FUNDUMENTAL CONCEPTS IN EARTHQUAKE RESISTANT STRUCTURES

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To

Kurdistan Engineers Union

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1.Introduction

1.1 ***What is an Earthquake?***

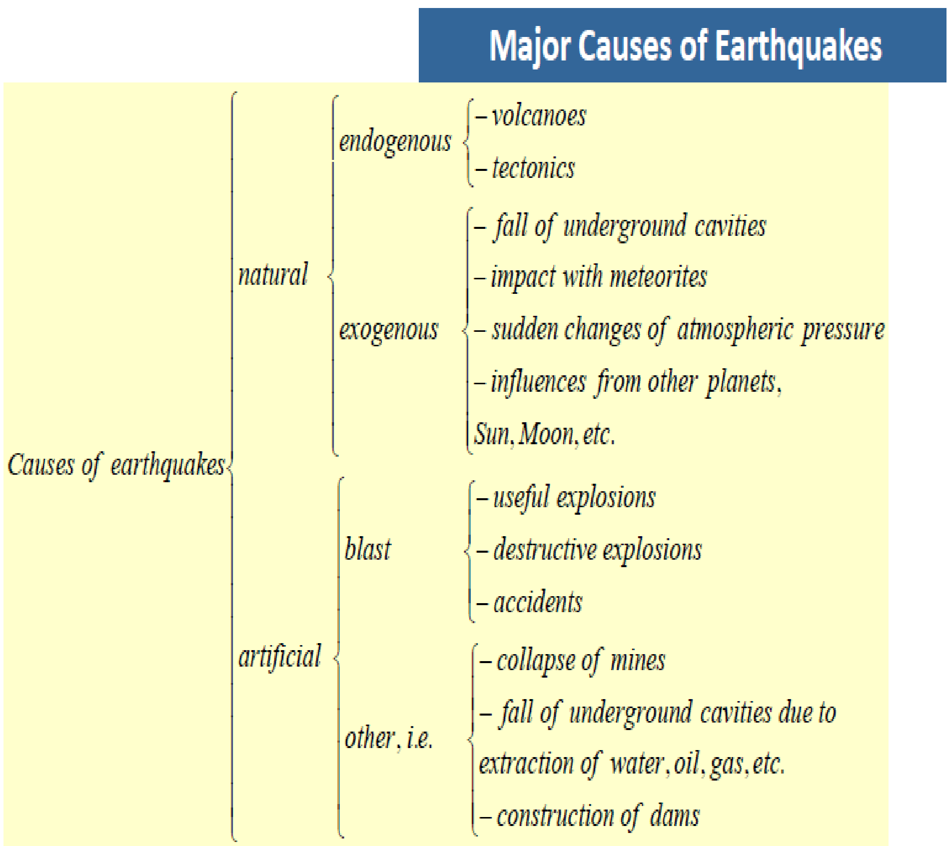
An earthquake is a transient violent movement of the Earth's surface that follows a release of energy in the Earth's crust

In order to get an Earthquake:

• A mechanism is needed to supply the energy and stress the material

• Brittle material should be present

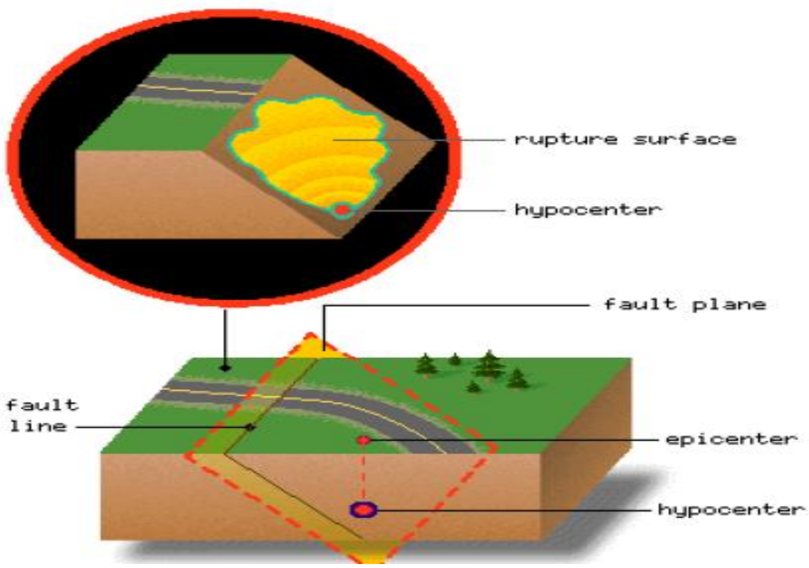
• The material should be able to store significant amounts of Energy

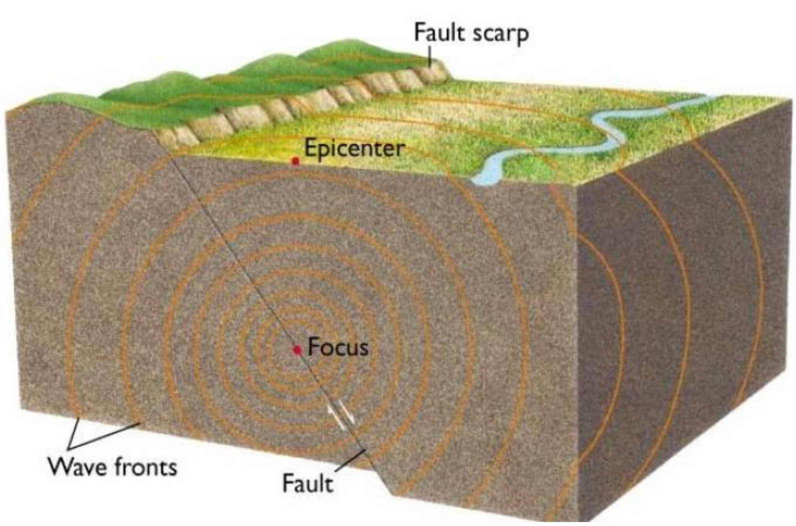


1.2 Epicenter and Hypocenter

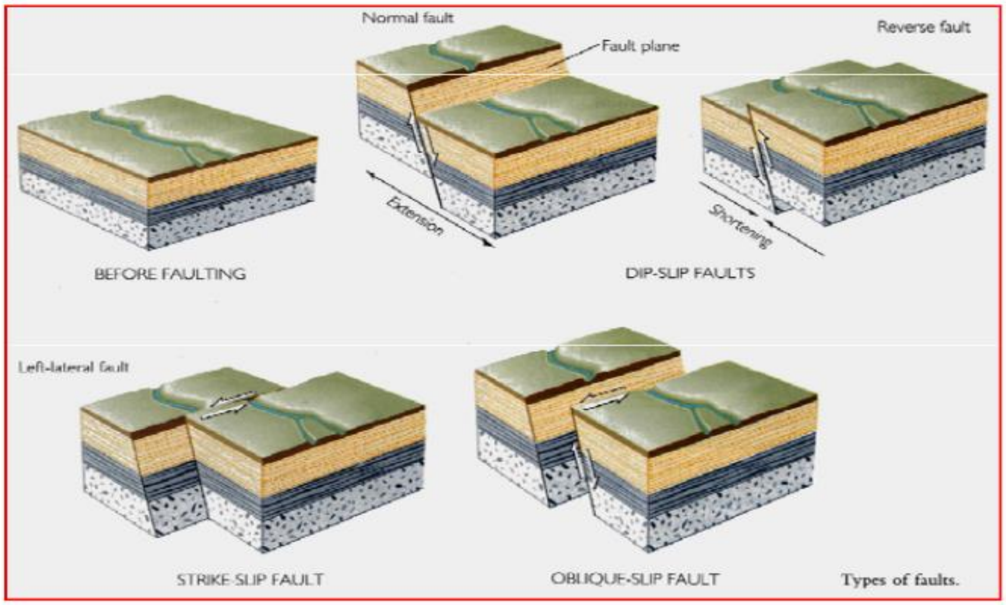
The hypocenter (focus) is the point within the earth where an earthquake rupture starts.

The epicenter is the point on the earth's surface vertically above the hypocenter, point in the crust.



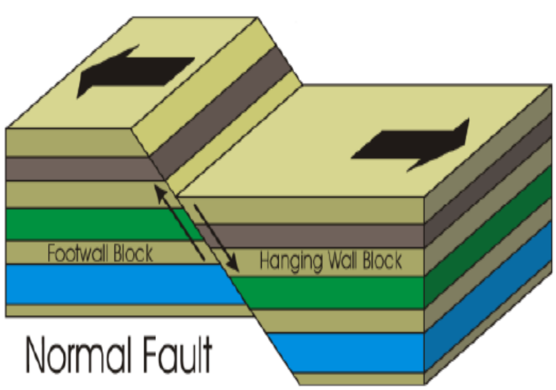


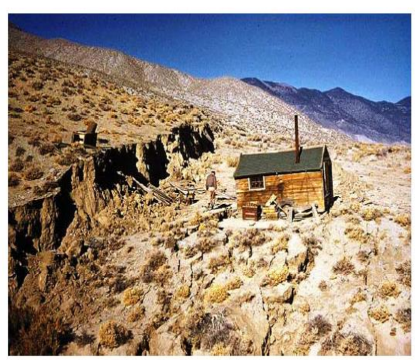
1.3 Types of Faults:



1.3.1 Normal Faulting

The hanging wall slides down the fault - as you would expect (that's why it's called "normal").

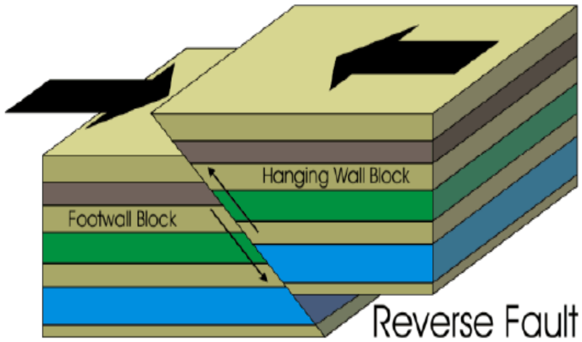




Dixie Valley-Fairview Peaks, Nevada earthquake, December 16, 1954

1.3.2 Reverse Faulting

The hanging wall is pushed g g p up the fault - not what you would expect (that's why it's called "reverse").

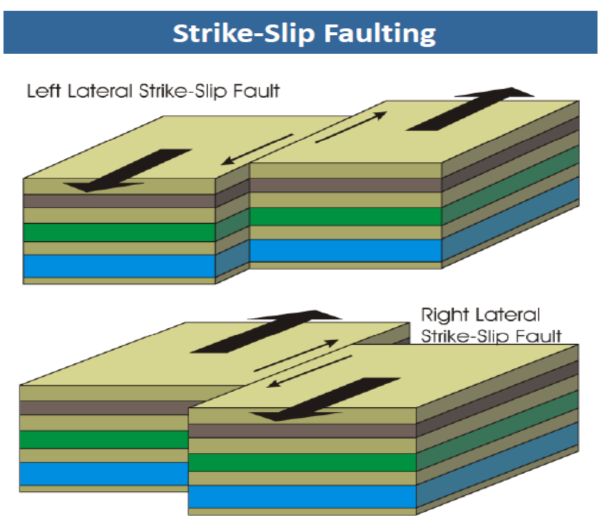


Reverse faulting, El Asnam earthquake (North-Western Africa, 1980)

1.3.3 Strike-Slip Faulting

• The hanging wall horizontally (no motion in the direction of fault dip).

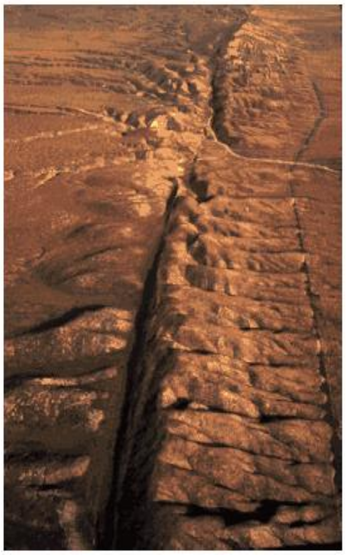
• There are 2 cases depending on how the rocks on the other side of the fault move - right lateral and left lateral.

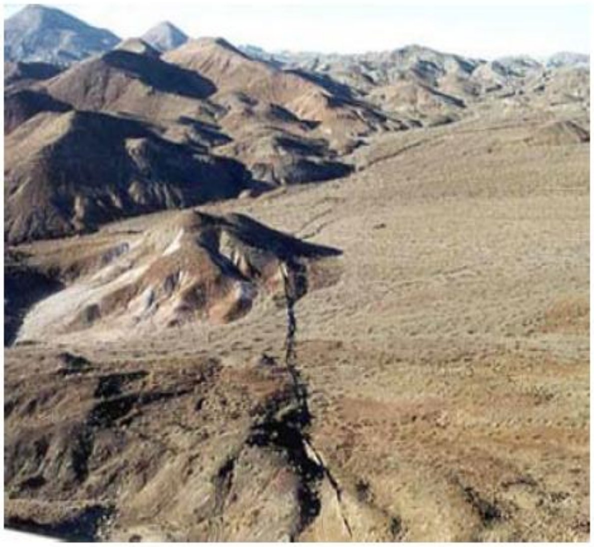


Left-Lateral Strike-Slip Offset (1990 Luzon, Philippines)

1.3.4 Active Fault

Faults are commonly considered to be active if they have moved one or more times in the last 10,000 years.





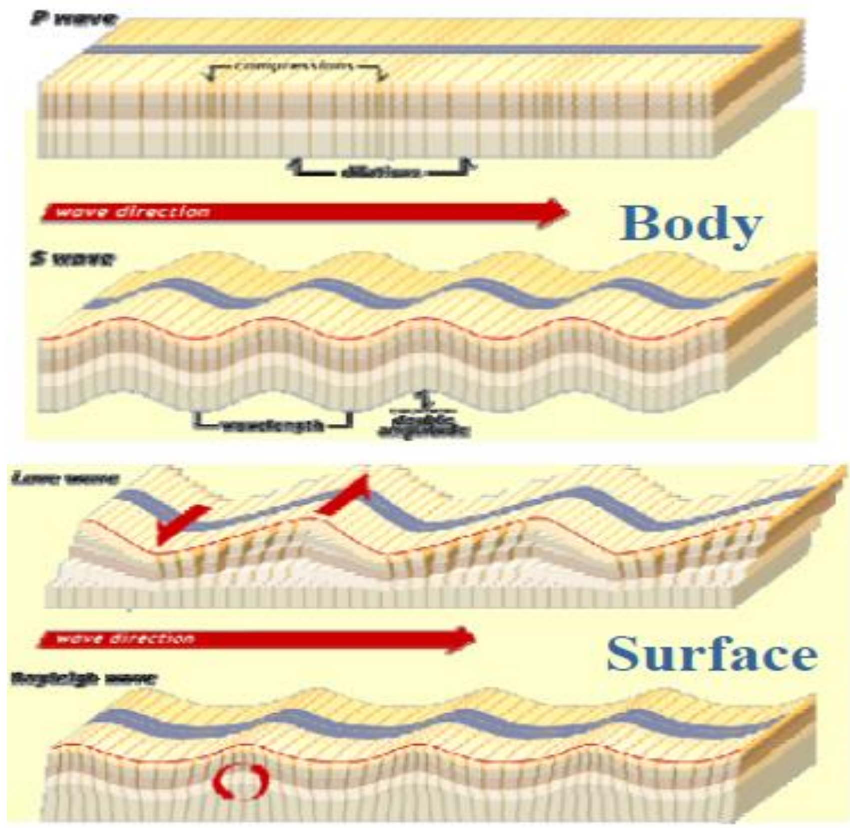
1.4 Propagation of Seismic Waves

Body waves move through the interior of the earth, as opposed to surface waves that travel near the earth's surface.

P wave: A P wave, or compressional wave, shakes the ground back and forth in the same direction and the opposite direction as the direction the wave is moving.

S wave: An S wave, or shear wave, shakes the ground back and forth perpendicular to the direction the wave is moving. S wave can travel only through solids.

There are two types of surface waves: ***Rayleigh waves*** and ***Love waves***. Because of their low frequency, long duration, and large amplitude, they can be the most destructive type of seismic wave.



2. Seismic Risk Assessment/Design

•Ductility Design Concept

•Seismic Analysis Procedures

•Performance-based Design Approach

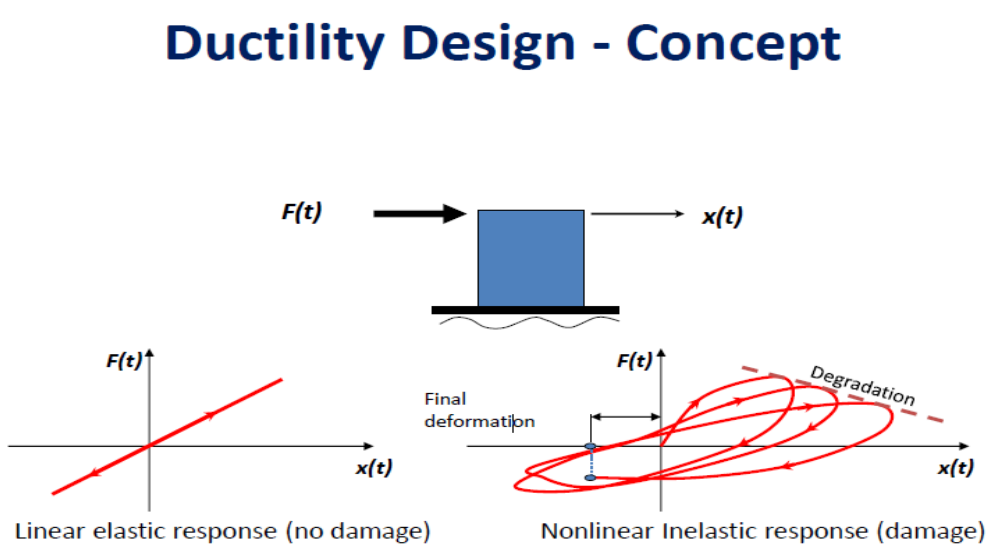
•P-Δ effects

•Vibration Control

•Site Amplification

•Soil-structure Interaction

2.1 Ductility Design – Concept



•Designing structures to remain elastic in large earthquakes is likely to be uneconomic.

•More economical design can be achieved by accepting some level of damage.

•Considering ductility of structure may reduce the force demands to acceptable levels.

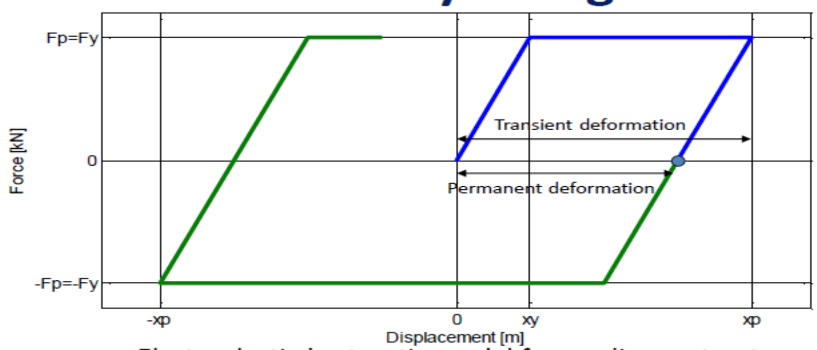
Ductility Design - Definition

• Ductility is defined as the ability of structure or member to withstand large deformations beyond its yield point without fracture.

• Ductility Demand is the maximum ductility that the structure experiences during an earthquake.

• Ductility Supply is the maximum ductility the structure can sustain without fracture.

Ductility Design

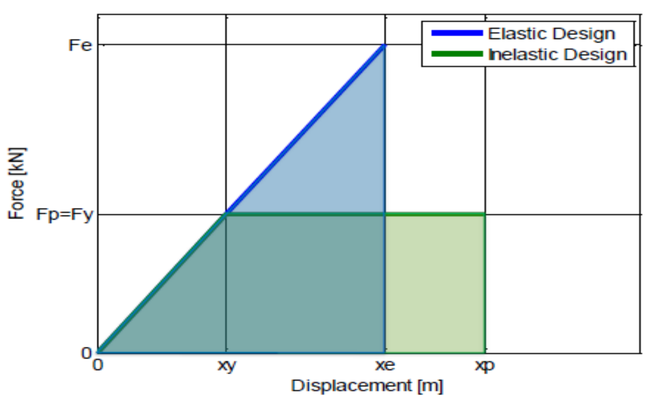


Elasto-plastic hysteretic model for nonlinear structures

Ductility: $\mu = \frac{\text{Max. inelastic displacement}}{\text{Yield displacement}} = \frac{x_p}{x_y}$

Additional damping = Area under the hysteresis loop.

Ductility Design



$$E(elastic) = \frac{1}{2} k \cdot x_e^2$$

$$E(elasto-plastic) = k \cdot x_y \cdot x_p - \frac{1}{2} k x_y^2 = (\mu - \tfrac{1}{2}) k \cdot x_y^2 \qquad (\mu = x_p / x_y)$$

$$x_y = \frac{x_e}{\sqrt{2\mu - 1}}, \qquad x_p = \frac{\mu x_e}{\sqrt{2\mu - 1}}, \qquad F_p = k \cdot x_y = m \cdot \omega^2 \cdot x_y$$

Ductility Design - Practical Considerations

•Ensuring plastic hinges form in beams before columns

• Providing adequate confinement to concrete using closely spaced steel

•Ensuring that steel members fail away from connections

•Avoiding large irregularities in structural form

•Ensuring flexural strengths are significantly lower than shear strengths

2.2 Seismic Analysis Procedures

•Linear Static Procedure

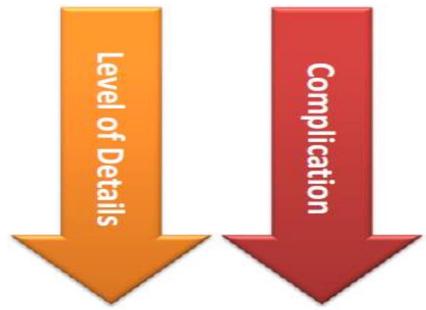
•Linear Dynamic Procedure:

–Response Spectrum Method

–Time History Method

•Nonlinear Static (Pushover) Procedure

•Nonlinear Dynamic procedure



2.2.1 Linear Static Procedure

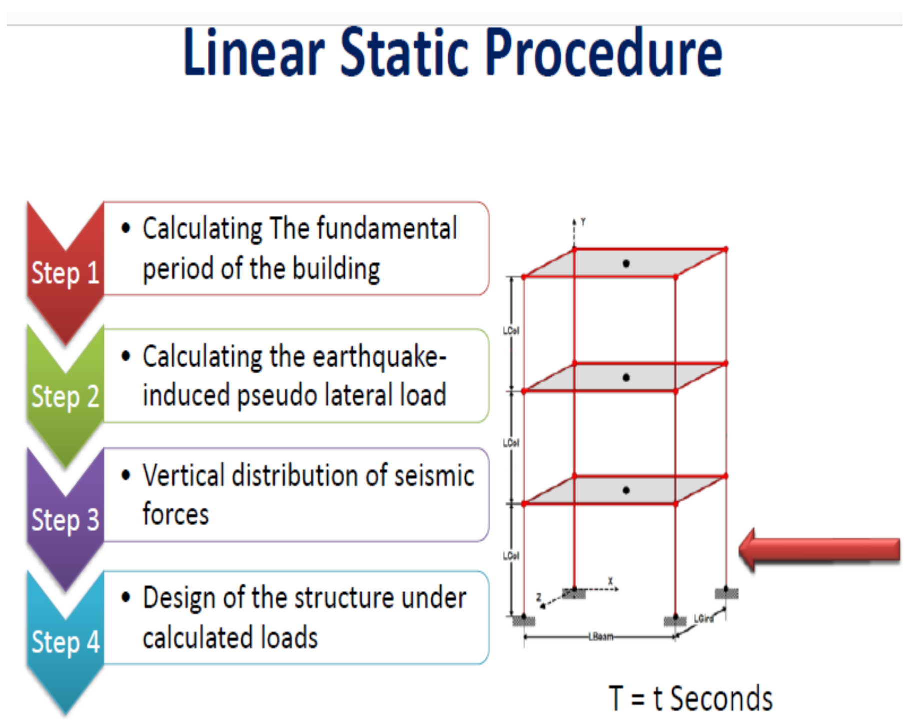
•Series of forces acting on a building to represent the effect of earthquake ground motion

•Assumes that the building responds in its fundamental mode

•Buildings shall be modeled with:

–Linearly elastic stiffness

–Equivalent viscous damping values consistent with components responding at or near yield level



2.2.2 Linear Dynamic Procedure

2.2.2.1 Linear Dynamic Procedure Response Spectrum Method

•Buildings shall be modeled with:

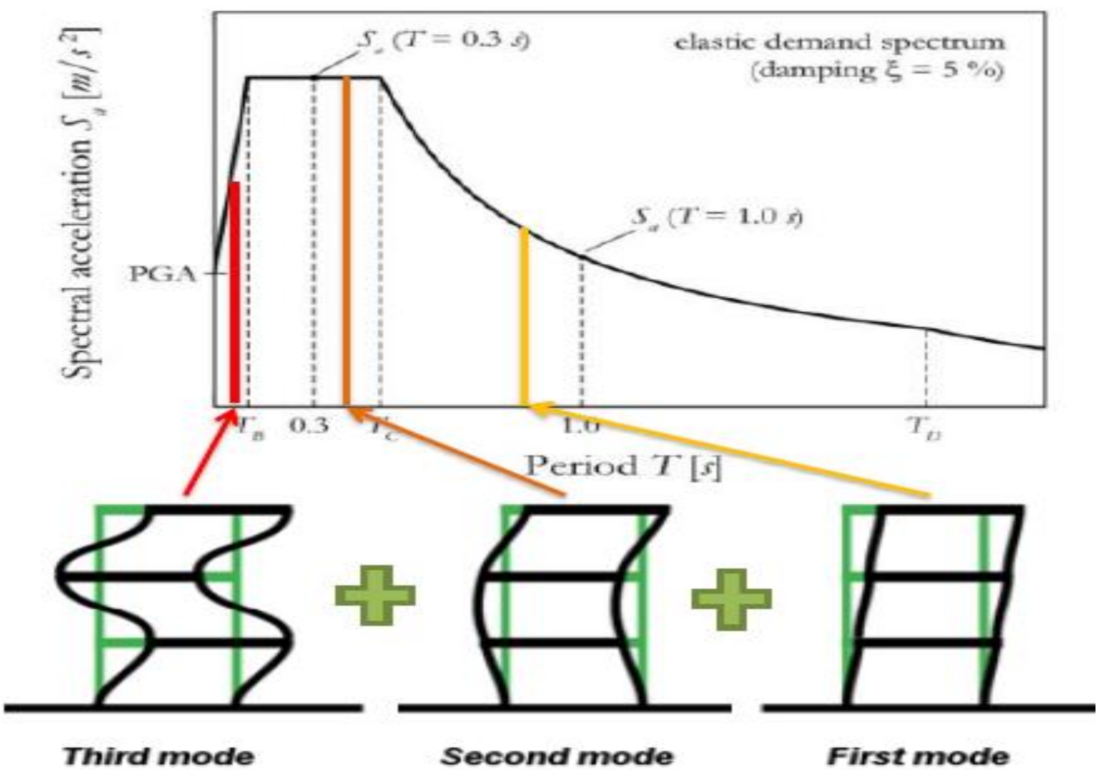
–Linearly elastic stiffness

–Equivalent viscous damping values

•Modal spectral analysis using linearly elastic response spectra

•Combining results using SRSS or CQC

•Phase data is lost



2.2.2.2 Linear Dynamic Procedure Time-history Method

•Time-step-by-time-step evaluation of building response, using discretized recorded or synthetic earthquake records as base motion input

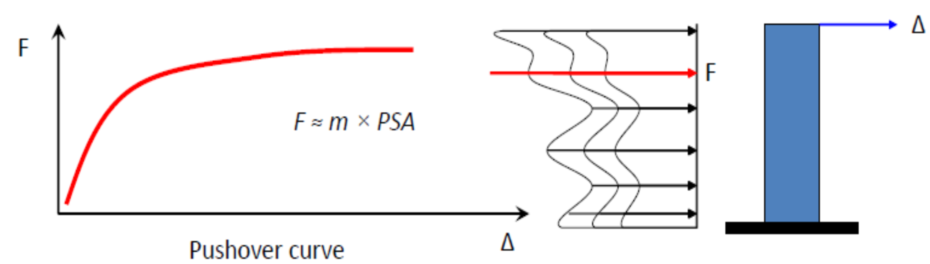
•Linear structural analysis

•Several earthquake time-histories

•Max/average response will be considered

2.2.3 Nonlinear (static) Pushover Analysis

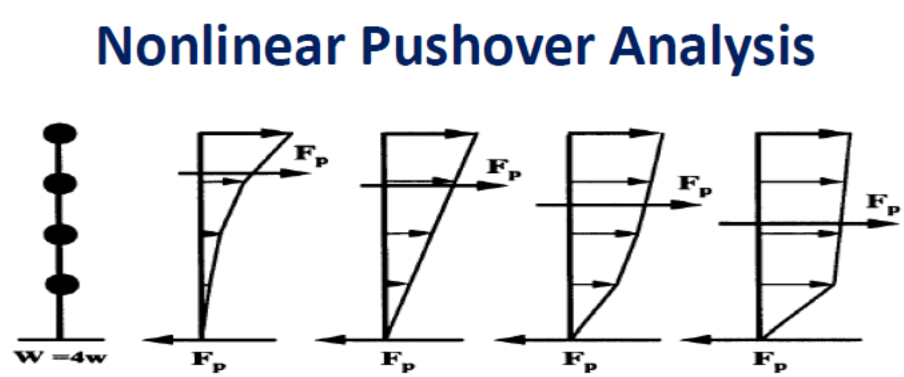
(Incremental Nonlinear Static Analysis)



•Incremental nonlinear static analysis

•Used to determine the force-displacement relationship, or the capacity curve, for a structure or structural element.

•The analysis involves incrementally applying horizontal loads, in a prescribed pattern and plotting the total applied shear force and associated lateral displacement at each increment, until the structure reaches a limit state or collapse condition.



Sample load patterns used for pushover analysis

2.2.4 Nonlinear Dynamic procedure Time-history Method

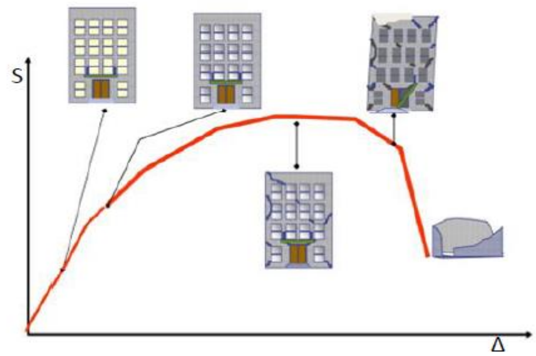
•Time-step-by-time-step evaluation of building response, using discretized recorded or synthetic earthquake records as base motion

•Nonlinear structural analysis

•Several earthquake time-histories

•Max/average response will be considered

2.3 Performance-based Design Approach



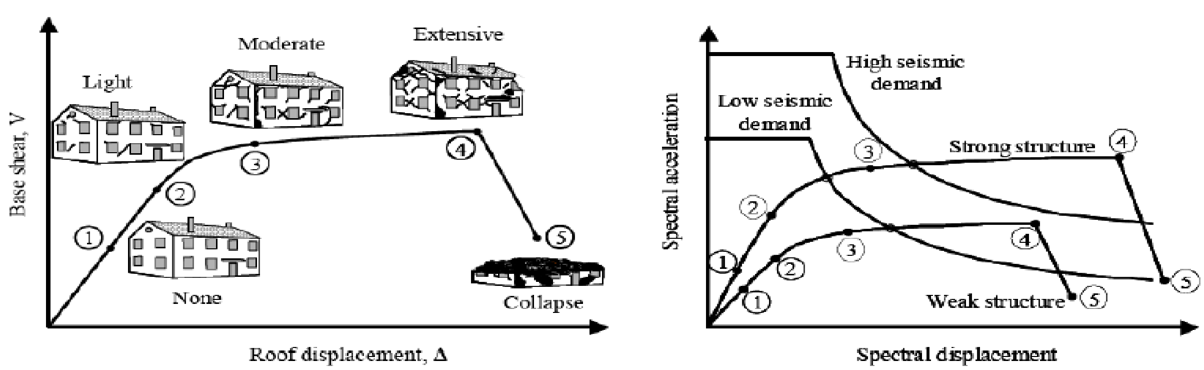
Performance-based Design

• Performance Point is the intersection between the demand and capacity curves.

• It represents the damage state likely to be experienced by the structure.

• It gives a global performance evaluation of the structure behavior and indicates if any local collapse may occur.

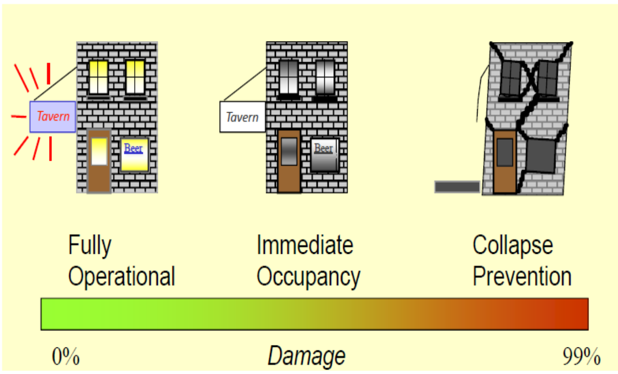
Performance-Based Design



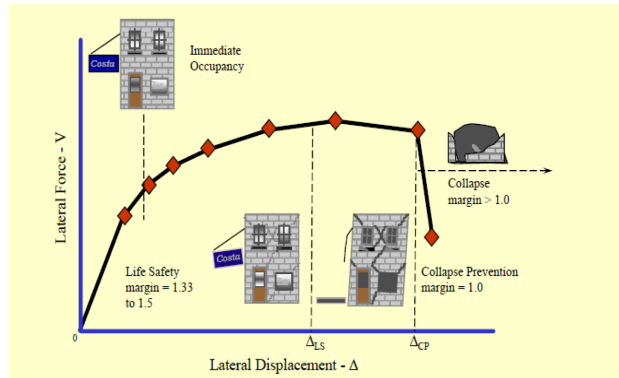
(a) Damage states shown on V-Δ curve (b) Damage levels based on seismic demand

Structural vulnerability and damage states for various levels of seismic demand

Performance Levels



Performance Parameters



Performance Levels and Damage

Concrete Frames

Collapse Prevention	Life Safety	Immediate Occupancy
Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (<1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks <1/8" wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).

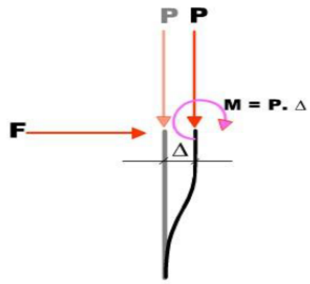
Drift and Drift Ratio

• Drift of a DOF is the difference between the relative displacements of this DOF and the one below (interstory displacement).

• Interstory Drift Ratio is the interstory displacement (drift) divided by height of the story.

• Roof Drift Ratio is the relative displacement of the top DOF divided by height of the building.

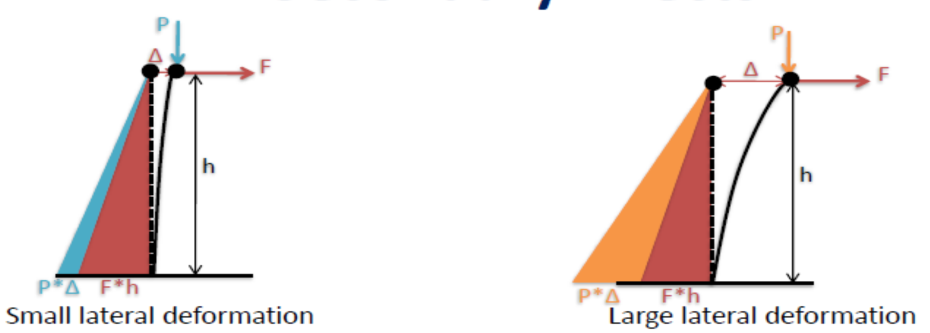
2.4 P-Δ effects



P-Δ effects

P-Δ Secondary Effects

P-Δ Secondary Effects



P is the permanent vertical load (i.e. self-weight), F is the lateral load.

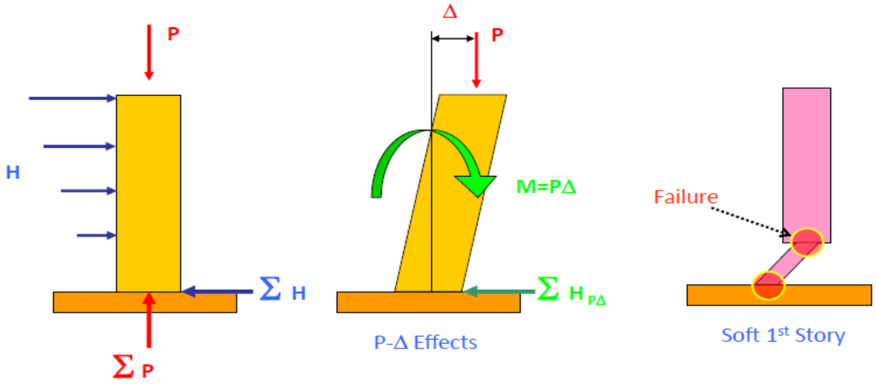
$$M \approx F.h$$

$$F_y = \frac{M_y}{h} = k_e x_y$$

$$M = F.h + P.\Delta$$

$$F_y = \frac{M_y - P.x_y}{h} = (k_e + k_g) x_y = k_T x_y$$

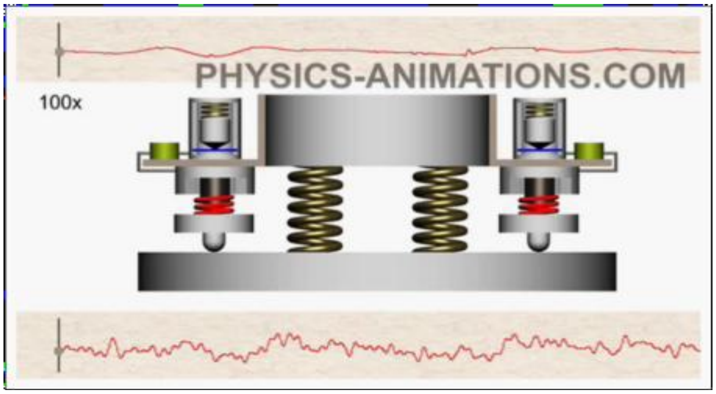
P-Δ Secondary Effects



2.5 Vibration Control

Excessive vibration can lead to:

- Discomfort of users
- Formation of cracks
- Structural and mechanical failures
- Frequent and costly maintenance
- Machinery malfunctions



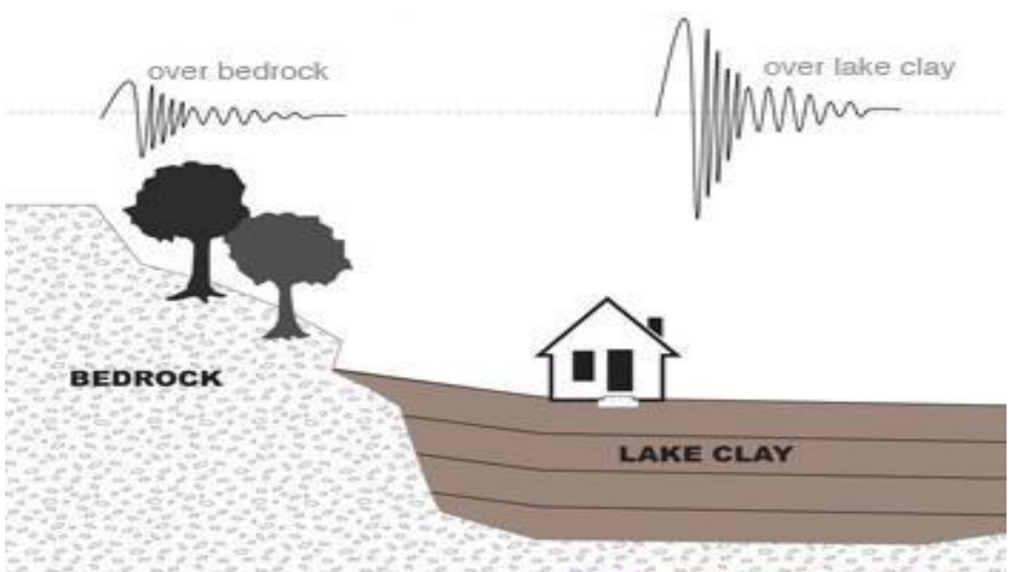
(Hence it is necessary to eliminate or reduce vibration)

Vibration Control Methods

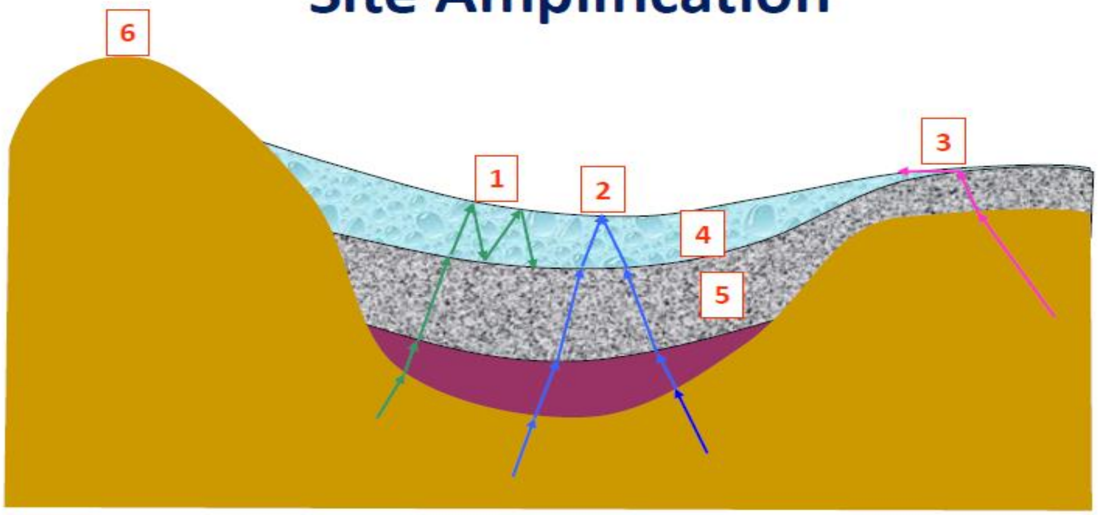
Vibration control methods can be classified as:

- •Passive Control Methods
- •Active Control Methods
- •Hybrid Control Methods
- •Semi-active Control Methods

2.6 Site Amplification



Site Amplification

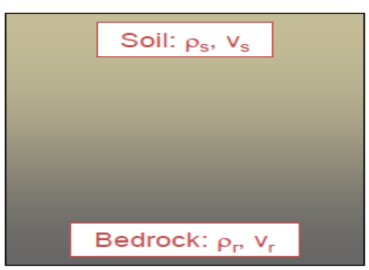


1- Resonances due to impedance contrasts
2- Focusing due to subsurface topography
3- Body waves converted to surface waves
4- Water content
5- Randomness of the medium
6- Surface topography

Site Amplification

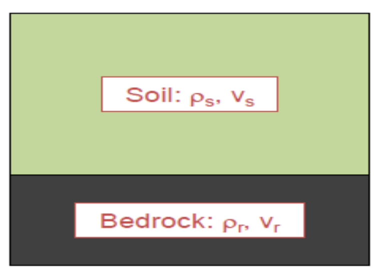
Impedance=Density x Wave propagation velocity

Gradual change of impedance



$$A_{\max} = \sqrt{\frac{\rho_r v_r}{\rho_s v_s}}$$

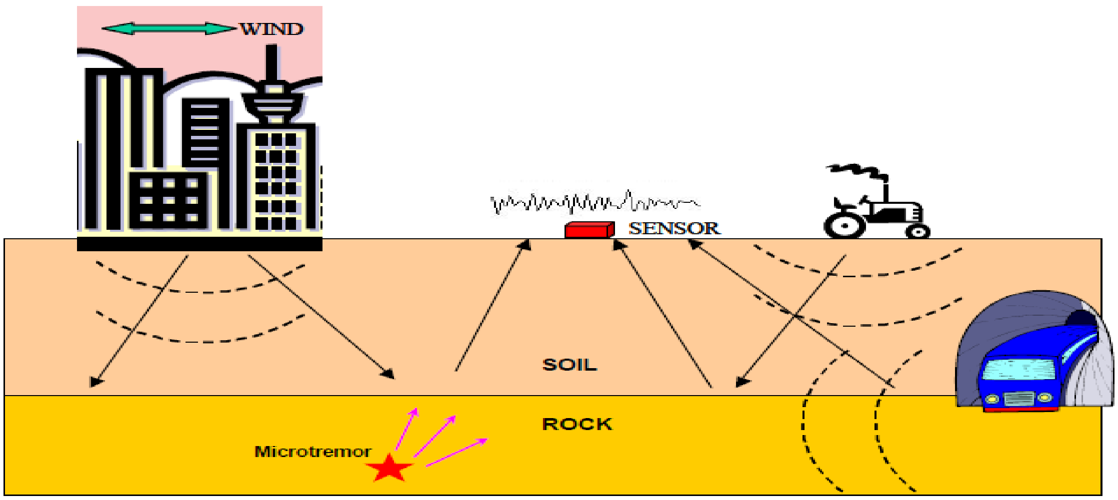
Sudden change of impedance



$$A_{\max} = \frac{\rho_r v_r}{\rho_s v_s}$$

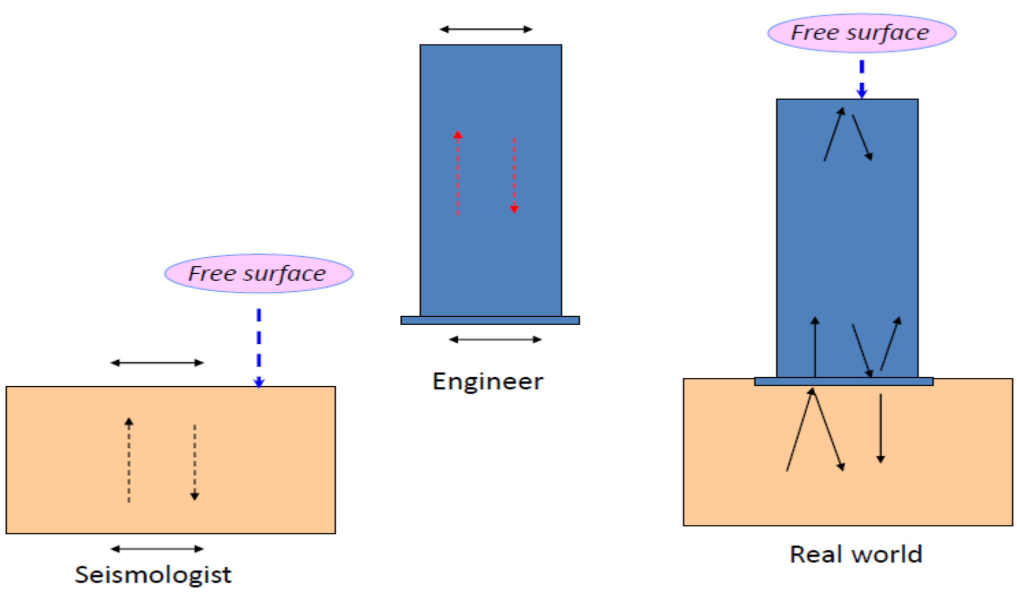
2.7 Soil-Structure Interaction

Soil-Structure Interaction



Example of SSI problem

• For seismic design of nuclear power plant (NPP), it was reported that fundamental mode period of a NPP with fixed base was estimated to be around 0.15 sec, but when considering the soil effect the period increased to 0.5 sec, resulting in a completely different seismic response.



3. Insufficient Structural Patterns in Seismic Zone

Some structural points make more risks during earthquake that should avoid them

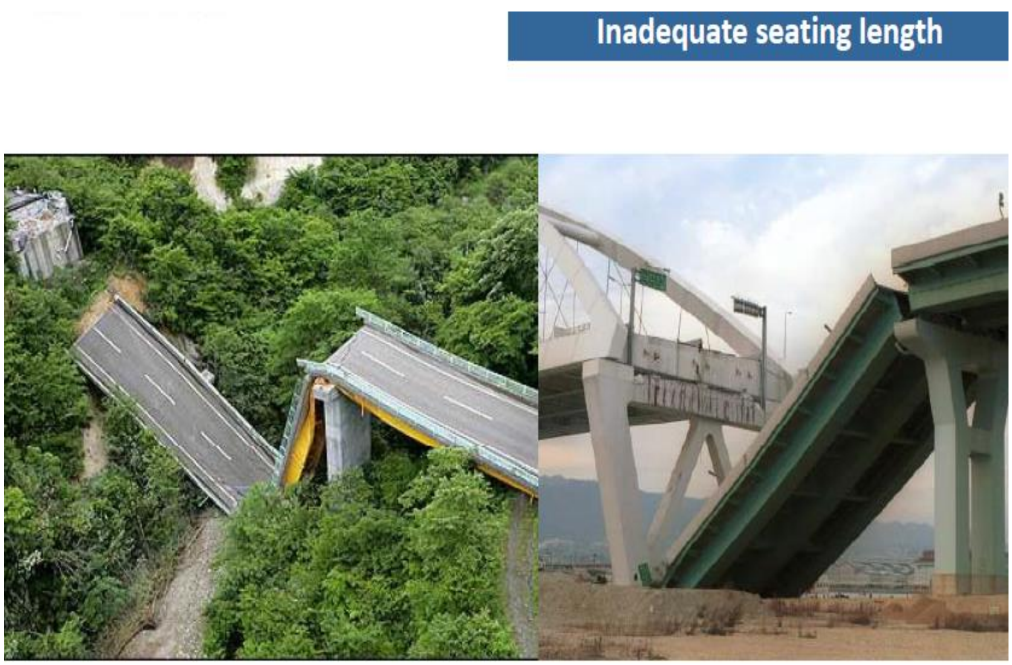
3.1 Non-Engineering Structures

3.2 Soft Story

3.3 Short Columns

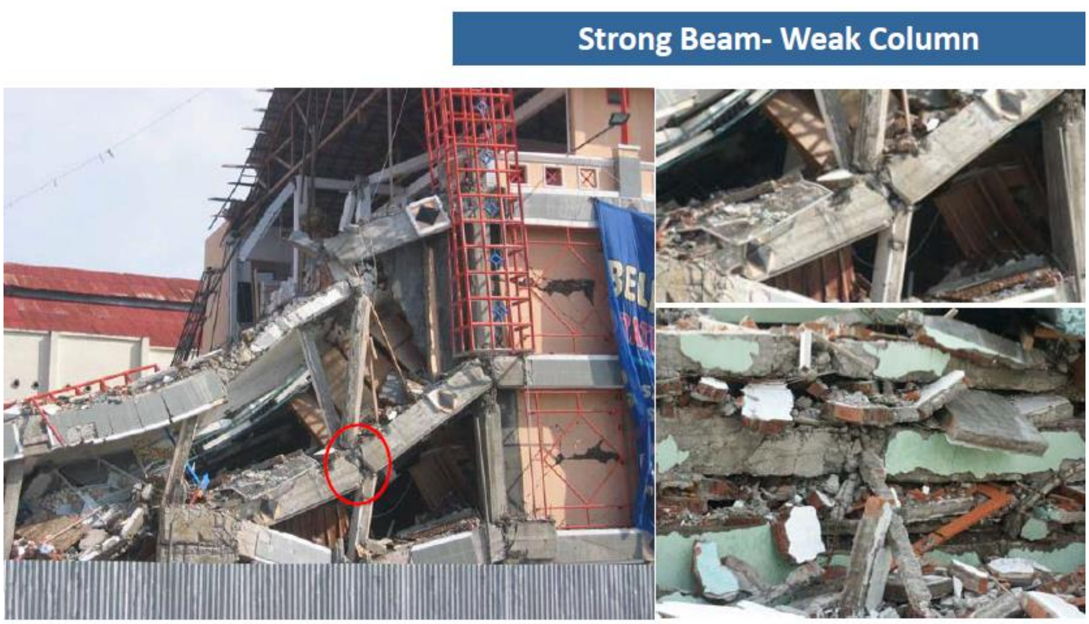
3.4 Single Pier- Inadequate ductility

3.5 Inadequate seating length



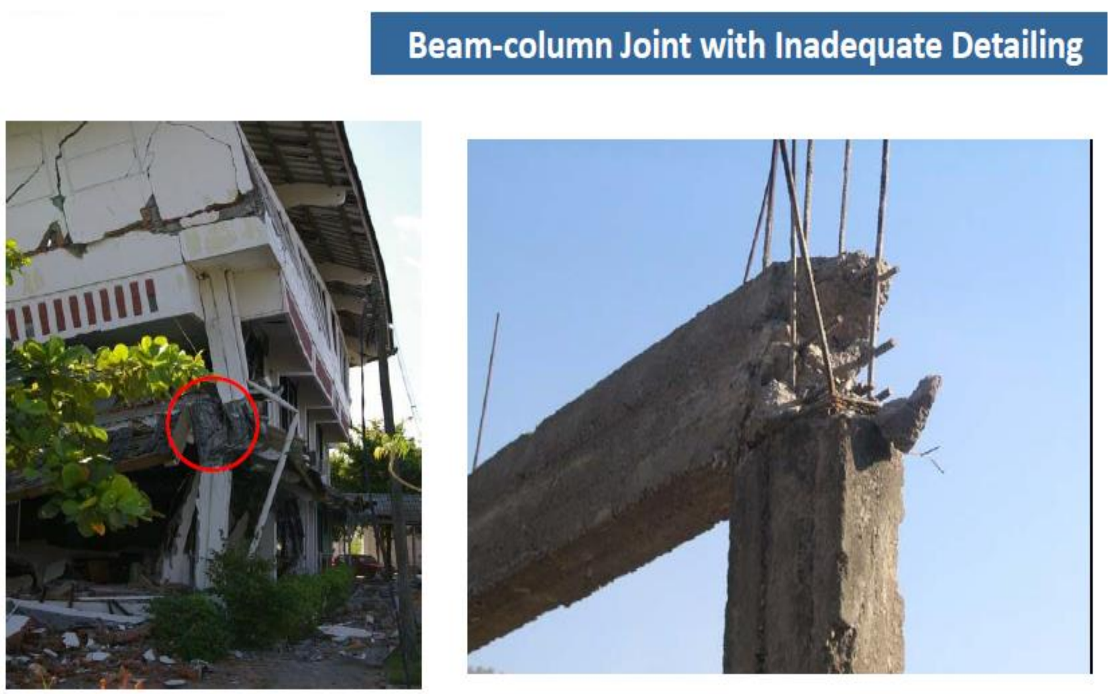
3.6 Discontinuous Force Resisting System

3.7 Strong Beam- Weak Column

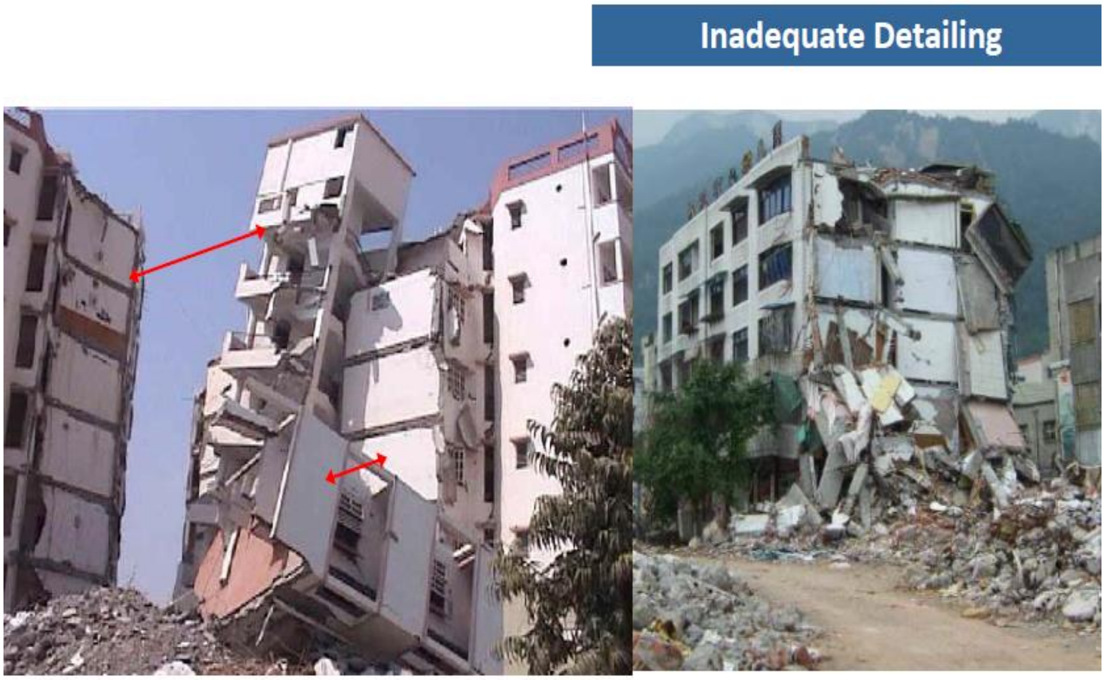


3.8 Inadequate Reinforcement Detailing

3.9 Beam-column Joint with Inadequate Detailing



3.10 Inadequate Detailing



3.11 Substandard Masonry Building

3.12 Interaction between infills and bare frame

Interaction between infills and bare frame

3.13 Poor Quality Concrete

Poor Quality Concrete

3.14 Insufficient Steel Connections

Insufficient Steel Connections

3.15 Building Pounding

Building Pounding

Earthquake Mitigation Strategies

1. **Using Energy Dissipation Devices**

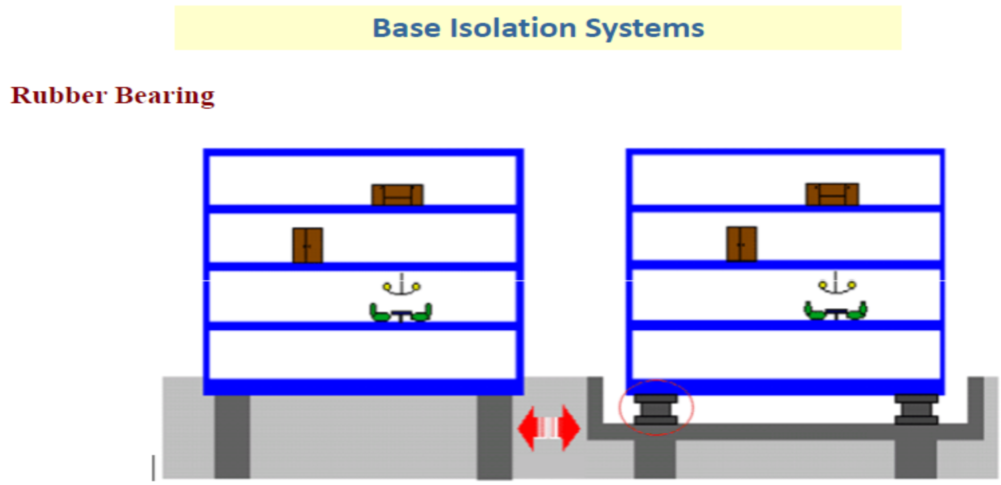
Using Energy Dissipation Devices

Viscous Dampers

Using Energy Dissipation Devices

Friction Dampers

2. **Base Isolation Systems**

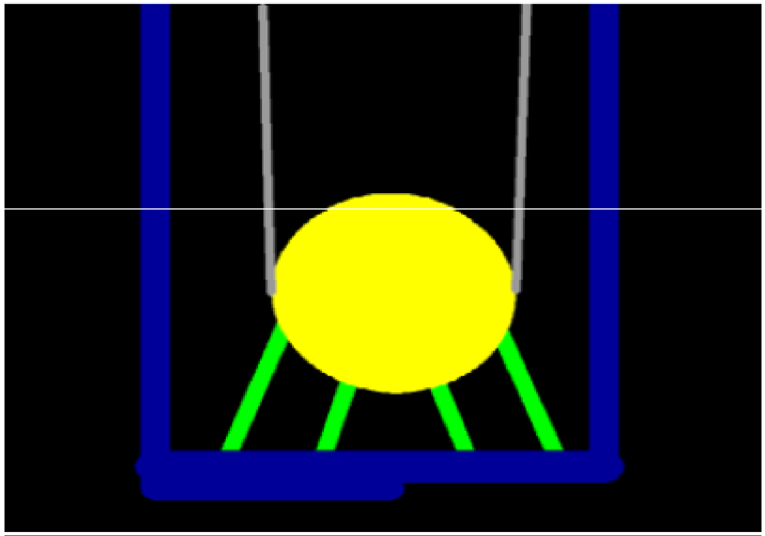


Rubber Bearing

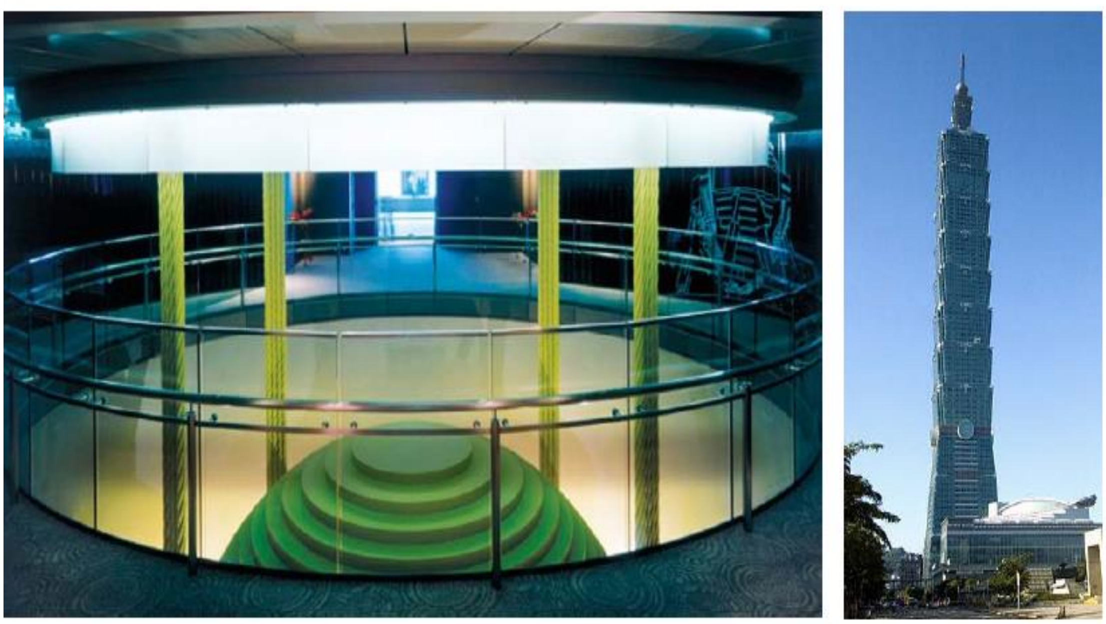
17-storey building in Tokyo (1986)

3. **Tuned Mass Dampers**

Tuned Mass Dampers



Active, semi-active and passive control systems for seismic protection

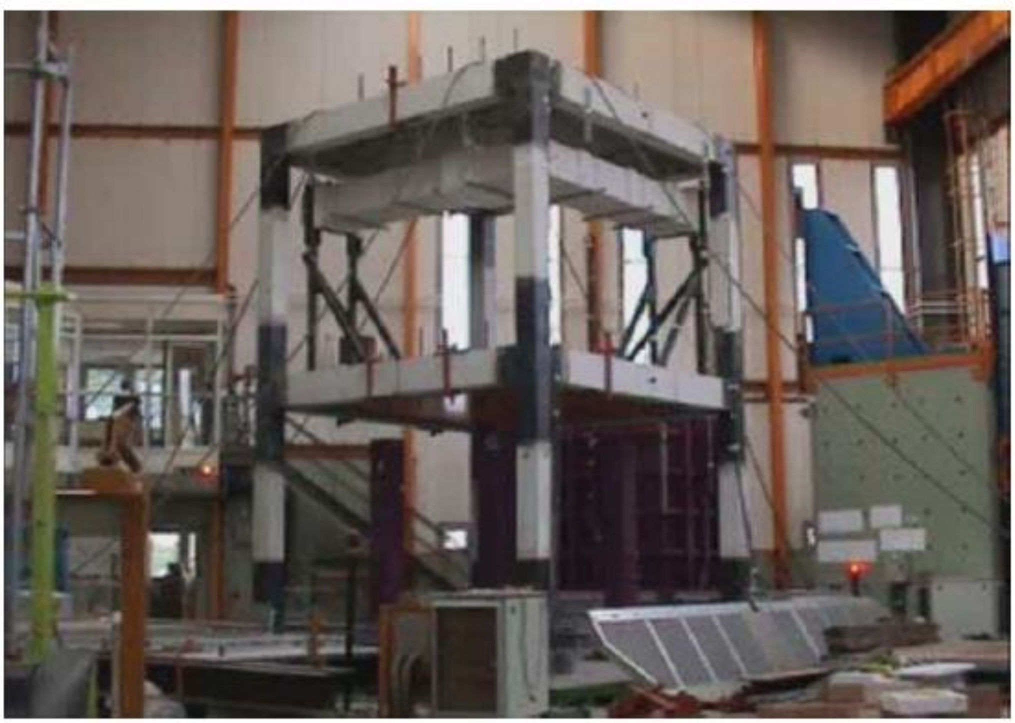


Taipei World Financial Centre in Taiwan (2004)

4. **Strengthening Using FRP Composites**

Strengthening Using FRP Composites

Shaking Table Tests



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