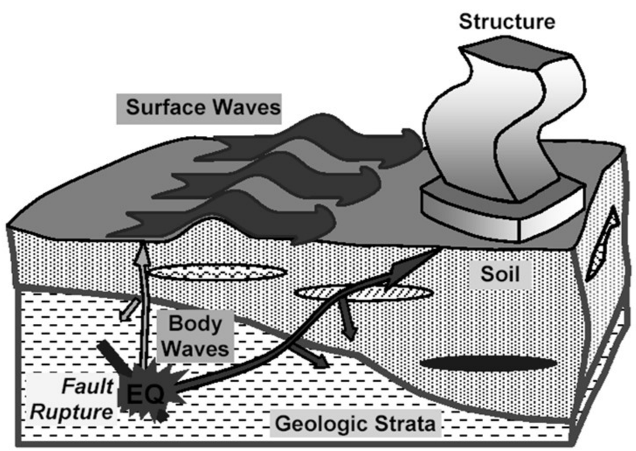


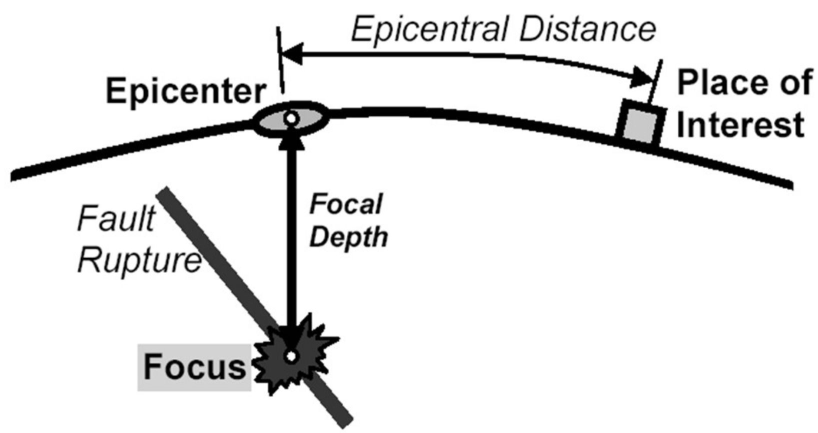


Introduction to Earthquakes and Its Effects on Buildings

❑ 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.

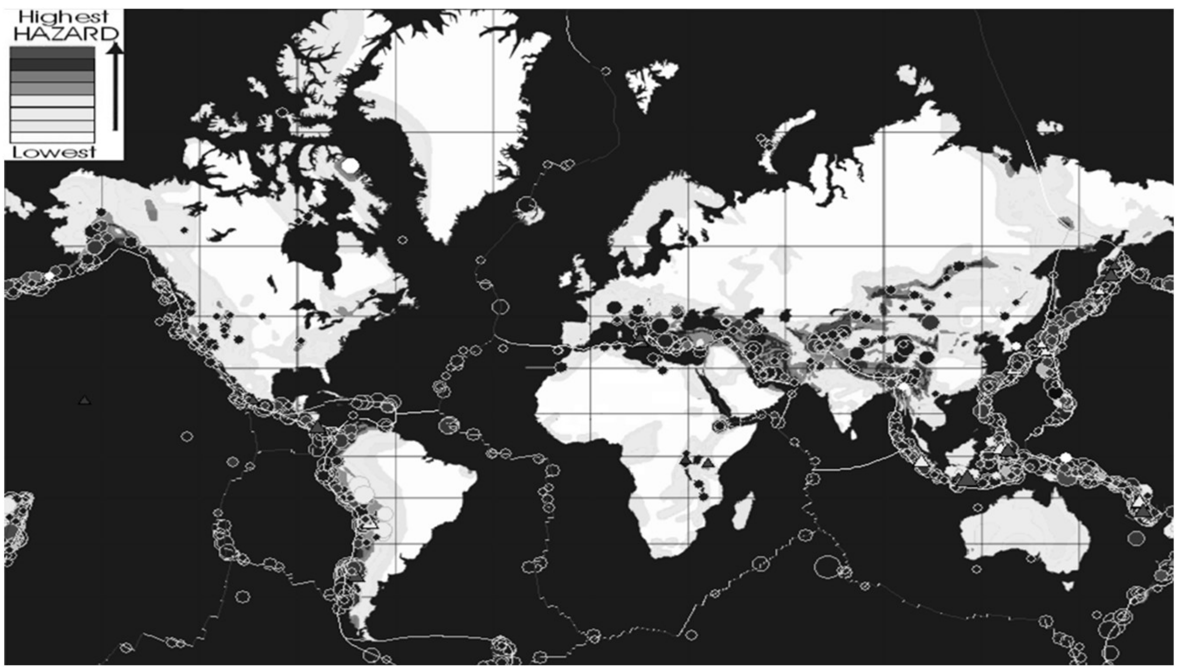




Introduction to Earthquakes and Its Effects on Buildings

❑ Seismic Events

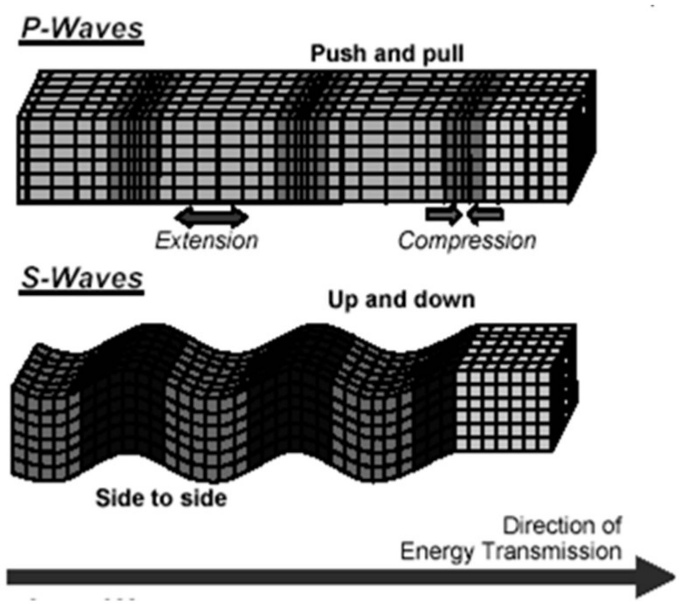
- Seismic events around the globe are shown below
- These events mostly take place at boundaries of Tectonic plates



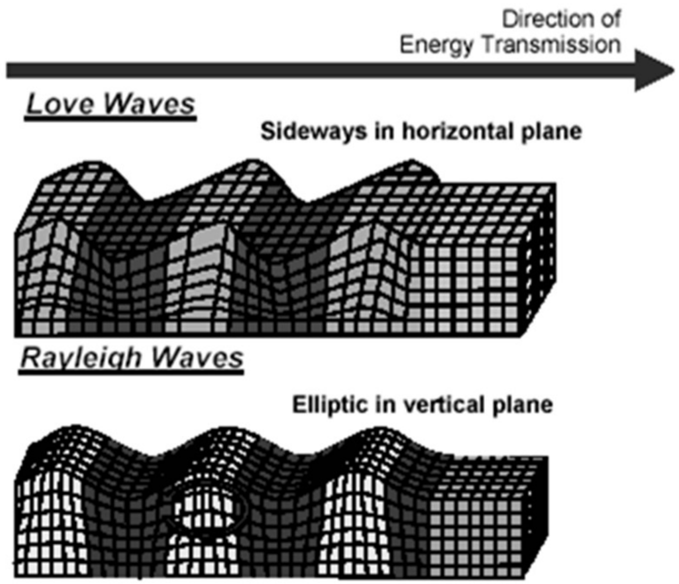
Dots represent an earthquake

Introduction to Earthquakes and Its Effects on Buildings

❑ Types of Waves Generated Due to Earthquake



Body Waves



Surface Waves

An Animation
explaining the various types of seismic waves and how they are recorded

Introduction to Earthquakes and Its Effects on Buildings

❑ Displacement due to Earthquake

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

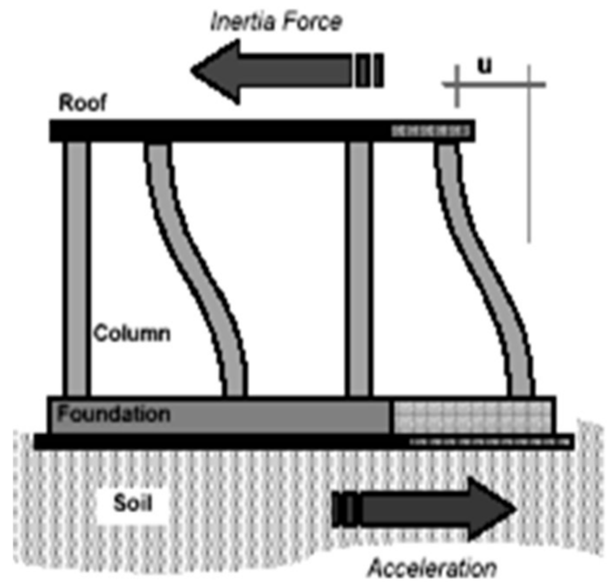


Figure 2: Inertia force and relative motion within a building

Introduction to Earthquakes and Its Effects on Buildings

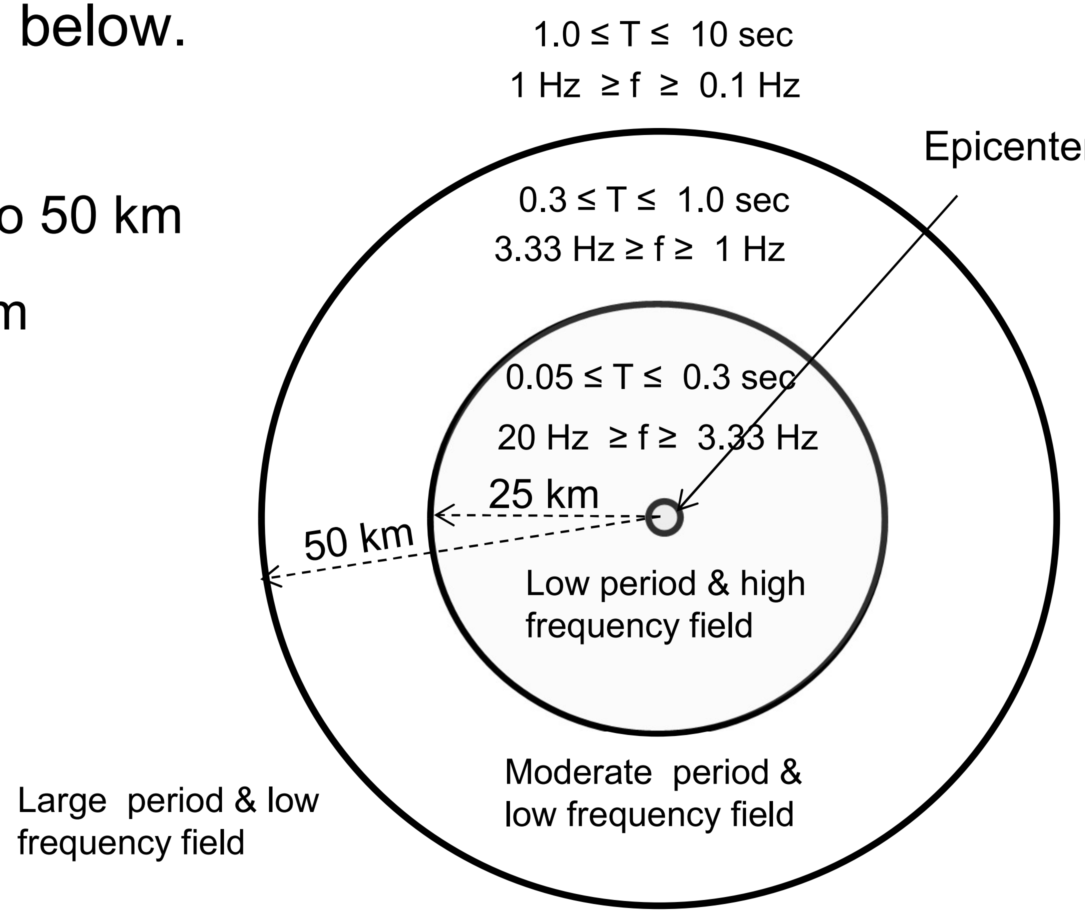
❑ Horizontal and Vertical Shaking

- 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.

Introduction to Earthquakes and Its Effects on Buildings

- **Earthquake characteristics**

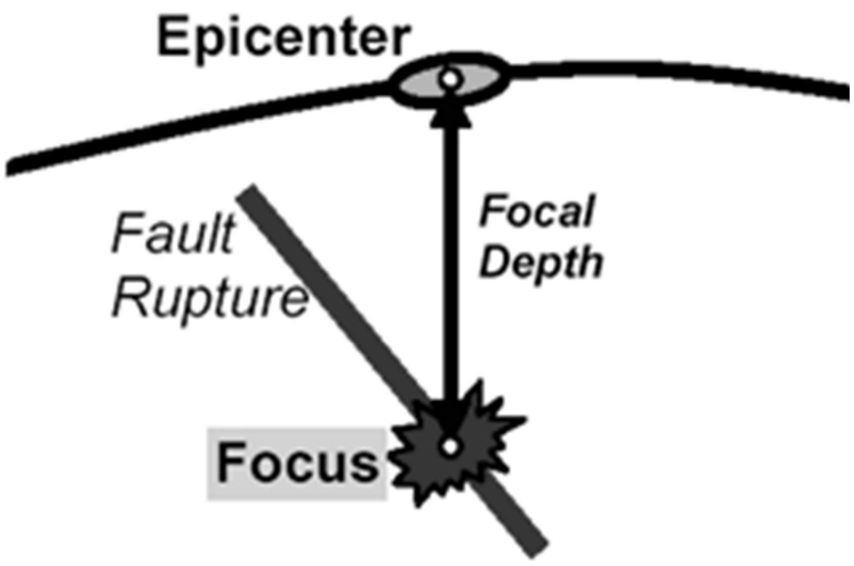
- The characteristics of earthquake with respect to distance from the epicenter are shown below.
  1. Near Field: 0 to 25 km
  2. Intermediate Field: 25 to 50 km
  3. Far Field: Beyond 50 km



Introduction to Earthquakes and Its 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.



Introduction to Earthquakes and Its 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).

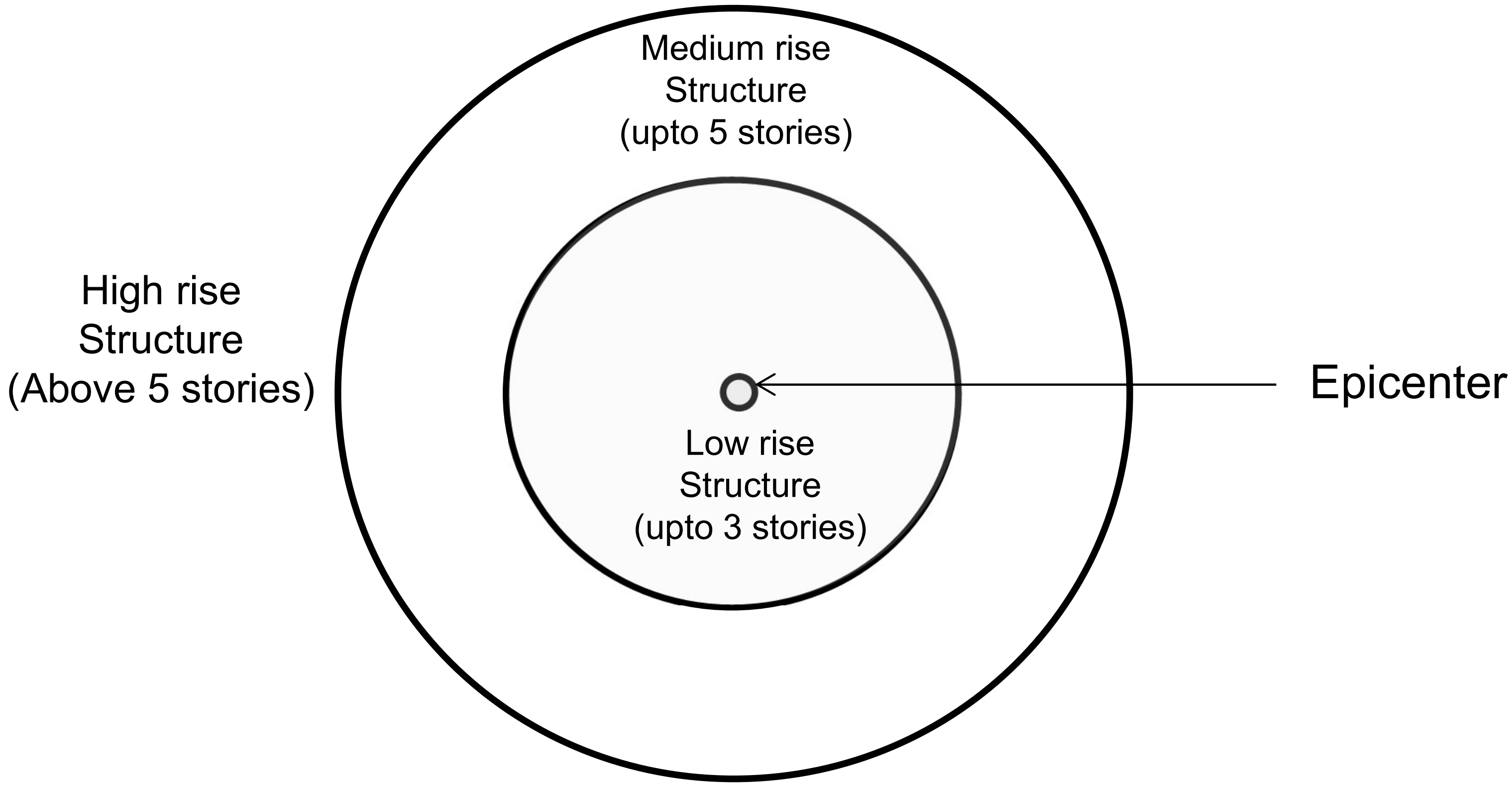
- For a particular structure, the natural time period is a function of mass and stiffness.

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

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

Introduction to Earthquakes and Its Effects on Buildings

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

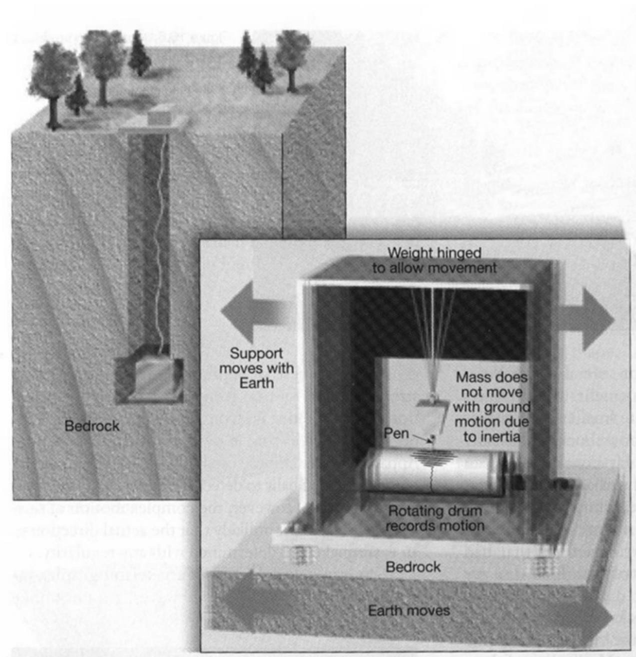


Introduction to Earthquakes and Its Effects on Buildings

❑ Earthquake Recording

❖ Seismograph

- Using multiple seismographs around the world, accurate location of the epicenter of the earthquake, as well as its magnitude or size can be determined.
- Working of seismograph shown in figure.

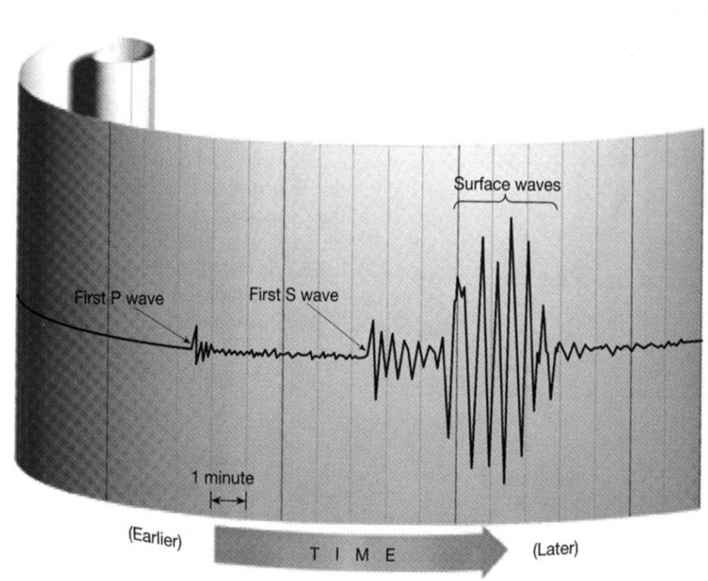


Introduction to Earthquakes and Its Effects on Buildings

❑ Earthquake Recording

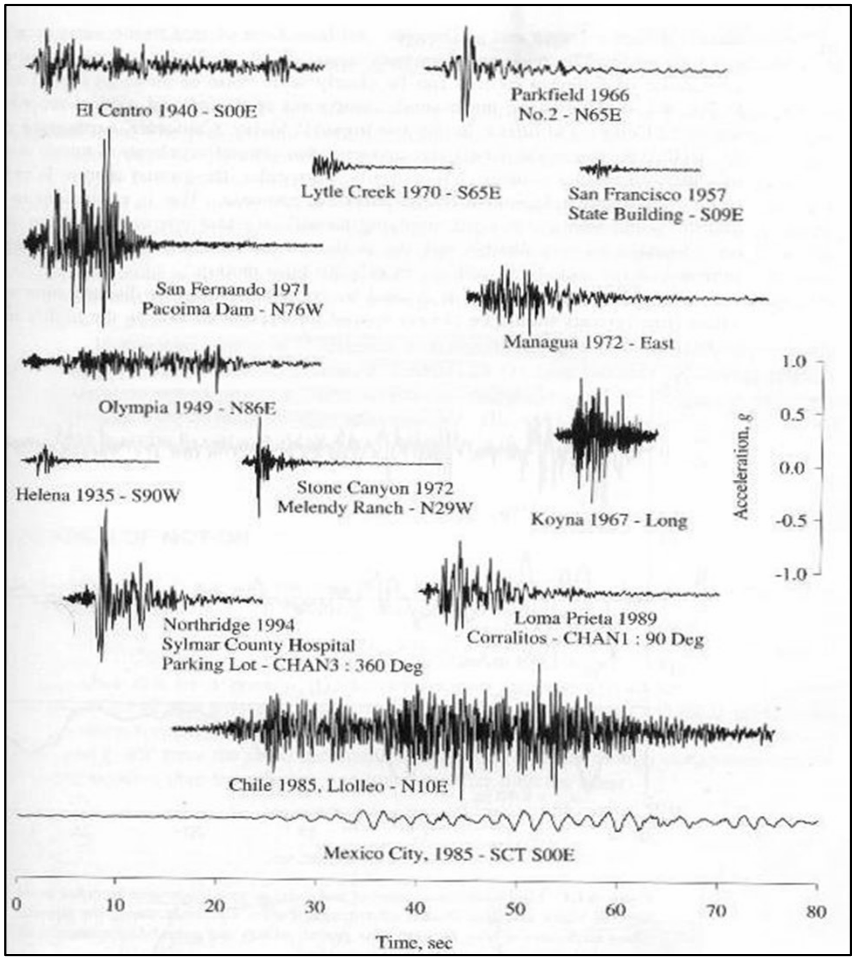
❖ Richter Scale

- In 1935, Charles Richter (US) developed this scale.
- The Richter scale is logarithmic, So, a magnitude 5 Richter measurement is ten times greater than a magnitude 4; while it is 10 x 10, or 100 times greater than a magnitude 3 measurement.



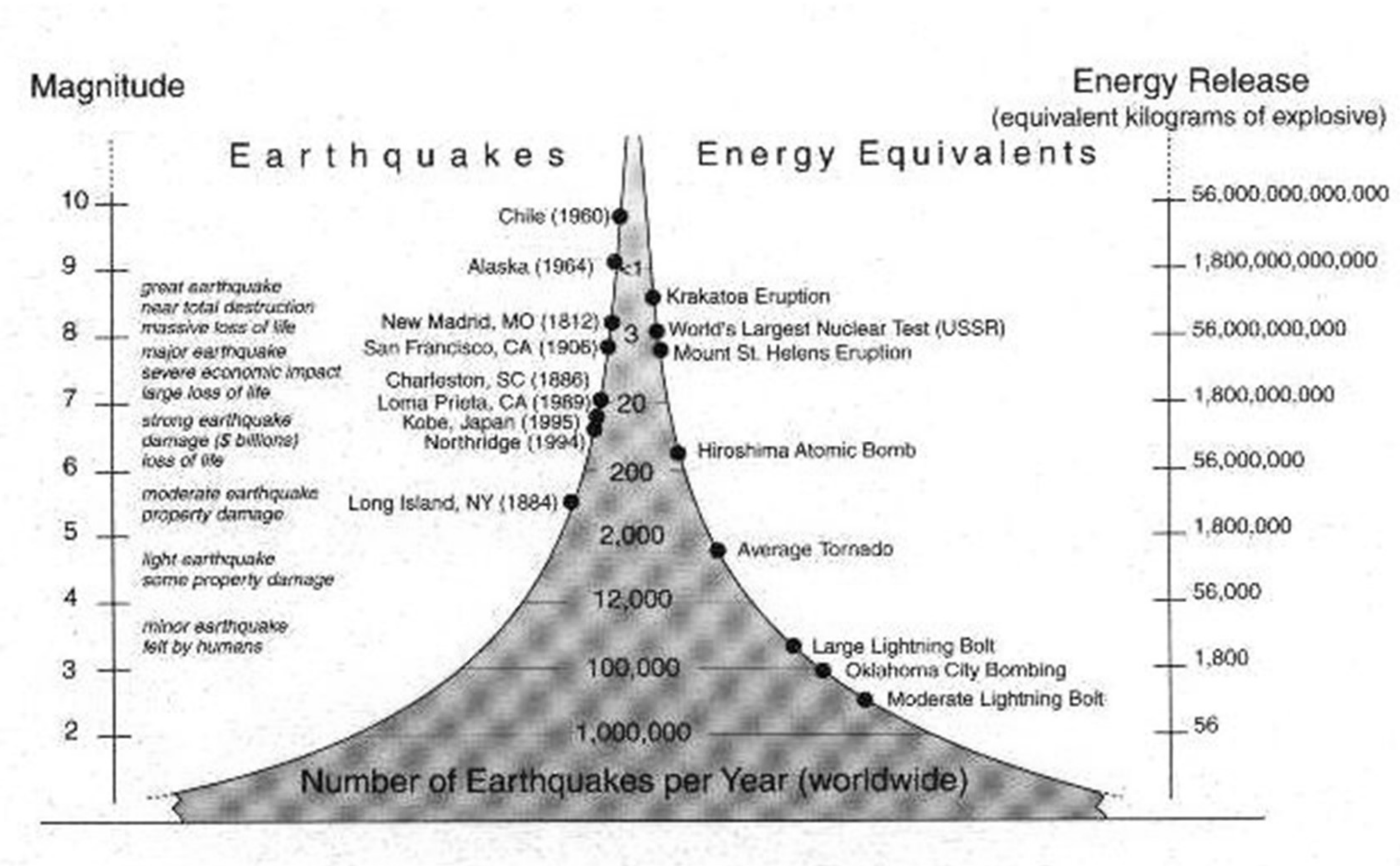
Introduction to Earthquakes and Its Effects on Buildings

- **Earthquake Recording**
  - ❖ **Some Famous Earthquake Records**



Introduction to Earthquakes and Its Effects on Buildings

❑ Earthquake Occurrence



Introduction to Earthquakes and Its 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.

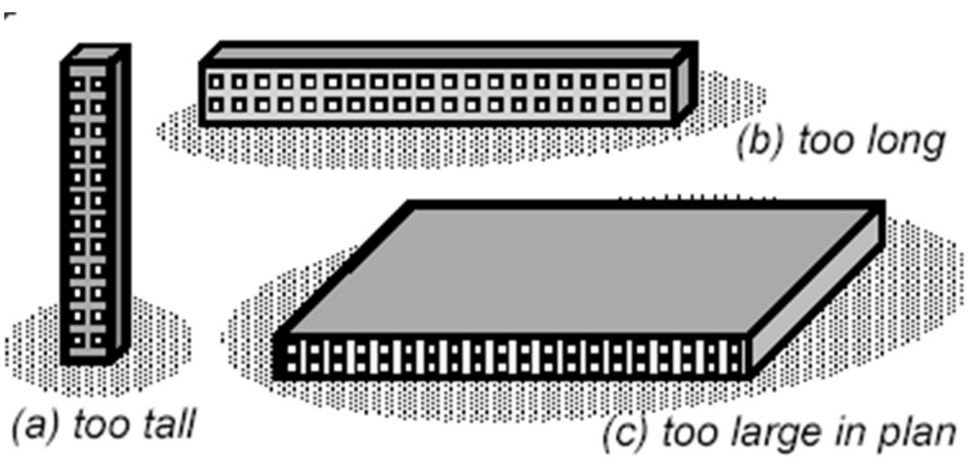


Figure 1: Buildings with one of their overall sizes much larger or much smaller than the other two, do not perform well during earthquakes.

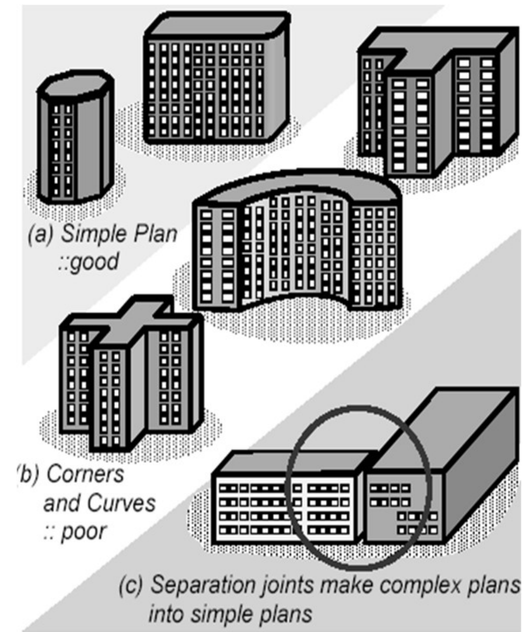


Figure 2: Simple plan shape buildings do well during earthquakes.

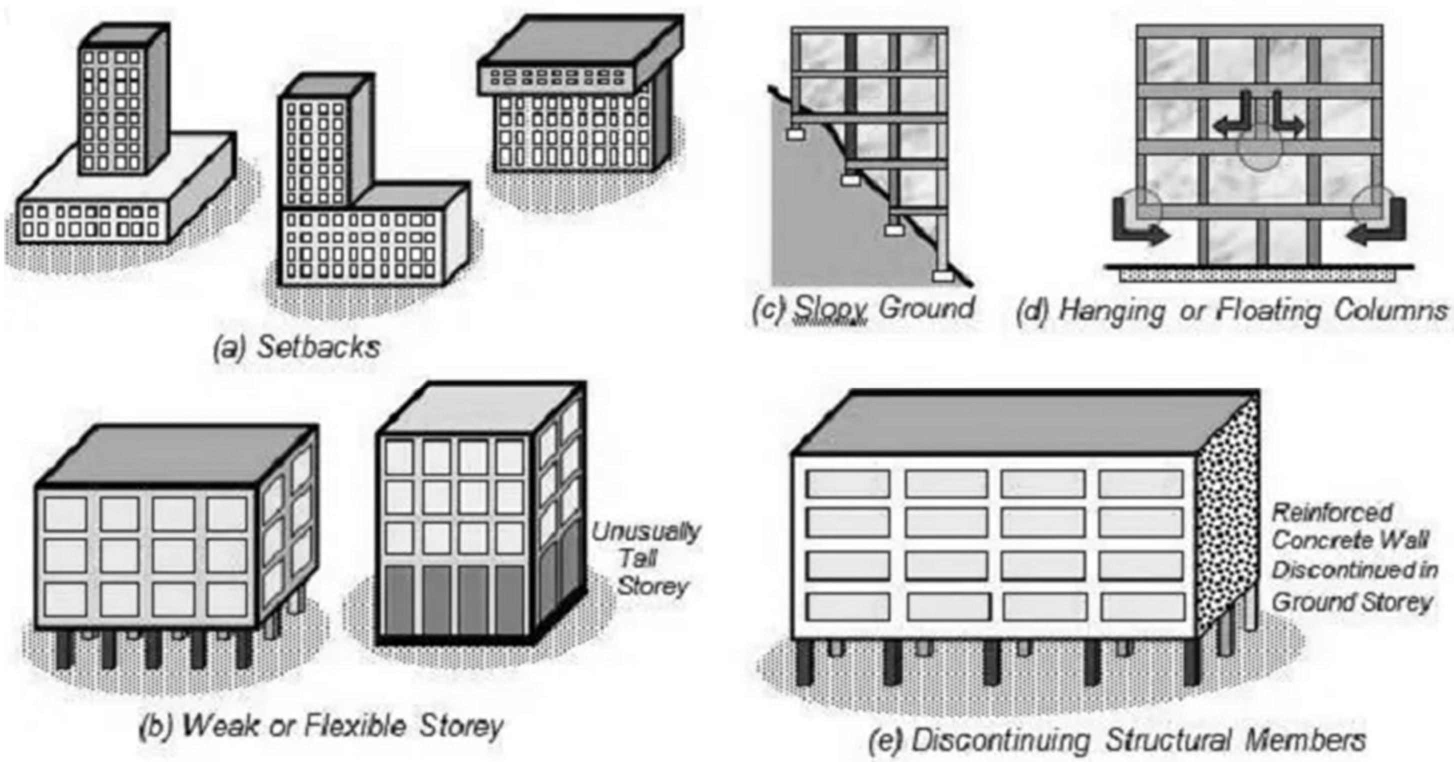
Introduction to Earthquakes and Its Effects on Buildings

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.

Introduction to Earthquakes and Its Effects on Buildings

❑ Other Undesirable Scenarios



(a) Setbacks

(b) Weak or Flexible Storey

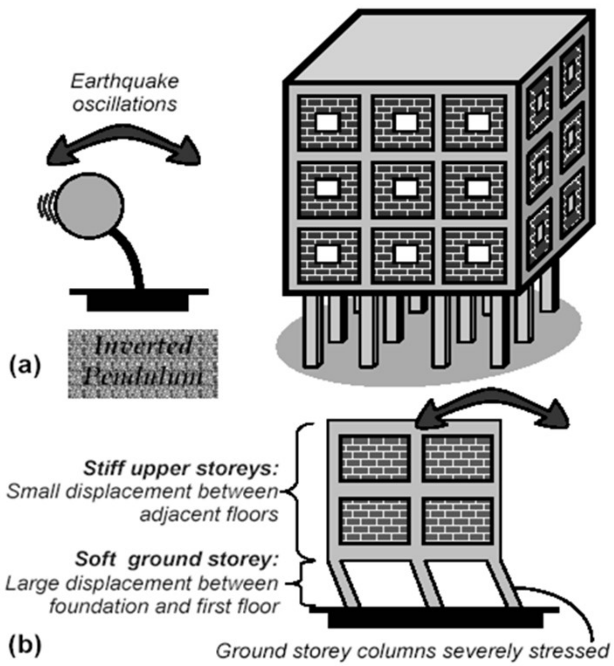
(c) Slopy Ground

(d) Hanging or Floating Columns

(e) Discontinuing Structural Members

Introduction to Earthquakes and Its Effects on Buildings

❑ Other Undesirable Scenarios



Introduction to Earthquakes and Its Effects on Buildings

❑ Earthquake Design Philosophy

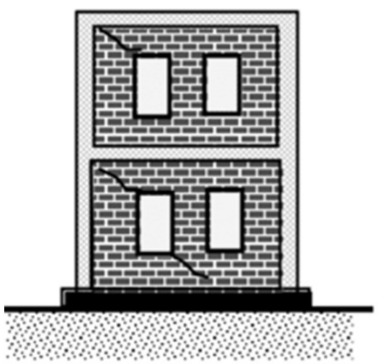
- Designing buildings to respond elastically to earthquakes without suffering any damage might be highly uneconomical.
- Hence, the design philosophy for earthquake resistant design is:

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

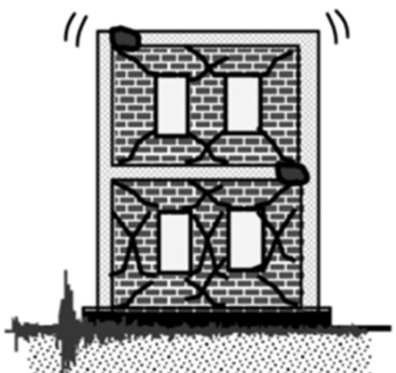
Introduction to Earthquakes and Its Effects on Buildings

❑ Earthquake Design Philosophy

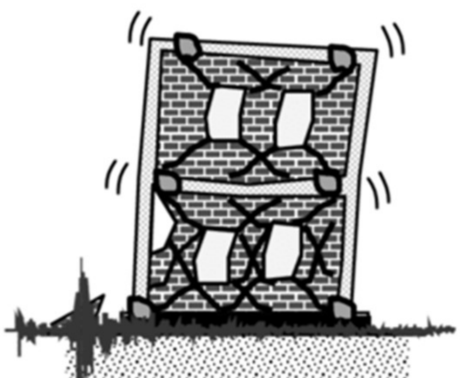
- Buildings should be able to resist;
  1. Minor Shaking with No/unnoticeable damage
  2. Moderate Shaking with Minor to moderate structural damage
  3. Severe Shaking with Structural damage, but no collapse



1. Minor Shaking



2. Moderate Shaking

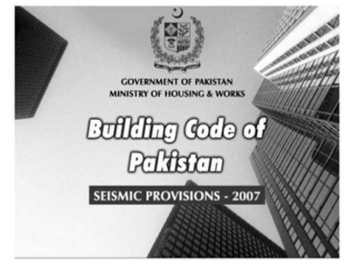


3. Severe Shaking

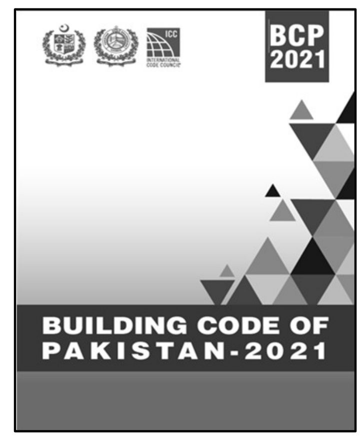
Seismic Loading Criteria

❑ 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).



- In this course, BCP SP 2007 will be followed.

Brief Visit to BCP 2007

Seismic Loading Criteria

❑ Seismic Zones

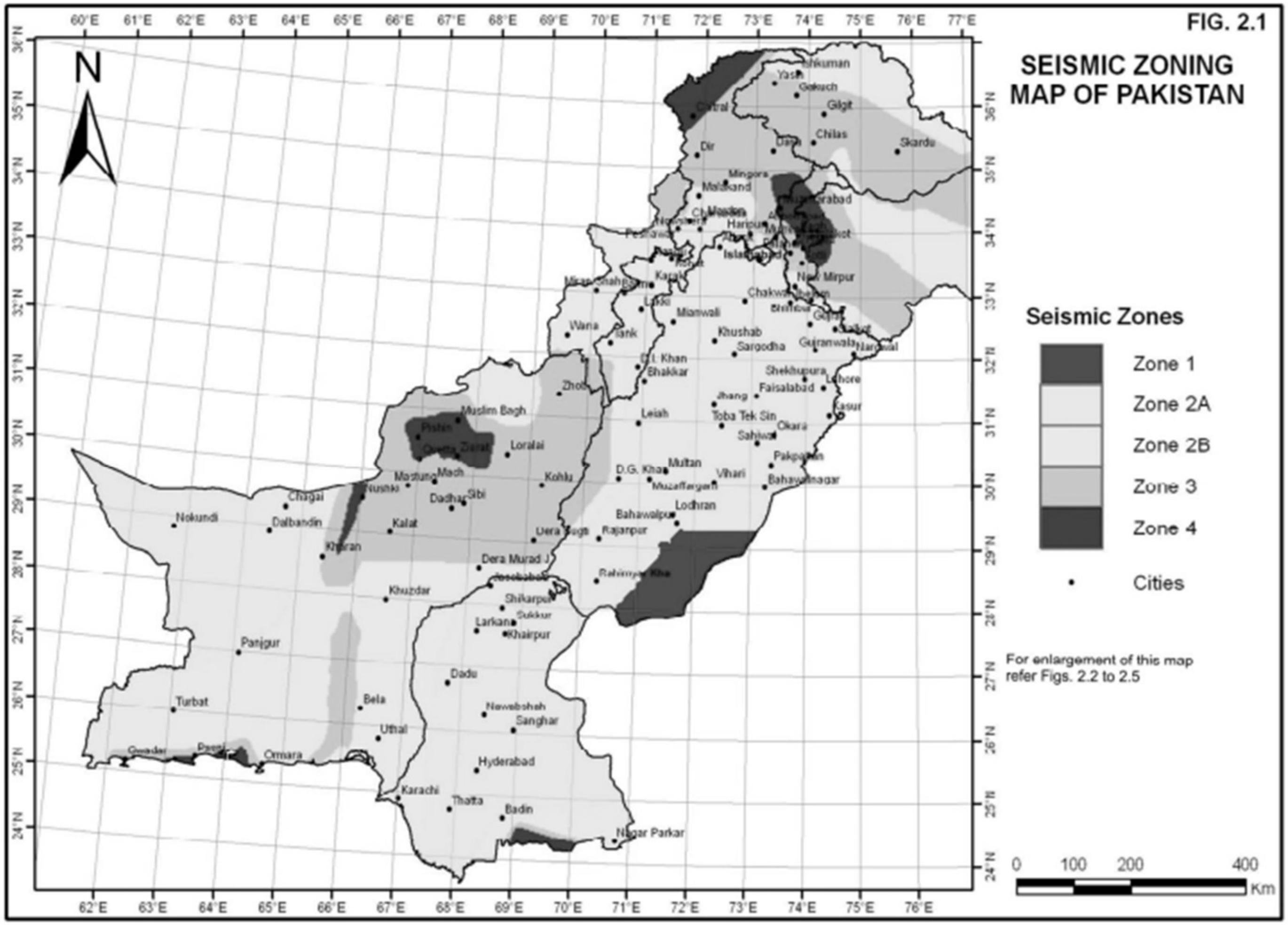
- According to BCP-SP 2007, Pakistan has been divided into five seismic zones. These zones are based on the peak ground acceleration ranges summarized in Table below

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 Zones**



Seismic Loading Criteria

❑ 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)
    2. Static lateral force procedure (Sec. 5.30.2, BCP-2007)

Seismic Loading Criteria

❑ Determination of Lateral Force

- BCP 5.31 includes information on dynamic lateral force procedures that involve the use of:

  i. Time history analysis.

  ii. Response spectrum analysis.

- The details of these methods are presented in sections 5.31.4 and 5.31.6 respectively.

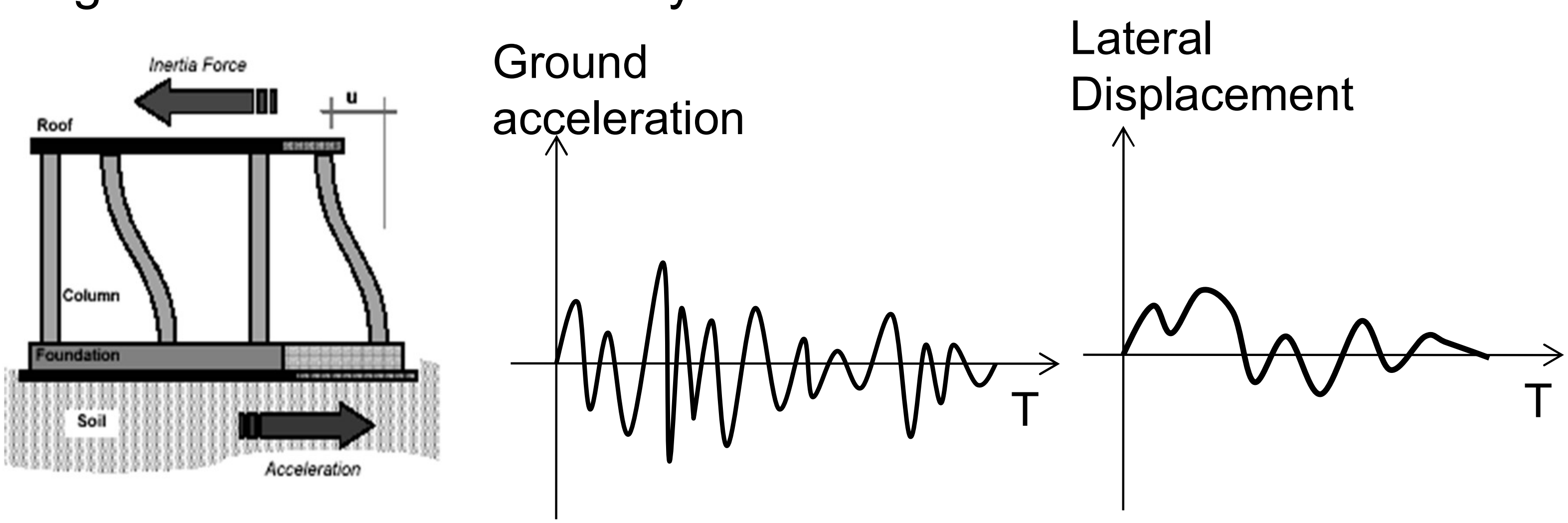
Seismic Loading Criteria

❑ Determination of Lateral Force

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

Determination of Lateral Force

1. **Dynamic Lateral Force Procedure**

   ii. Response Spectrum Analysis

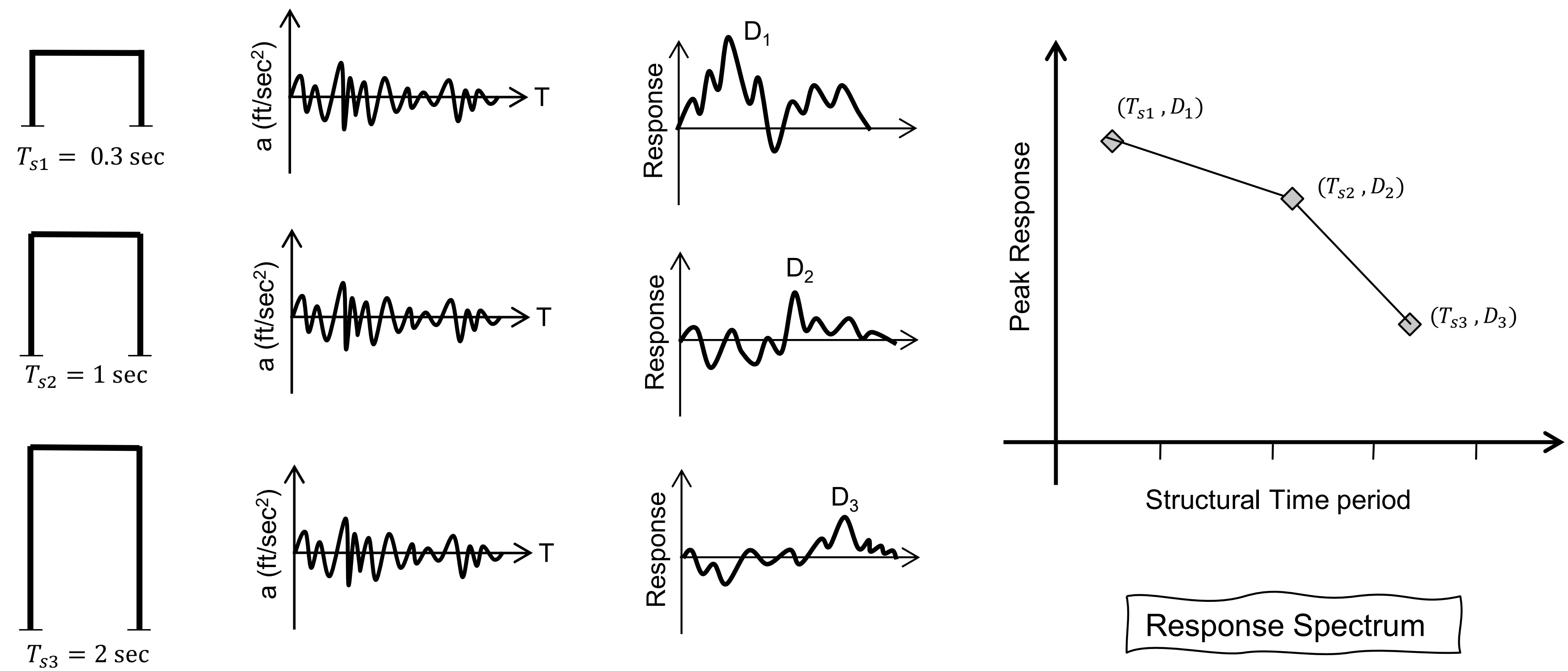
- Response Spectrum is a plot of peak response (acceleration, velocity, displacement) of a structure with respect to its natural time period.
- RSA is a linear dynamic statistical method that is used for measuring the maximum seismic response of an elastic structure subjected to ground motion.

Seismic Loading Criteria

❑ Determination of Lateral Force

1. Dynamic Lateral Force Procedure

ii. Response Spectrum Analysis

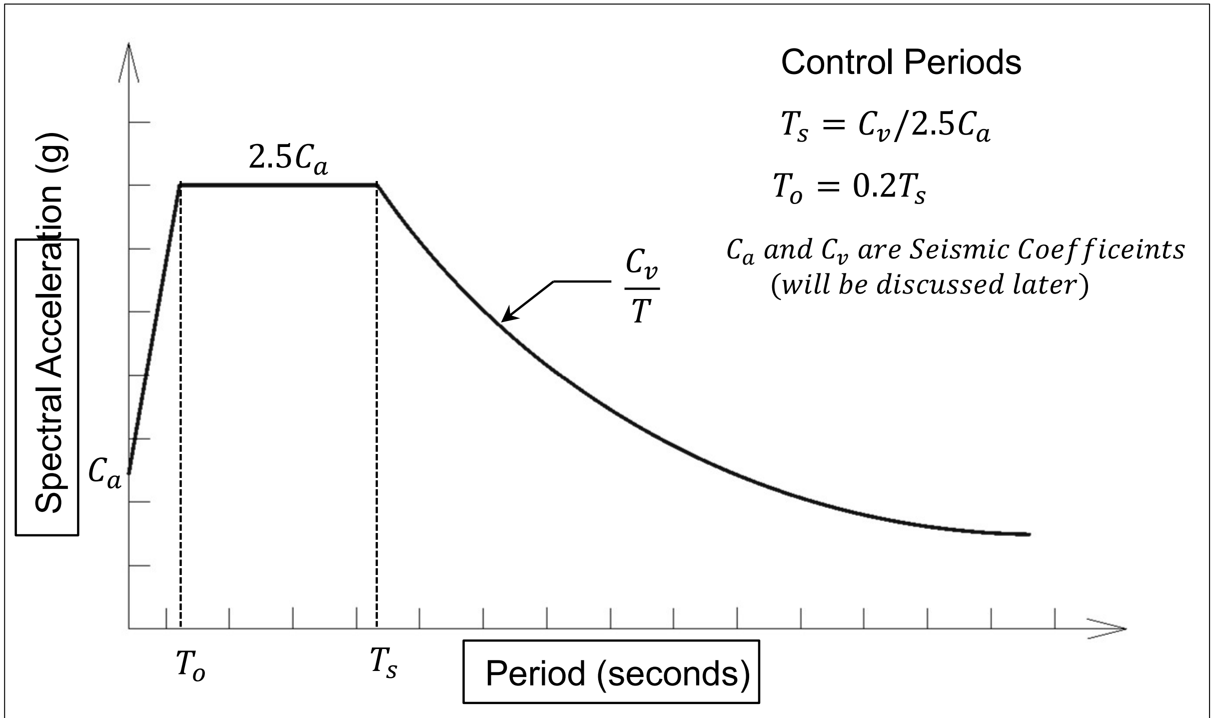


Seismic Loading Criteria

❑ Determination of Lateral Force

1. Dynamic Lateral Force Procedure

ii. Response Spectrum Analysis



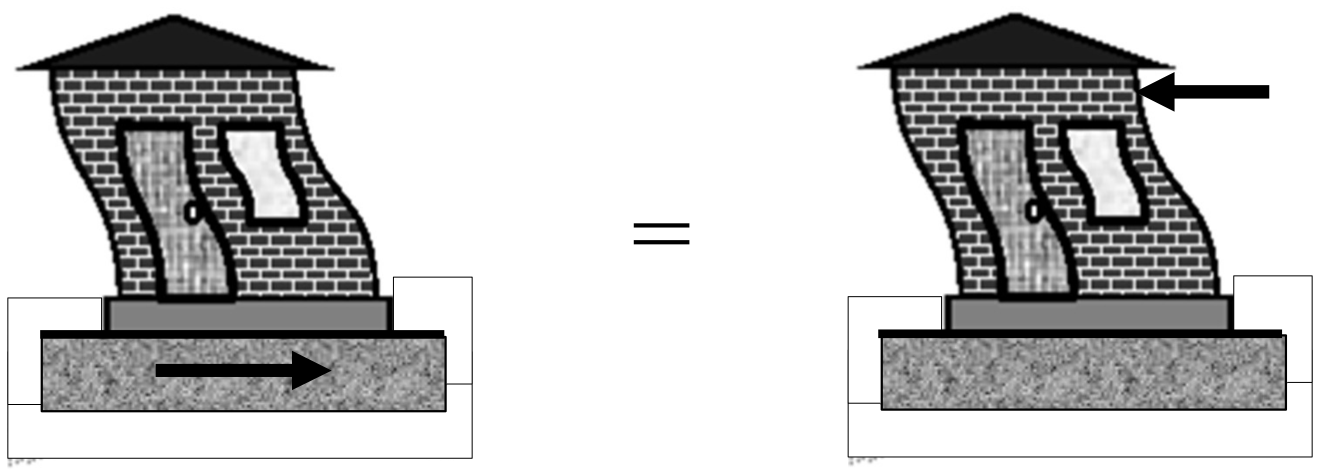
Response Spectra (BCP SP-2007)

Seismic Loading Criteria

❑ Determination of Lateral Force

2. Static Lateral 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.



Seismic Loading Criteria

❑ Determination of Lateral Force

2. Static Lateral Force Procedure (5.30.2)

- The total design base shear (V) in a given direction can be determined from the following formula;

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

Where;

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

Seismic Loading Criteria

❑ Determination of Lateral Force

2. Static Lateral Force Procedure (5.30.2)

- Base Shear Limits

$$V_{min} = 0.11C_a IW$$

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

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

Where; N_v = near source factor (Table 5.19)

Z = Seismic zone factor (Table 5.9)

Static Lateral Force Procedure

Steps involved in determination of Base Shear

- Step 1: Find Site Specific details
- Step 2: Select Seismic Coefficients
- Step 3: Select Seismic Importance factor
- Step 4: Select Response Modification factor
- Step 5: Determine structure's time period
- Step 6: Calculate base shear and apply base shear limits
- Step 7: Distribute base shear in vertical direction

Static Lateral Force Procedure

❑ Step 1: Find Site Specific Details

- Following list of data needs to be obtained:

    i. Seismic Zone

    ii. Soil Profile Type

    iii. Past earthquake magnitude (required only for Zone 4).

    iv. Closest distance to known seismic source (required only for Zone 4).

Static Lateral Force Procedure

❑ Step 1: Find Site Specific Details

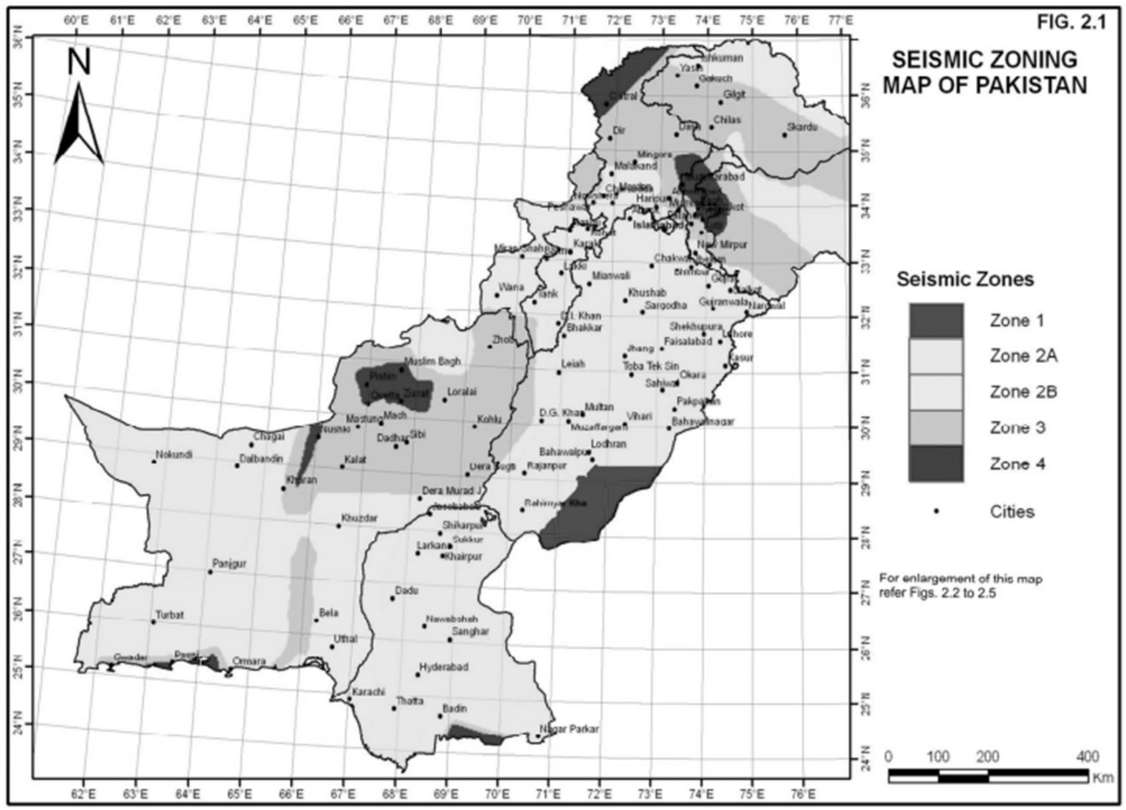
i. Seismic Zone

- Seismic Zone for a given site can be selected from the seismic zoning map of the country.
- The seismic zoning map of Pakistan is given in Figure 2.1, while Seismic zoning map of each province have been provided in Figures 2.2 to 2.5 of BCP-SP 2007, are shown in next slides.
- Table 2.2 of BCP lists the seismic zones for all tehsils of the country. This table has been included as an appendix to this Lecture.

Static Lateral Force Procedure

- Step 1: Find Site Specific Details

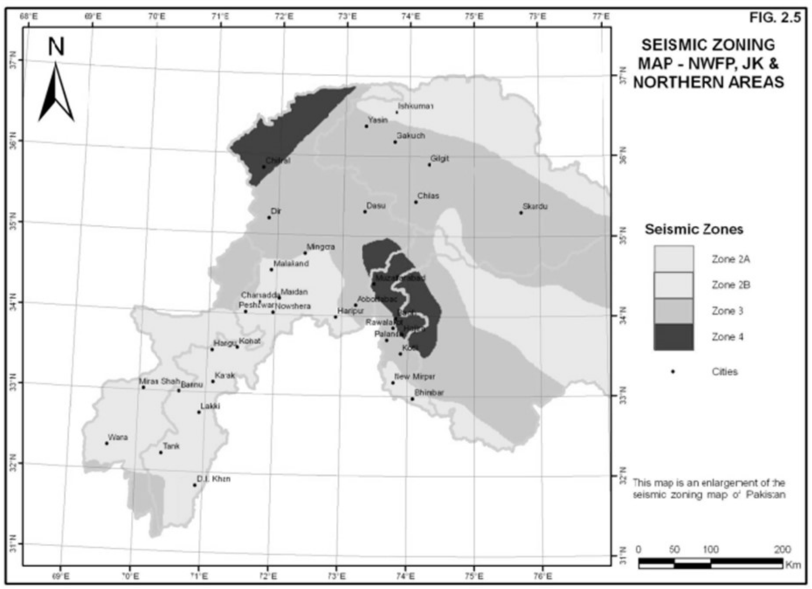
  i. Seismic Zone

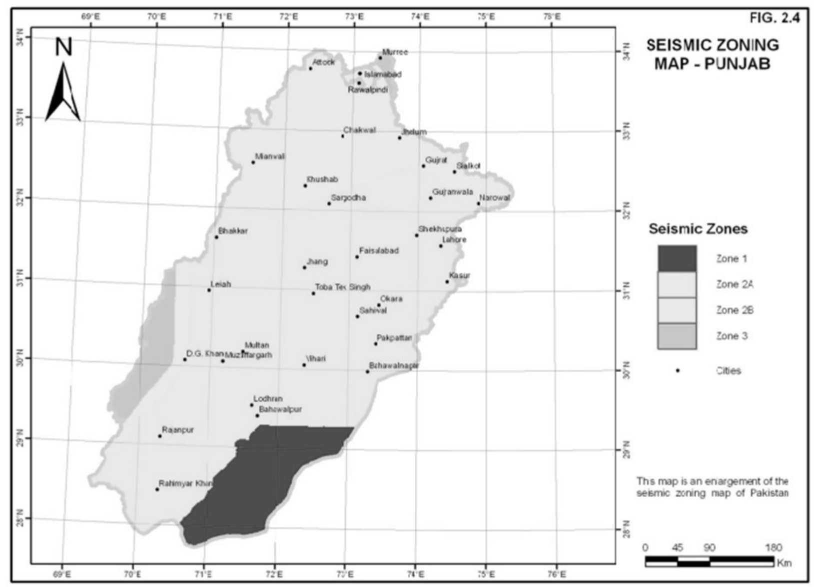


Static Lateral Force Procedure

- **Step 1: Find Site Specific Details**

  i. **Seismic Zone**

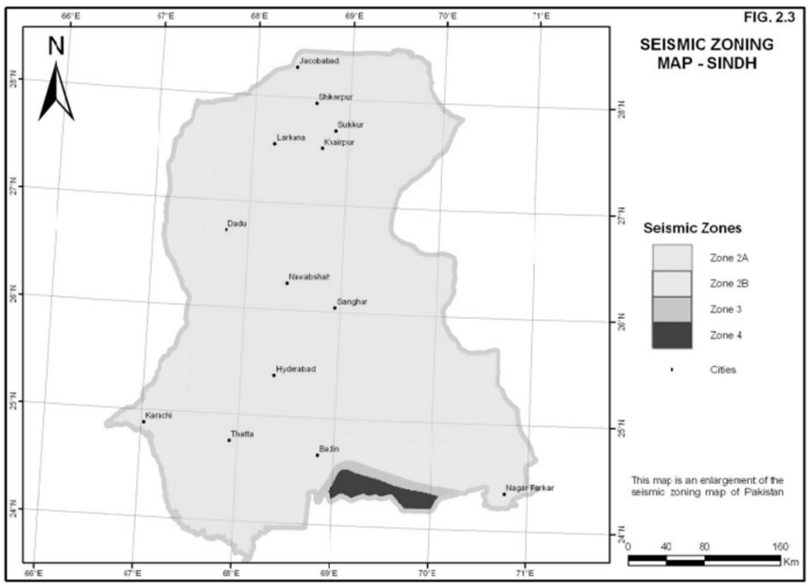


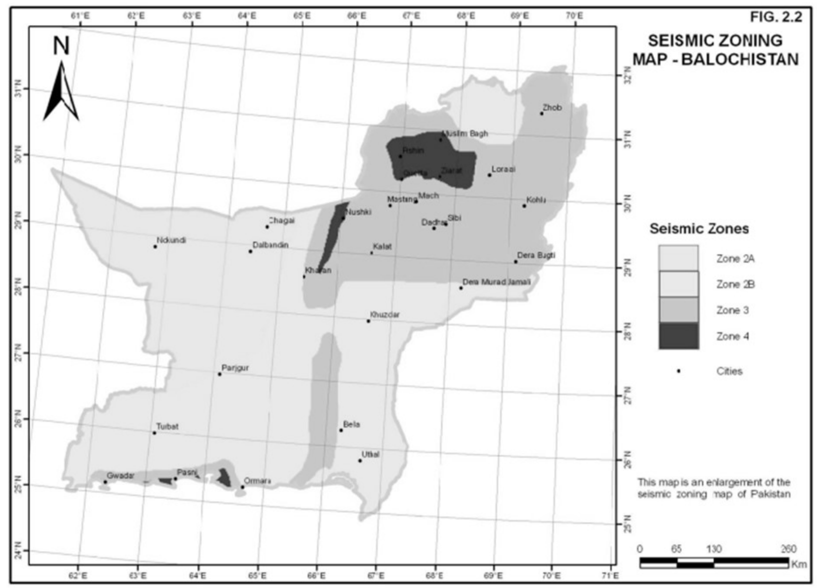


Static Lateral Force Procedure

- ❑ **Step 1: Find Site Specific Details**

  i. **Seismic Zone**





Static Lateral Force Procedure

Step 1: Find Site Specific Details

i. Seismic Zone

- After selecting the Seismic zone, Seismic zone factor Z can be chosen from 5.9 of BCP SP 2007.

Table 5.9 —Seismic Zone Factor Z					
Zone	**1**	**2A**	**2B**	**3**	**4**
Z	0.075	0.15	0.20	0.30	0.40

Static Lateral Force Procedure

- **Step 1: Find Site Specific Details**

ii. **Soil Profile Type**

- Soil Profile Types have been defined in Table 4.1 of BCP SP 2007

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			

Static Lateral Force Procedure

❑ Step 1: Find Site Specific Details

ii. Past Earthquake Magnitude

- This is required only for seismic zone 4 to decide about seismic source type.

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	$M < 6.5$	$SR \leq 2$

Static Lateral Force Procedure

- **Step 1: Find Site Specific Details**

  ii. **Distance to Known Seismic Source**

  - Distance to known seismic source is also required to determine additional coefficients for zone 4.

Static Lateral Force Procedure

Step 2: Determination of Seismic Coefficients

- The values of seismic acceleration coefficient C_a can be taken from Table 5.16 of BCP SP 2007.

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.

Static Lateral Force Procedure

❑ Step 2: Determination of Seismic Coefficients

- The values of seismic velocity coefficient C_v can be taken from Table 5.17 of BCP SP 2007.

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.

Static Lateral Force Procedure

Step 2: Determination of Seismic Coefficients

- The values N_a and N_v can be taken from Tables 5.18 & 5.19 of BCP SP 2007. These values are required for Zone 4 only.

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

Static Lateral Force Procedure

Step 2: Determination of Seismic Coefficients

- The values N_a and N_v can be taken from Tables 5.18 & 5.19 of BCP SP 2007. These values are required for Zone 4 only.

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

Static Lateral Force Procedure

- **Step 3: Determination of Seismic Importance Factor**
  - Based on the occupancy category, Seismic Importance Factor "I" can be selected from Table 5.10 of BCP SP 2007.

Static Lateral Force Procedure

❑ Step 3: Determination of Seismic Importance Factor

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

Static Lateral Force Procedure

❑ Step 3: Determination of Seismic Importance Factor

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

Static Lateral Force Procedure

Step 4: Determination of Response Modification Factor

- Response modification factor basically reduces base shear "V" to make the system economical.
- However, the structure will suffer some damage as explained in the earthquake design philosophy.
- R depends on overall structural response of the structure under lateral loading. For structures exhibiting good performance, R will be high.

Static Lateral Force Procedure

❑ Step 4: Determination of Response Modification Factor

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

Static Lateral Force Procedure

❑ Step 4: Determination of Response Modification Factor

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

Static Lateral Force Procedure

❑ Step 4: Determination of Response Modification Factor

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.

Static Lateral Force Procedure

❑ Step 5: Determination of Response Modification Factor

❖ Structural Period (5.30.2.2)

- For all buildings, the value T may be approximated from the following formula:

$$T = C_t(h_n)^{3/4}$$

Where;

C_t = 0.035 for steel moment-resisting frames.

C_t = 0.030 for reinforced concrete moment-resisting frames and eccentrically braced frames. C_t = 0.020 for all other buildings.

h_n = Actual height (feet or meters) of the building above the base to the nth level.

Static Lateral Force Procedure

- **Step 6: Calculation of Base shear and applying Base Shear limits**

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

The calculated value of “V” should be within the following 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 ; $V = (0.8 Z N_v I / R) W$

Static Lateral Force Procedure

❑ Step 7: Vertical Distribution of Base Shear

- As per section 5.30.5 of BCP SP 2007, The lateral force at a particular story level x of the structure is given as:

$$F_x = (V - F_t)\frac{w_x h_x}{\sum_{i=1}^{i=n}(W_i h_i)}$$

Where;

- $n = Number\ of\ stories$
- $F_t = 0.07\text{TV} \leq 0.25V$ (may be considered as zero where $T \leq 0.7sec$)

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.

Design Examples

❑ Example 6.1

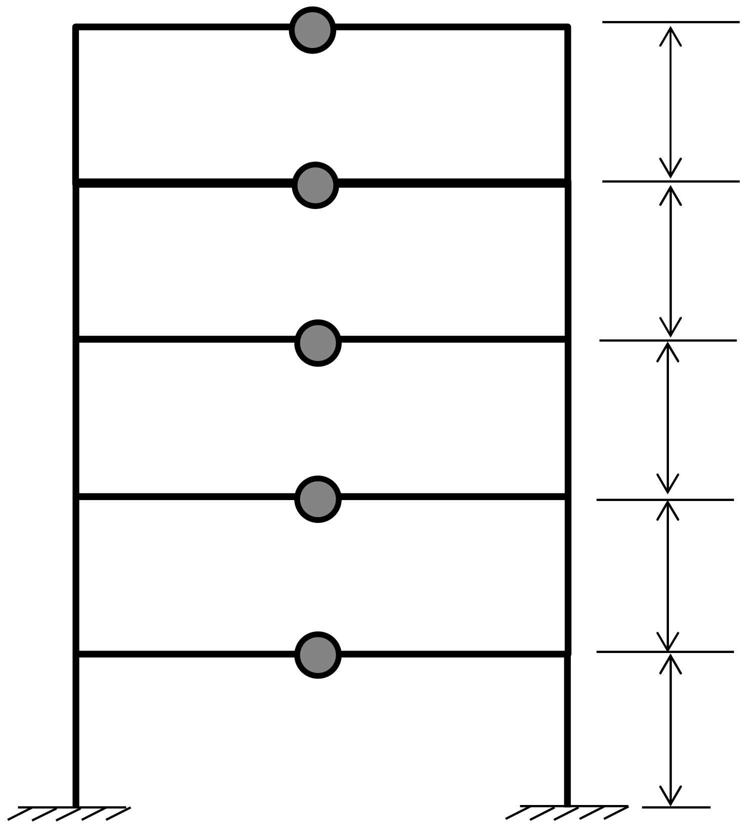
- A five-story reinforced concrete residential building as shown in figure on the next slide, is required to be designed as SMF System. The structure is situated in Abbottabad, KP. It has been found from the geotechnical investigation that the soil at the location is class S_D.

  a. ***Calculate*** the base shear using static later force procedure

  b. ***Determine*** joint forces at each story level

Design Examples

- **Example 6.1**



Design Examples

- **Solution (Example 6.1)**

  - **Given Data**

    Structural system: SMF (concrete)

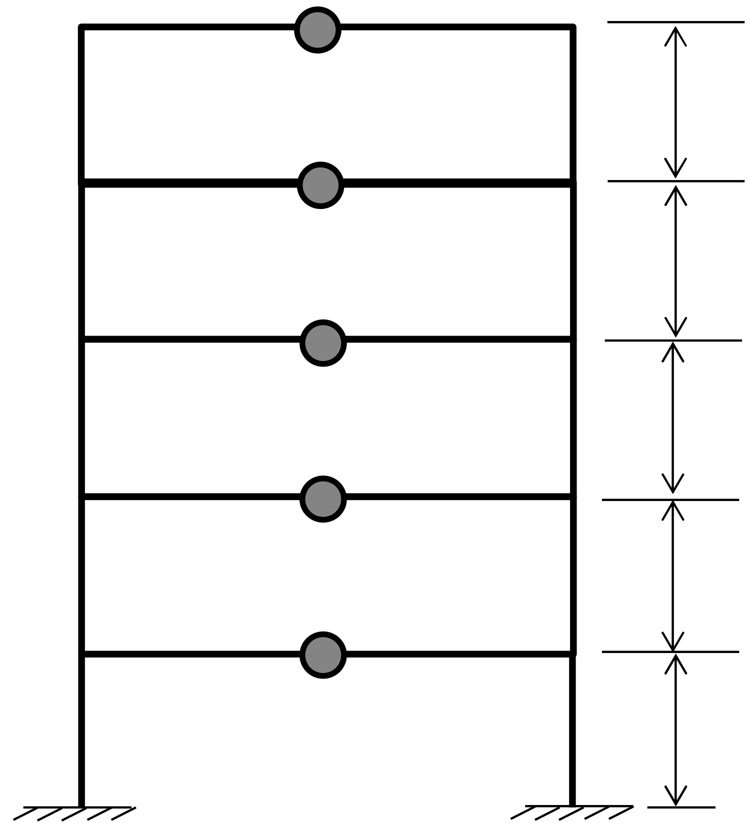
    Occupancy : Residential

    Site : Abbottabad, KP

    Soil Profile Type: S_D

    Number of stories: 5

    Story height: 12ft each



  - **Required Data**

    a. Base Shear V

    b. Story Forces, F_x

    c. Overturning Moment M_{OT}

Design Examples

- **Solution (Example 6.1)**

  - **Step 1: Site Specific Details**

    - Abbottabad comes under Zone 3. (From Seismic Zoning Map)
    - Seismic Zone factor "Z" for zone 3 is 0.3 (From Table 5.9)

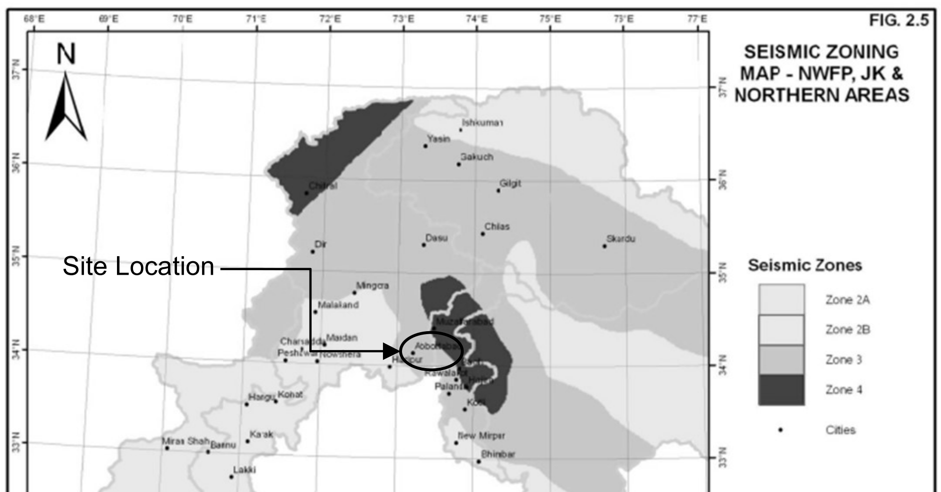


Table 5.9 —Seismic Zone Factor Z					
Zone	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

Design Examples

- **Solution (Example 6.1)**

  - **Step 2: Selection of Seismic Coefficients (C_a and C_v)**

  - Knowing Soil profile Type and Seismic zone factor, the values of C_a and C_v can be picked up from the relevant tables.

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				

Design Examples

- **Solution (Example 6.1)**

  - **Step 2: Selection of Seismic Coefficients (C_a and C_v)**

  - Knowing Soil profile Type and Seismic zone factor, the values of C_a and C_v can be picked up from the relevant tables.

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				

Design Examples

- **Solution (Example 6.1)**
  - **Step 3: Selection of Seismic Importance Factor (I)**
  - The occupancy of the given building is residential which comes under *Standard Occupancy structures* category.

Table 5.10 — Occupancy Category		
Occupancy Category	**Occupancy or Function of Structure**	**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

Design Examples

- **Solution (Example 6.1)**
  - **Step 4: Selection of Response Modification Factor (R)**
  - For SMRF systems composed of concrete , the value of R from Table 5.13 is 8.5.

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	8.5
	b. Concrete	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	4.5
	b. Concrete	3.5
	5.Special truss moment frames of steel (STMF)	6.5

Design Examples

- **Solution (Example 6.1)**

  - **Step 5: Determine Structure's Time period**

  - The value of T can be determined as follows;

$$T = C_t(h_n)^{3/4}$$

Here;

$$C_t = 0.030 \; for\ concrete\ frames$$

$$h = Total\ height\ of\ structure = 5 \times 12 = 60'$$

By substituting relevant values, we get

$$T = 0.030(60)^{3/4} = 0.647 sec$$

Design Examples

- **Solution (Example 6.1)**
  - **Step 6: Calculate Base shear and apply base shear limits**

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

Here;

$$W = W_1 + W_2 + W_3 + W_4 + W_5 = 800 + 800 + 800 + 800 + 700$$

$$= 3900\ kips$$

Substituting values and solving gives;

$$V = \frac{0.54 \times 1}{8.5 \times 0.647} \times (3900) = 382.94\ kips$$

Design Examples

- **Solution (Example 6.1)**

  - **Step 6: Calculate Base shear and apply base shear limits**

Applying base shear limits;

$$V_{min} = 0.11C_aIW = 0.11(0.36)(1)(3900) = 154.44kips$$

And;

$$V_{max} = \frac{2.5C_aI}{R}W = \frac{2.5 \times 0.36 \times 1 \times 3900}{8.5} = 412.94kips$$

$$V_{min} < V < V_{max} \rightarrow OK!$$

Therefore;

$$\boxed{V = 382.94kips}$$

[This is the required answer for part (a)]

Design Examples

- **Solution (Example 6.1)**

  - **Step 7: Vertical Distribution of Base shear/ Story forces**

The joint force F_x at level x is given by

$$F_x = (V - F_t)\frac{w_x h_x}{\sum_{i=1}^{i=n}(W_i h_i)}$$

Since value of $T = 0.647 < 0.7$, therefore the value of $F_t = 0$

Using the above equation, the story forces have been calculated and tabulated on the next slide.

Design Examples

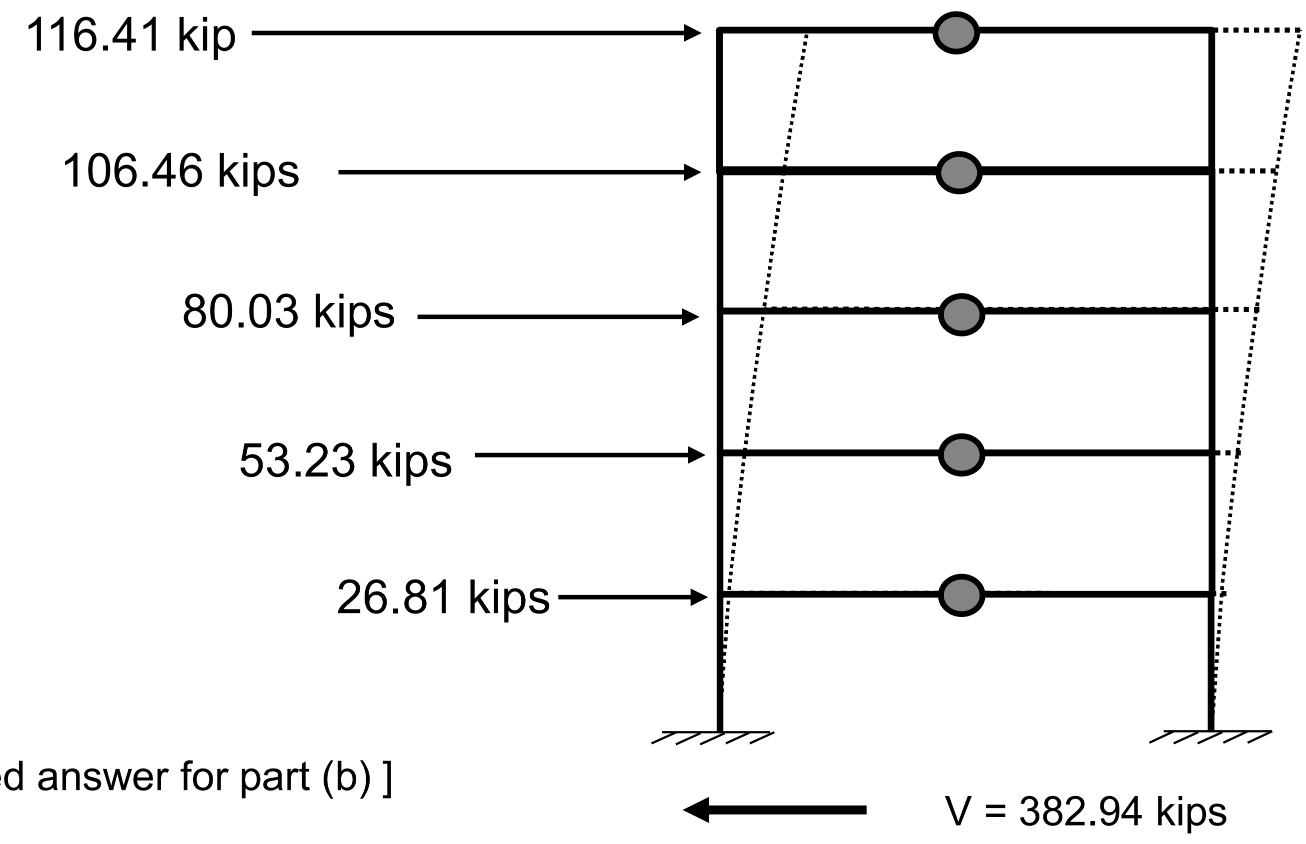
- **Solution (Example 6.1)**
  - **Step 7: Vertical Distribution of Base shear/ Story forces**

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: $\sum F_x = V$; $382.94 = 382.94 \rightarrow OK!$		

Design Examples

- **Solution (Example 6.1)**

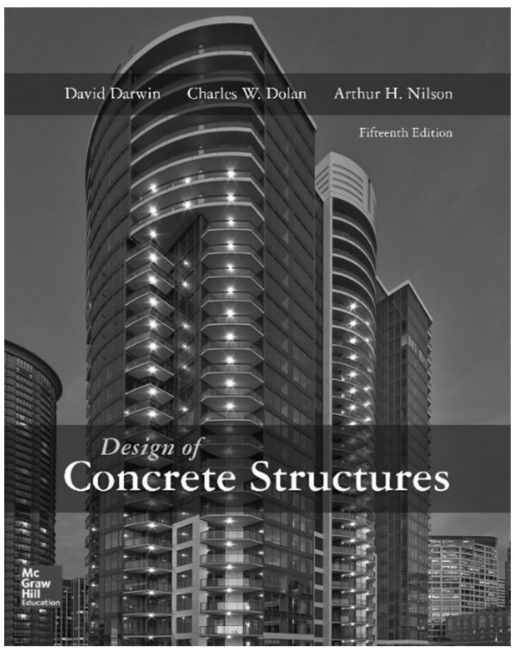
  - **Step 7: Vertical Distribution of Base shear/ Story forces**

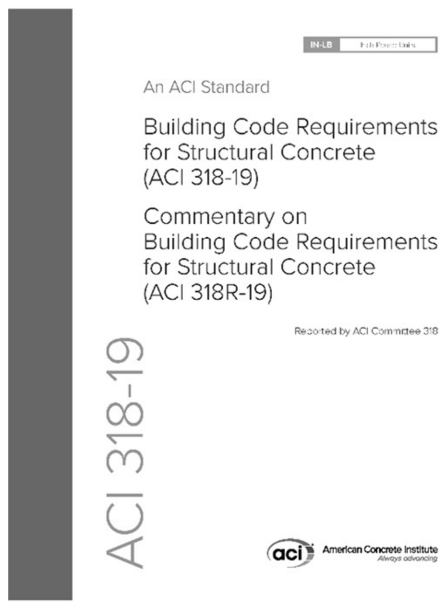


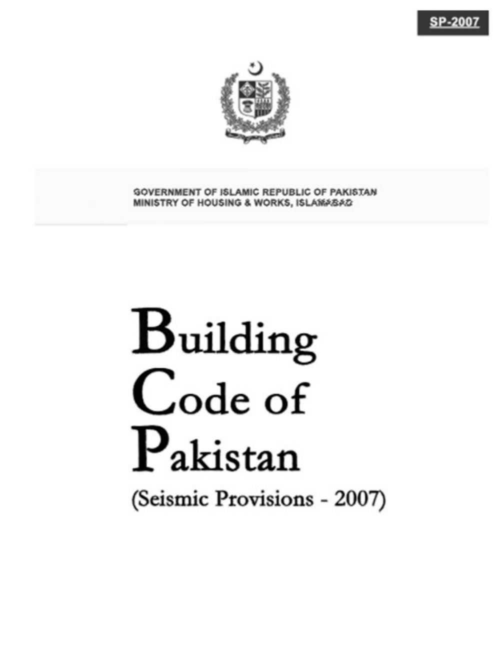
[This is the required answer for part (b)]

References

- Design of Concrete Structures 14th / 15th edition by Nilson, Darwin and Dolan.
- Building Code Requirements for Structural Concrete (ACI 318-19)
- Building Code of Pakistan Seismic Provisions 2007 / UBC-97 Volume 2







Appendix

Table 2.2 — Seismic Zones of Tehsils of Pakistan

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Punjab					
Attock	2B	Shorkot	2A	**Multan** City	2A
Hassanabdal	2B	**Toba Tek Singh**	2A	Multan Saddar	2A
Fateh Jang	2B	Kamalia	2A	Shujabad	2A
Pindi Gheb	2B	Gojra	2A	Jalalpur Pirwala	2A
Jand	2B	**Gujranwala** City	2A	**Lodhran**	2A
Rawalpindi	2B	Wazirabad	2A	Kahror Pacca	2A
Taxila	2B	Gujranwala Saddar	2A	Dunyapur	2A
Kahuta	2B	Nowshera Virkan	2A	**Khanewal**	2A
Murree	3	Kamoki	2A	Jehanian	2A
Kotli Sattian	3	**Hafizabad**	2A	Main Channu	2A
Gujar Khan	2B	Pindi Bhattian	2A	Kabirwala	2A
Jhelum	2B	**Gujrat**	2B	**Dera Ghazi Khan**	2A
Sohawa	2B	Kharian	2B	Taunsa	2B
Pind Dadan Khan	2B	Sarai Alamgir	2B	De-Ex.Area of D.G.Khan	2B
Dina	2B	**Mandi Bahauddin**	2B	**Rajanpur**	2A
Chakwal	2B	Malikwal	2B	Rojhan	2A
Talagang	2B	Phalia	2A	Jampur	2A
Choa Saidan Shah	2B	**Sialkot**	2B	De-Ex.Area of Rajanpur	2B

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Sargodha	2A	Daska	2B	**Leiah**	2A
Sillanwali	2A	Pasrur	2B	Chaubara	2A
Bhalwal	2A	**Narowal**	2B	Karor Lal Esan	2A
Shahpur	2B	Shakargarh	2B	**Muzaffargarh**	2A
Sahiwal	2A	**Lahore** City	2A	Alipur	2A
Kot Momin	2A	Lahore Cantt	2A	Jatoi	2A
Bhakkar	2A	**Kasur**	2A	Kot Addu	2A
Kalur Kot	2B	Chunian	2A	**Bahawalpur**	2A
Mankera	2A	Pattoki	2A	Hasilpur	2A
Darya Khan	2A	**Okara**	2A	Yazman	2A
Khushab	2B	Depalpur	2A	Ahmadpur East	2A
Nurpur	2A	Renala Khurd	2A	Khairpur Tamewali	2A
Mianwali	2B	**Sheikhupura**	2A	**Bahawalnagar**	2A
Isa Khel	2B	Nankana Sahib	2A	Minchinabad	2A
Piplan	2B	Ferozwala	2A	Fort Abbas	1
Faisalabad City	2A	Safdarabad	2A	Haroonabad	2A
Faisalabad Saddar	2A	**Vehari**	2A	Chishtian	2A
Chak Jhumra	2A	Burewala	2A	**Rahim Yar Khan**	2A
Sammundri	2A	Mailsi	2A	Khanpur	2A
Jaranwala	2A	**Sahiwal**	2A	Liaquatpur	2A
Tandlianwala	2A	Chichawatni	2A	Sadiqabad	2A
Jhang	2A	**Pakpattan**	2A		
Chiniot	2A	Arifwala	2A		

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Balochistan					
Quetta	3	**Dera Bugti**	3	Aranji (S/T)	2B
Panjpai (S/T)	3	Sangsillah (S/T)	3	**Awaran**	2B
Pishin	4	Sui	3	Mshki (S/T)	3
Hurramzai (S/T)	4	Loti	3	Jhal Jao	3
Barshore (S/T)	3	Phelawagh	3	**Kharan**	3
Karezat (S/T)	4	Malam (S/T)	3	Besima (S/T)	2B
Bostan (S/T)	4	Baiker (S/T)	3	Nag (S/T)	2B
Killa Abdullah	3	Pir Koh (S/T)	3	Wasuk (S/T)	2B
Gulistan (S/T)	3	**Jaffarabad/**Jhat Pat	2B	Mashkhel (S/T)	2A
Chaman	3	Panhwar (S/T)	2B	**Bela**	2B
Dobandi (S/T)	3	Usta Mohammad	2B	Uthal	2B
Chagai (S/T)	2A	Gandaka (S/T)	2B	Lakhra	2B
Dalbandin	2A	**Nasirabad/**Chattar	3	Liari (S/T)	2B
Nushki	4	Tamboo	3	Hub	2B
Nokundi S/T	2A	D.M.Jamali	2B	Gadani (S/T)	2B
Taftan	2A	**Bolan**/Dhadar	3	Sonmiani/Winder	2B
Loralai/Bori	3	Bhag	3	Dureji	2B
Mekhtar (S/T)	3	Balanari (S/T)	3	Kanraj	2B
Duki	3	Sani (S/T)	3	**Kech**	2B
Barkhan	3	Khattan (S/T)	3	Buleda (S/T)	2B
Musakhel	3	Mach	3	Zamuran (S/T)	2B

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Kingri (S/T)	3	**Kachhi**/Gandawa	2B	Hoshab (S/T)	2B
Killa Saifullah	3	Mirpur (S/T)	2B	Balnigor (S/T)	2B
Muslim Bagh	4	Jhal Magsi	2B	Dasht (S/T)	3
Loiband (S/T)	3	**Kala**t	3	Tump	2B
Baddini (S/T)	3	Mangochar (S/T)	3	Mand (S/T)	2B
Zhob	3	Johan (S/T)	3	**Gwadar**	3
Sambaza (S/T)	3	Surab	2B	Jiwani	2B
Sherani (S/T)	3	Gazg (S/T)	3	Suntsar (S/T)	2B
Qamar Din Karez	2B	**Mastung**	3	Pasni	3
Ashwat (S/T)	2B	Kirdgap (S/T)	3	Ormara	3
Sibi	3	Dasht	3	**Panjgur**	2B
Kutmandai (S/T)	3	Khad Koocha (S/T)	3	Parome (S/T)	2B
Sangan (S/T)	3	**Khuzdar**	2B	Gichk (S/T)	2B
Lehri	3	Zehri	2B	Gowargo	2A
Ziarat	4	Moola (S/T)	2B		
Harnai	3	Karakh (S/T)	2B		
Sinjawi (S/T)	4	Nal (S/T)	3		
Kohllu	3	Wadh (S/T)	2B		
Kahan	3	Ornach (S/T)	3		
Mawand	3	Saroona (S/T)	2B		

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
NWFP					
Chitral	4	**Swabi**	2B	**Kurram**	
Drosh	3	Lahore	2B	Lower **Kurram**	2B
Lutkoh	3	**Charsadda**	2B	Upper Kurram	2B
Mastuj	3	Tangi	3	Kurram F.R.	2B
Turkoh	3	**Peshawar**	2B	**Orakzai**	
Mulkoh	3	**Nowshera**	2B	Central **Orakzai**	2B
Dir	3	**Kohat**	2B	Lower Orkzai	2B
Barawal	3	Lachi	2B	Upper Orkzai	2B
Kohistan	3	**Hangu**	2B	Ismailzai	2B
Wari	3	**Karak**	2B	**South Waziristan**	
Khall	3	Banda Daud Shah	2B	Ladha	2B
Temergara	3	Takht-E-Nasrati	2B	Makin (Charlai)	2B
Balambat	3	**Bannu**	2B	Sararogha	2B
Lalqila	3	**Lakki Marwat**	2B	Sarwekai	2B
Adenzai	3	**Dera Ismail Khan**	2A	Tiarza	2B
Munda	3	Daraban	3	Wana	2B
Samarbagh (Barwa)	3	Paharpur	2B	Toi Khullah	2B
Swat		Kulachi	2B	Birmal	2B
Matta	3	**Tank**	2B	**North Waziristan**	
Shangla/Alpuri	3	**Bajaur**		Datta Khel	2B

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Besham	3	Barang	3	Dossali	2B
Chakesar	3	Charmang	3	Garyum	2B
Martung	3	Khar Bajaur	3	Ghulam Khan	2B
Puran	2B	Mamund	3	Mir Ali	2B
Buner/Daggar	2B	Salarzai	3	Miran Shah	2B
Malakand/Swat Ranizai	3	Utmankhel (Qzafi)	3	Razmak	2B
Sam Ranizai	2B	Nawagai	3	Spinwam	2B
Dassu	3	**Mohmand**		Shewa	2B
Pattan	3	Halimzai	3		
Palas	3	Pindiali	3		
Mansehra	3	Safi	3		
Balakot	4	Upper Mohmand	3		
Oghi	2B	Utman Khel(Ambar)	3		
T.A.Adj.Mansehra Distt	3	Yake Ghund	3		
Batagram	3	Pringhar	3		
Allai	3	**Khyber**			
Abbottabad	3	Bara	2B		
Haripur	2B	Jamurd	2B		
Ghazi	2B	Landi Kotal	3		
Mardan	2B	Mula Ghori	3		
Takht Bhai	2B				

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Sindh					
Jacobabad	2A	Khairpur Nathan Shah	2B	**Tharparkar**/Chachro	2A
Garhi Khairo	2A	Sehwan	2A	Nagar Parkar	2B
Thul	2A	Mehar	2A	Diplo	3
Kandhkot	2A	Johi	2B	Mithi	2B
Kashmor	2A	Kotri	2A	**Karachi East**	2B
Shikarpur	2A	Thano Bula Khan	2A	**Karachi West**	2B
Khanpur	2A	**Hyderabad** City	2A	**Karachi South**	2B
Garhi Yasin	2A	Matiari	2A	**Karachi Central**	2B
Lakhi	2A	Tando Allahyar	2A	**Malir**	2B
Larkana	2A	Hala	2A		
Miro Khan	2A	Latifabad	2A	**FEDERAL AREA**	
Rato Dero	2A	Hyderabad	2A	Islamabad	2B
Shahdadkot	2B	Qasimabad	2A		
Dokri	2A	Tando Mohd Khan	2A	**AJK**	
Kambar	2B	**Badin**	2B	Bagh	4
Warah	2A	Golarchi	2A	Bhimbar	2B
Sukkur	2A	Matli	2A	Hajira	4
Rohri	2A	Tando Bagho	2B	Kotli	3
Pano Aqil	2A	Talhar		Muzaffarabad	4
Salehpat	2A	**Thatta**	2A	New Mirpur	2B

Appendix

Tehsil	Seismic Zone	Tehsil	Seismic Zone	Tehsil	Seismic Zone
Ghotki	2A	Mirpur Sakro	2A	Palandri	3
Khangarh	2A	Keti Bunder	2A	Rawalakot	3
Mirpur Mathelo	2A	Ghorabari	2A		
Ubauro	2A	Sujawal	2A	**NORTHERN AREA**	
Daharki	2A	Mirpur Bathoro	2A	Chilas	3
Khairpur	2A	Jati	2A	Dasu	3
Kingri	2A	Shah Bunder	2A	Gakuch	3
Sobhodero	2A	Kharo Chan	2A	Gilgit	3
Gambat	2A	**Sanghar**	2A	Ishkuman	2B
Kot Diji	2A	Sinjhoro	2A	Skardu	3
Mirwah	2A	Khipro	2A	Yasin	3
Faiz Ganj	2A	Shahdadpur	2A		
Nara	2A	Jam Nawaz Ali	2A		
Naushahro Feroze	2A	Tando Adam	2A		
Kandioro	2A	**Mirpur Khas**	2A		
Bhiria	2A	Digri	2A		
Moro	2A	Kot Ghulam Moh	2A		
Nawab Shah	2A	**Umerkot**	2A		
Skrand	2A	Samaro	2A		
Daulatpur	2A	Kunri	2A		
Dadu	2A	Pithoro	2A		