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# Introduction to Seismic Analysis and Design

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# Conceptual/Schematic Design

# Schematic Design

- Selection of Structural systems
  - Load paths
  - Materials
  - Approximate sizing of members
  - Primary mechanisms of inelastic behavior

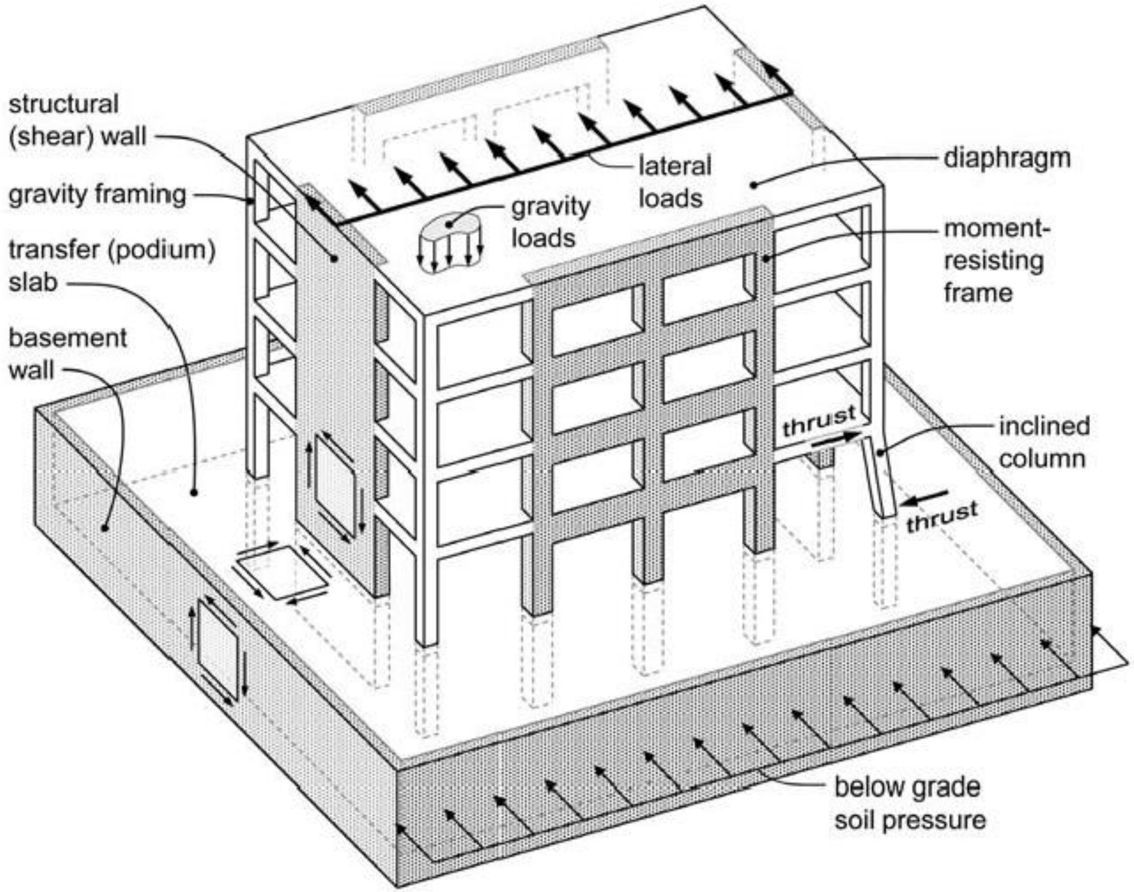
- Review in terms of
  - Dynamic response parameters
    - *Mode shapes, natural periods, modal participating mass ratios*
  - Lateral load response parameters
    - *Base shear, base moment, lateral displacement, story drift, shear distribution between frame and shear walls*

# Structural Systems

# The Building Structural System - Conceptual

- The Gravity  Load Resisting System
  - The structural system (beams, slab, girders, columns, etc) that act primarily to support the gravity or vertical loads
- The Lateral Load Resisting System
  - The structural system (columns, shear walls, bracing, etc) that primarily acts to resist the lateral loads
- The Floor Diaphragm
  - The structural system that transfers lateral loads to the lateral load resisting system and provides in-plane floor stiffness

# Structural System




**Source: NEHRP Seismic Design Technical Brief No. 3**

# Lateral Load Resisting System

**Purpose**

"To transfer lateral loads applied at any location in the structure down to the foundation level"

- Primary Lateral Loads
  - Load generated by Wind Pressure
  - Load generated due to Seismic Excitation

# Selection of Structural Systems

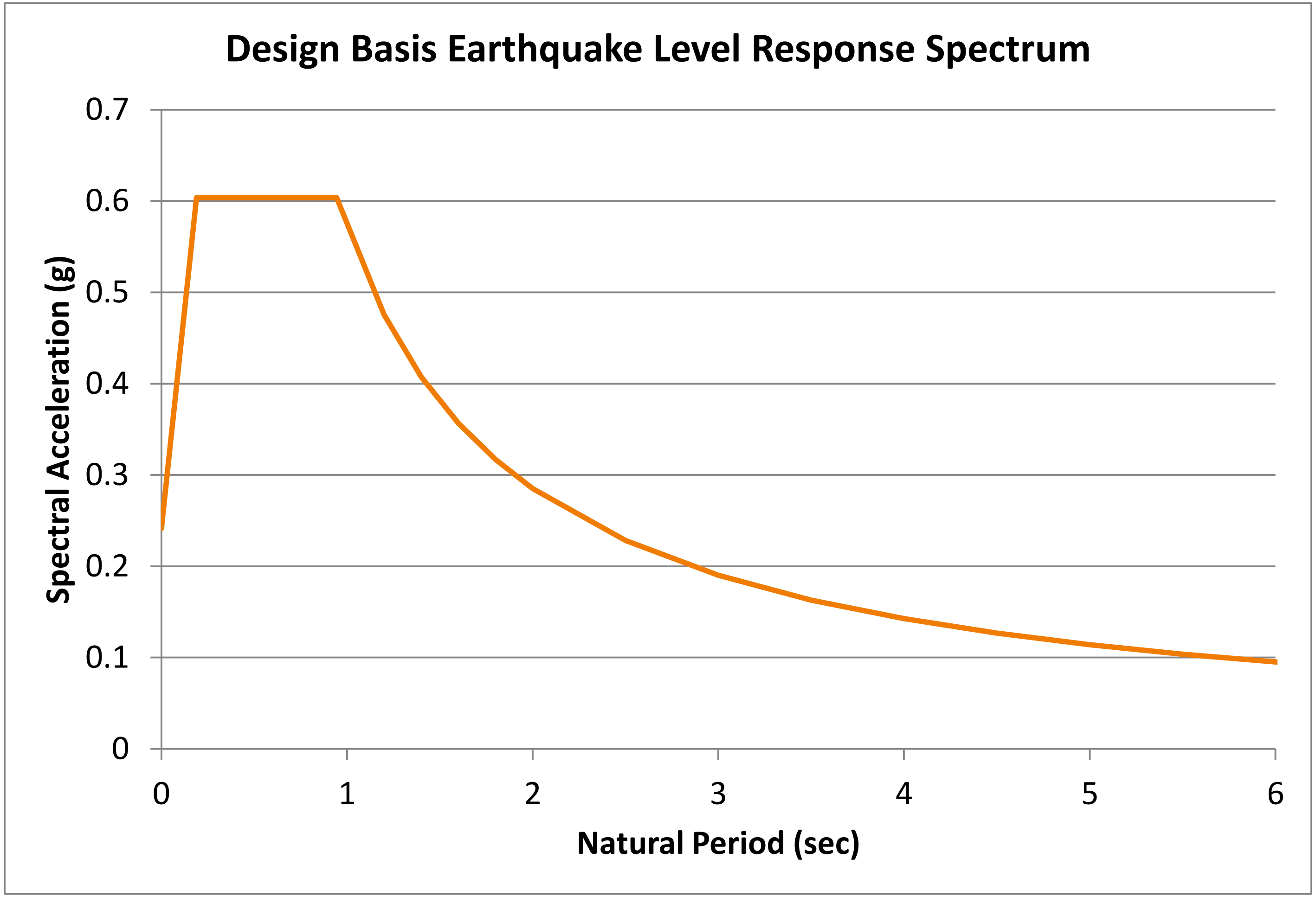
- In low seismic zones, expected ground motion will not produce the same large inelastic response demands that would occur in high seismic zones.
- When the seismic force is small compared to the gravity load and wind load requirements, there is more reserve strength to resist seismic forces.
- Permit to use systems and configurations with lower energy dissipation capabilities in low seismic zones such as concrete intermediate and ordinary moment-resisting frames, and concrete braced frames.
- In high seismic zones, usually systems with high energy dissipation capacities are allowed.

# Seismic Loading Criteria

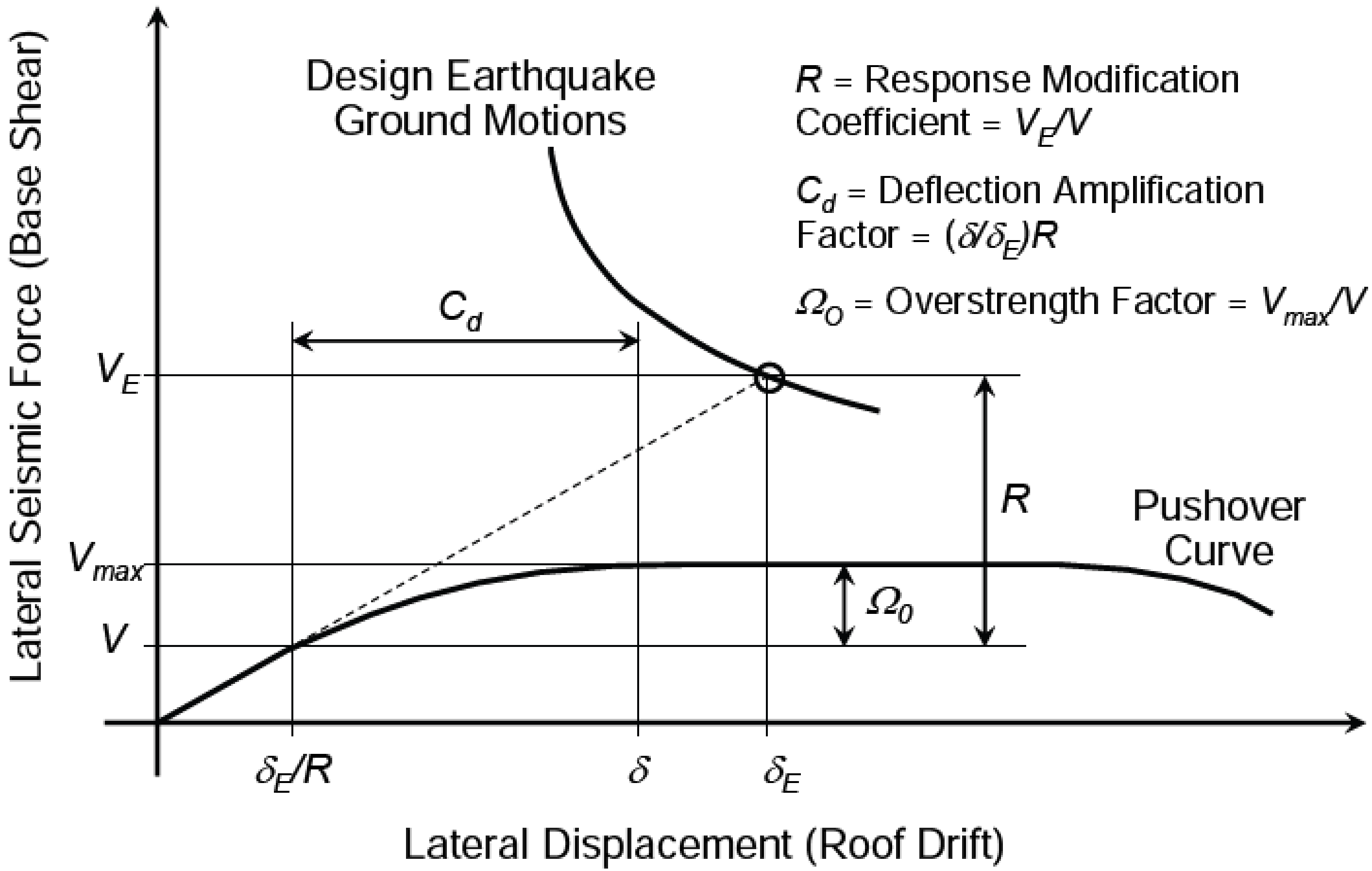
# Loading Criteria (Seismic Loading)

| Parameter | Value |
|---|---|
| Spectral acceleration (5% damped) at short periods (0.2 s) of horizontal ground motion (2500-yr. return period), $S_S$ | 0.77 g |
| Spectral acceleration (5% damped) at long periods (1 s) of horizontal ground motion (2500-yr. return period), $S_1$ | 0.31 g |
| Spectral acceleration (5% damped) at short periods (0.2 s) of horizontal ground motion (2500-yr. return period) adjusted for site class effects, $S_{MS}$ | 0.91 g |
| Spectral acceleration (5% damped) at long periods (1 s) of horizontal ground motion (2500-yr. return period) adjusted for site class effects, $S_{M1}$ | 0.88 g |
| Design spectral acceleration (5% damped) at short periods (0.2 s) of horizontal ground motion, $S_{DS}$ | 0.60 g |
| Design spectral acceleration (5% damped) at short periods (1 s) of horizontal ground motio, $S_{D1}$ | 0.58 g |
| Site class | E |
| Short period site coefficient, $F_a$ | 1.176 |
| Long period site coefficient, $F_v$ | 2.76 |
| Response modification coefficient, R (Dual system, Shear wall + IMRF) | 6.5 |

# Response Spectrum



# Scaling the Results




**Source: FEMA P695 / June 2009**

# Response Modification Factor (R)

- To provide rational relationship between elastic response spectrum demand and the inelastic reduction capacities of a given structural system
- Represents potential capacity of a system for ductile response and energy dissipation

# Deflection Amplification Factor ($C_d$)

- To provide rational relationship between elastic response spectrum demand and the inelastic reduction capacities of a given structural system.

# System Overstrength Factor ($\Omega_0$)

- Intended to reflect upper bound lateral strength of the structure and estimates the maximum forces in elements that are to remain non-yielding during the design basis ground motion.
- Represents
  - Ratio in lateral strength between minimum design seismic force level to the point of nominal first significant yield (e.g., the formation of a plastic hinge in a moment frame) based on nominal material strengths.
  - Material overstrength (difference between nominal and actual material strengths).
  - System overstrength beyond the first significant yield point.

# Analysis Procedures

# Structural Analysis

## Modeling

- An analysis model must capture the important aspects of behavior of the real structure. A useful model does this with sufficient accuracy, economy and detail for practical purpose.
- A model does not have to be exact, and never will be.

## Computation

- Complex process, involving finite element theory, complex logic, and extremely large numerical computations.
- The numerical computations (given the analysis model, get the analysis results) will almost be done by computer.

## Interpretation

- Challenge is to use the results to make design decisions for the actual structures.
- Develop a "feel" for structural behavior.

# Modeling

- Materials
  - Nominal strength of materials shall be used in the determination of modulus of elasticity.
- Section Stiffness
  - Cracked sections for seismic analysis
- Soil-Structure Interaction
  - Springs representing the effects of soil on the foundation system
  - The vertical and horizontal spring stiffness determined based on the lateral and vertical sub-grade reaction modulus of the soil.
- Damping
  - to represent the reduction in dynamic (vibration) response due to energy dissipation

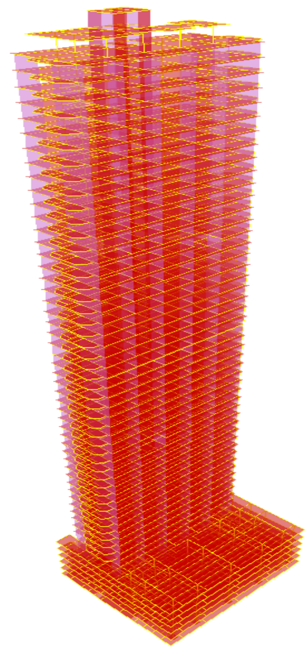
# Analysis Procedures

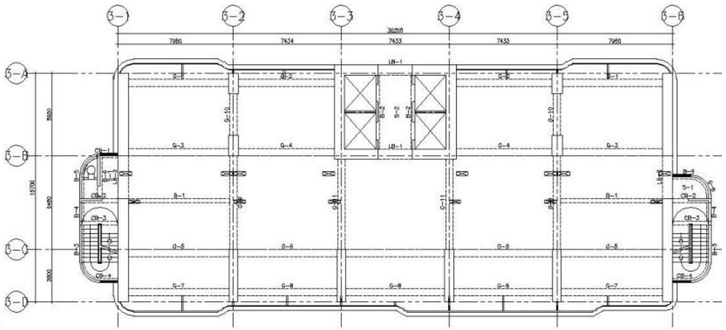
| Load Case | Analysis |
|---|---|
| To check the dynamic properties | Modal analysis |
| Dead load | Construction sequence analysis |
| Live load | Linear static analysis |
| Seismic load | Static/Response spectrum |
| Wind load | Linear static analysis |

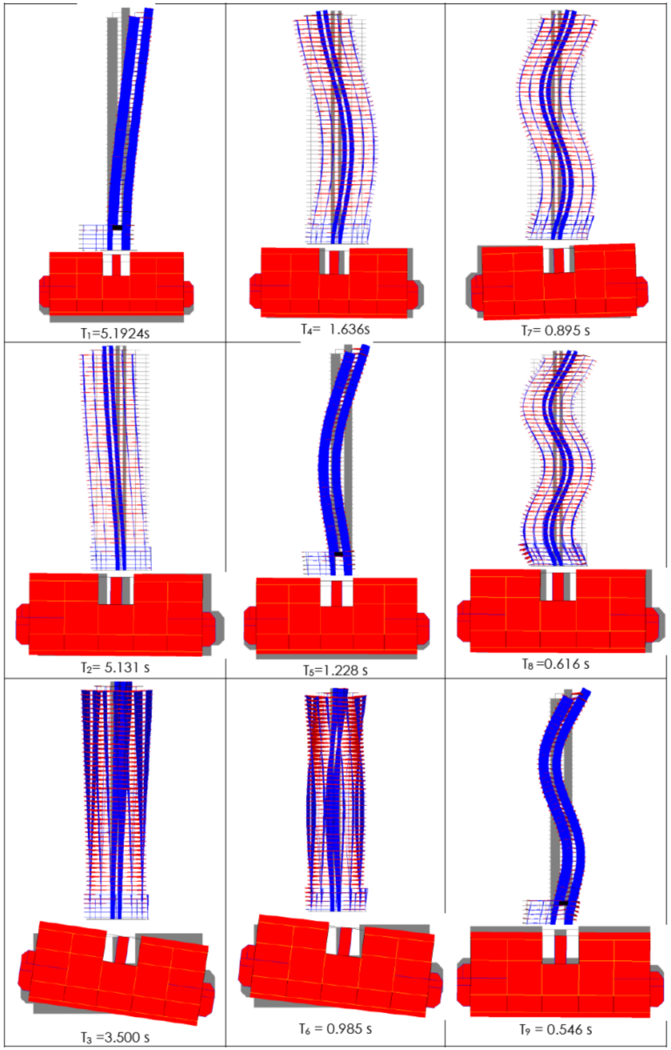
# Modal Analysis

- To determine vibration modes of building
- To understand behavior of building in schematic design stage
  - Adequacy of lateral stiffness
  - Minimize torsional response under earthquake
  - Tune to structure to be dynamically regular
  - Determine the principal directions of building
- Mass source
  - 100% of dead load and 25% of live load

# Modal Analysis







# Construction Sequence Analysis

- The entire building is modeled as a single structure and loaded all at once which greatly conflicts with reality
  - Differential shortening of columns and shear walls causes overestimation of moment and shear demands in beams connecting them
  - Underestimation of design forces in transfer systems
- The real building is constructed in stages over a long time
  - Elastic deformations and long-term effects alter the geometry and the loads distribution paths

# Construction Sequence Analysis

- The entire structure is modeled at once
  - Parts of structure are assigned into different groups
  - Each group is added or removed from the overall model in specified sequence
  - The loading can be done in sequence
  - Each sequences uses the results from previous structure and loading history
- Nonlinear static analysis
  - Material and geometrical nonlinearity is optional

# Response Spectrum Analysis (Seismic Loading)

- Behavior of building during an earthquake is vibration problem.
- But by internally generated inertial forces caused by vibration of building mass.
- Interrelationship of building behavior and seismic ground motion depends on building natural period as formulated in the so-called response spectrum. The response of the building having a broad range of period is summarized in single graph.
- A standard time-history ground motion is not defined in the code for the purpose of design.
- Most engineers use response spectrum analysis for the purpose of basic design.

# Response Spectrum Analysis

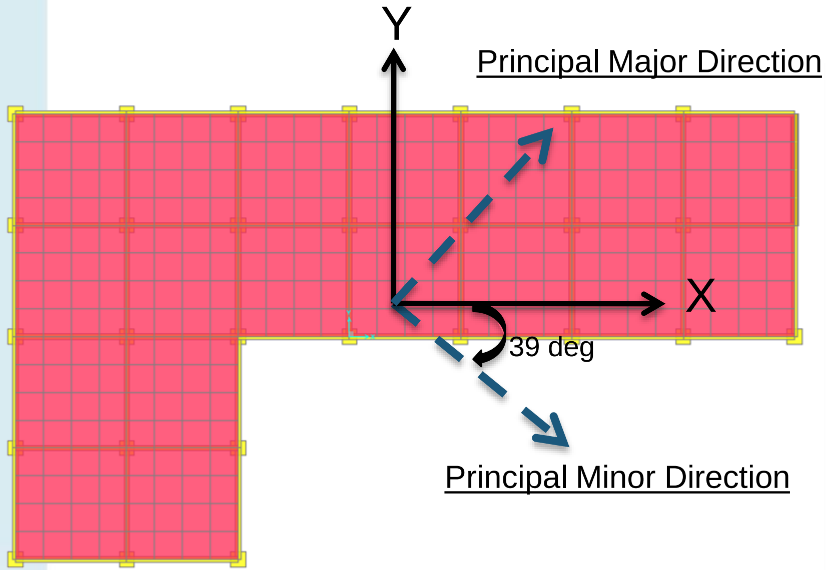
- Static methods specified in building codes are based on single mode response and appropriate for simple and regular structures
- Dynamic analysis should be used for complex buildings to determine significant response characteristics
  - Effects of structure's dynamic characteristics on vertical distribution of lateral forces
  - Increase in dynamic loads due to torsional motions
  - Influence of higher modes, resulting in an increase in story shear and deformations

# Principal Directions

- Lack of definitions of the principal directions in code
- The direction of the base reaction of the mode shape associated with the fundamental frequency of the system is used to define the principal direction

# Principal Directions

- Run modal analysis
- Extract base shear of mode 1
- Find angle between X and Y components of base shear
- Another direction is 90 degrees apart




Fx = -1,041 kN
Fy = 846 kN
Angle = tan-1 (Fy/Fx)
= -39 deg.

# Directional and Orthogonal Effects

- Seismic forces act in both principal directions of the building simultaneously
- But seismic effects in two directions are unlikely to reach their maxima simultaneously
- 100% of seismic forces in one principal direction combined with 30% of seismic forces in the orthogonal direction

# Scaling the Results

- Reduce the elastic response for design purpose, but design base shear is not less than elastic base shear divided by R
- Generally, design base shear is scaled to static lateral force base shear.

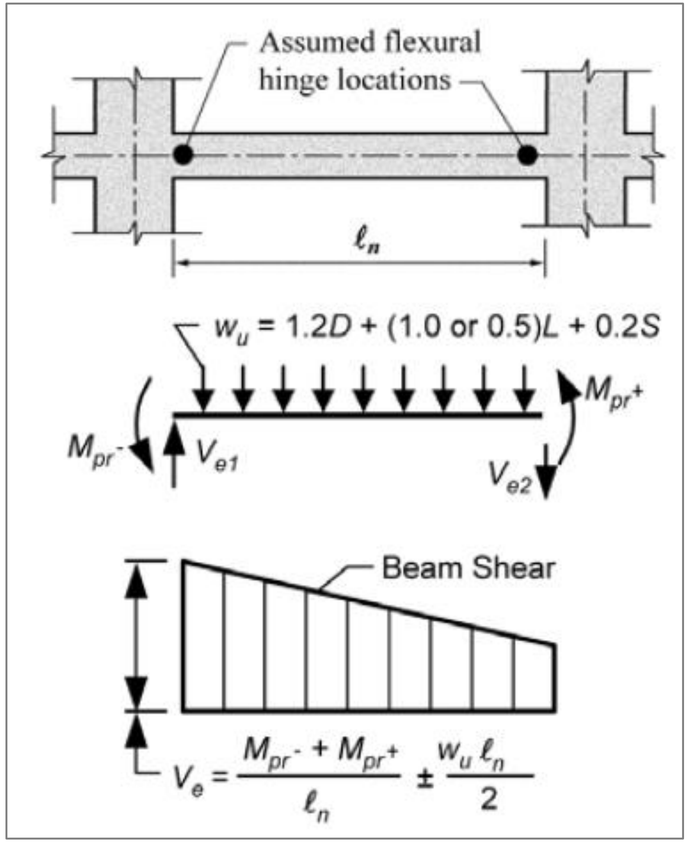
# Structural Design of Members

# Structural Design of Members

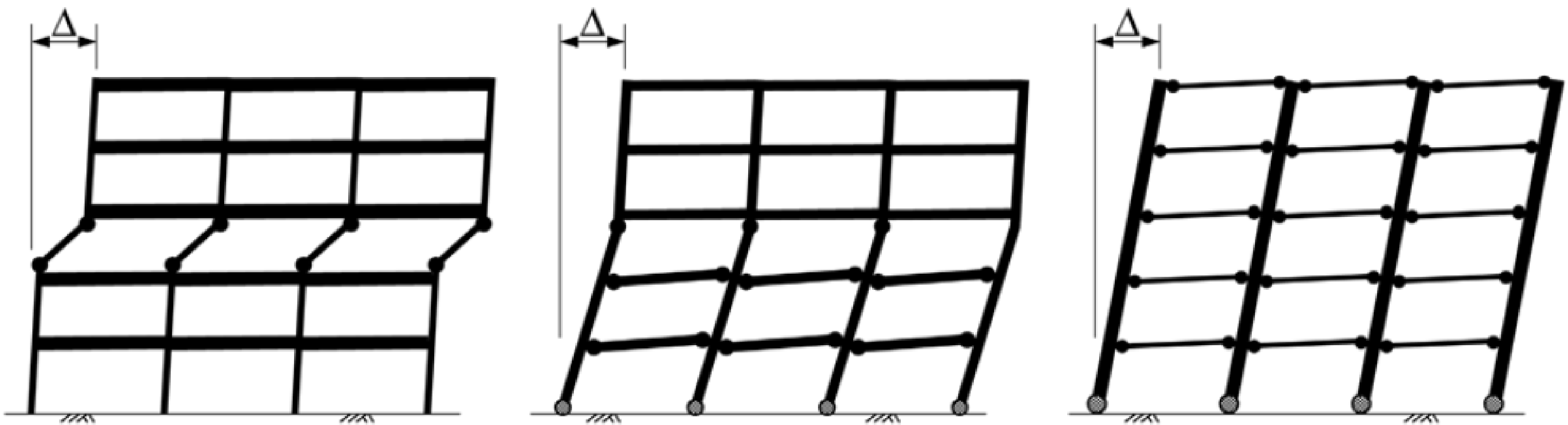
| Member | Design Actions |
|---|---|
| Beam | Flexure, Shear |
| Column | PMM, Shear |
| Shear wall | PMM, Shear |
| Coupling beam<br>• Conventional reinforced<br>• Diagonal reinforced | <br>Flexure, Shear<br>Shear |
| Slab | Flexure, Shear |
| Diaphragm | Flexural, Shear, Axial |
| Mat foundation | Flexure, Shear |
| Piles | PMM, Shear |

# Capacity Design Approach

- Assuming beam is yielding in flexure, beam end moments are set equal to probable moment strengths.
- Design shear is based on the probable moment to maintain the moment equilibrium.



# Strong-Column/Weak Beam Frame

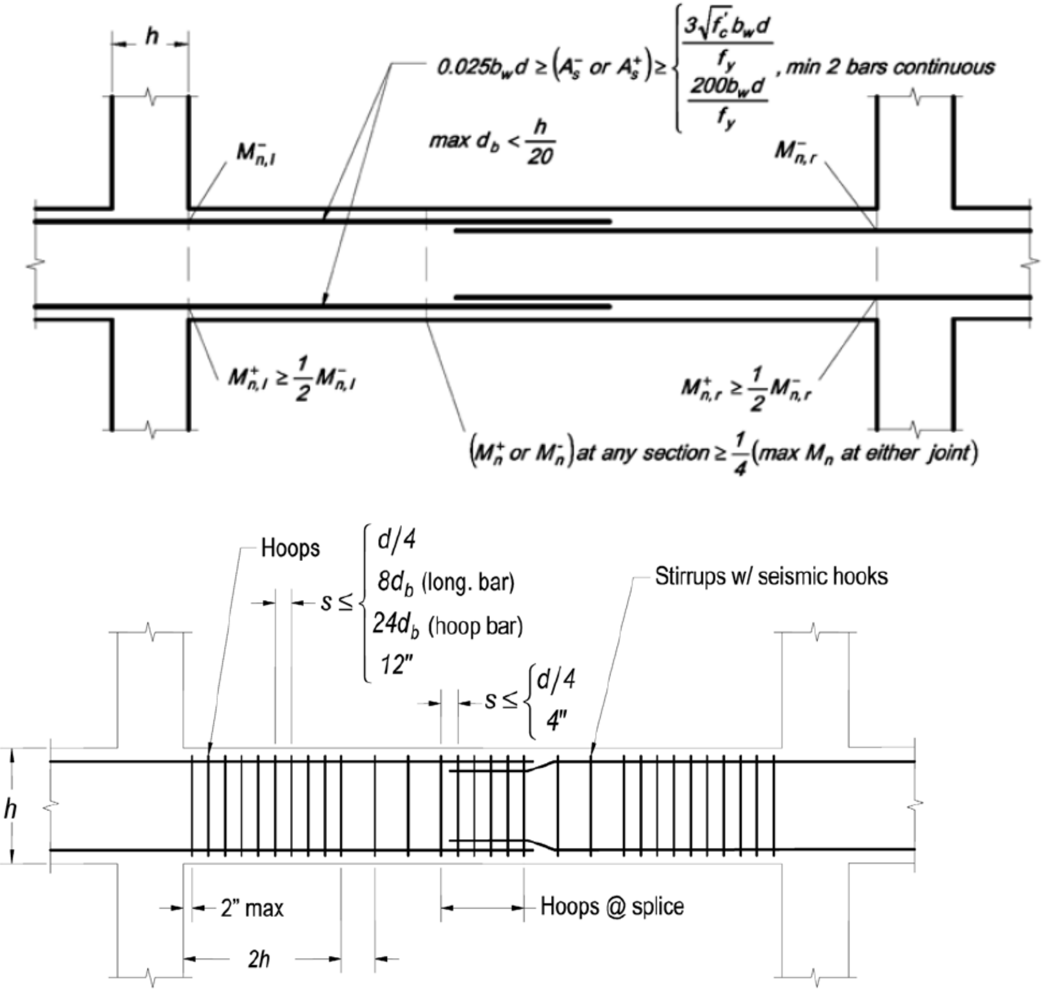



(a) Story mechanism (b) Intermediate mechanism (c) Beam mechanism

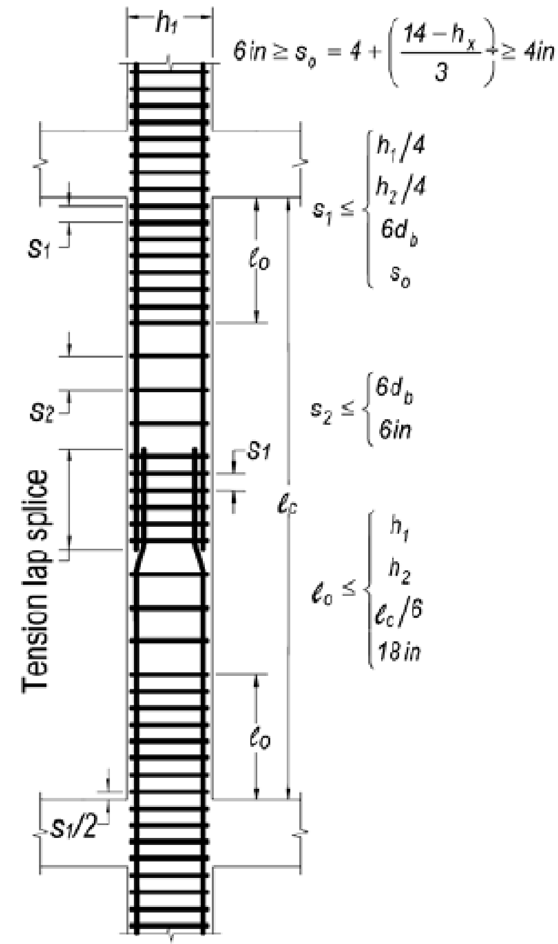
**<u>Strong-Column/Weak Beam Frame Requirement for SMRF</u>**

**<u>Source: NEHRP Seismic Design Technical Brief No. 1</u>**

# Beam and Column Reinforcement Details

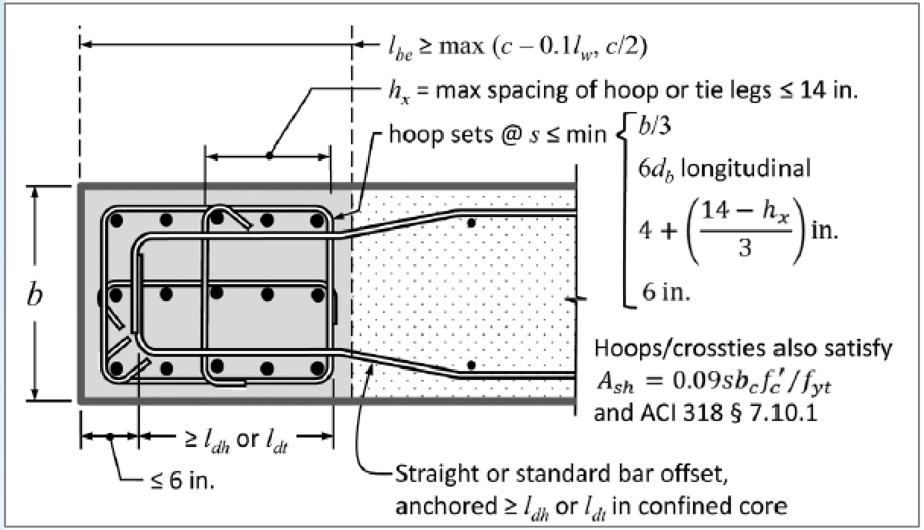



**Beam Reinforcement Details**




**Column Reinforcement Details**

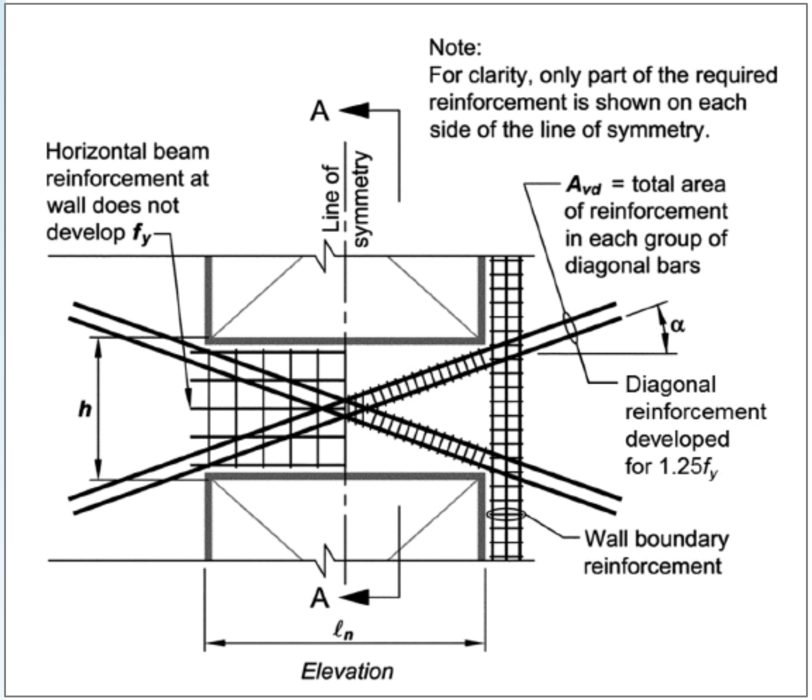
# Shear Wall Reinforcement Details




**Boundary Confinement in Shear Walls**

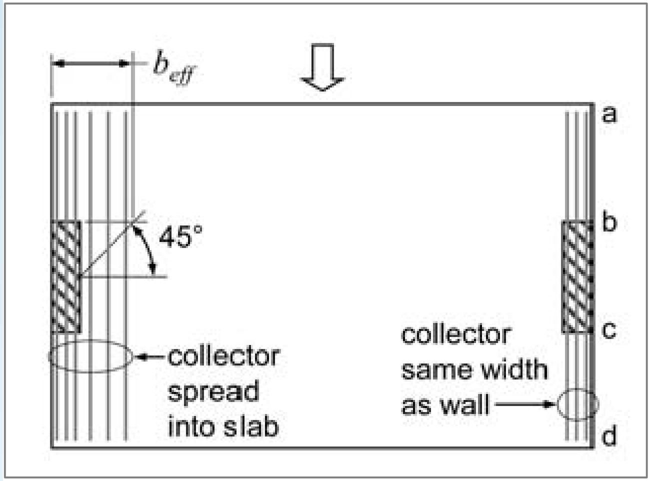
**Source: NEHRP Seismic Design Technical Brief No. 6**

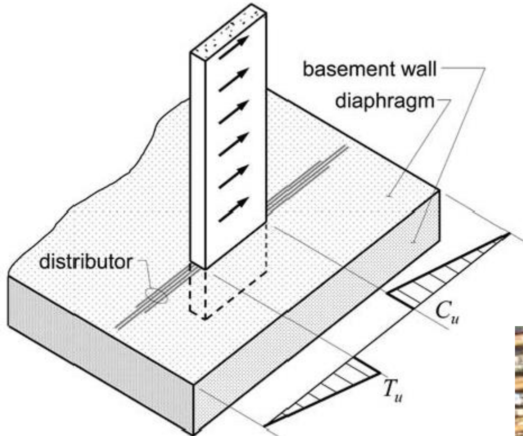
# Coupling Beam Reinforcement Details



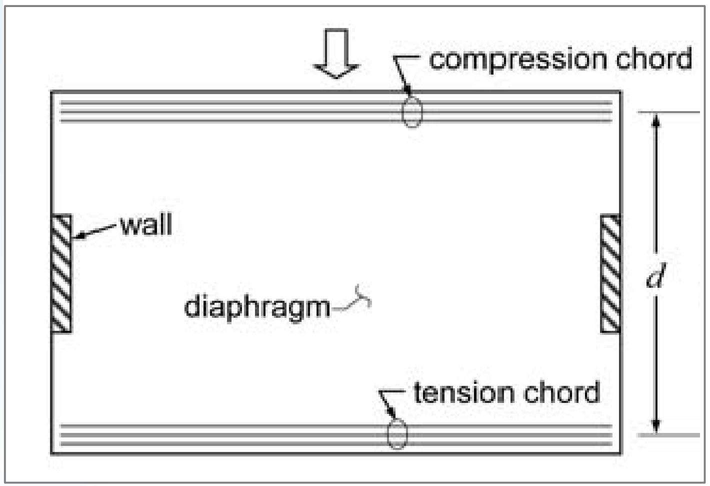

**Diagonal Reinforced Coupling Beam**

# Diaphragm Reinforcement



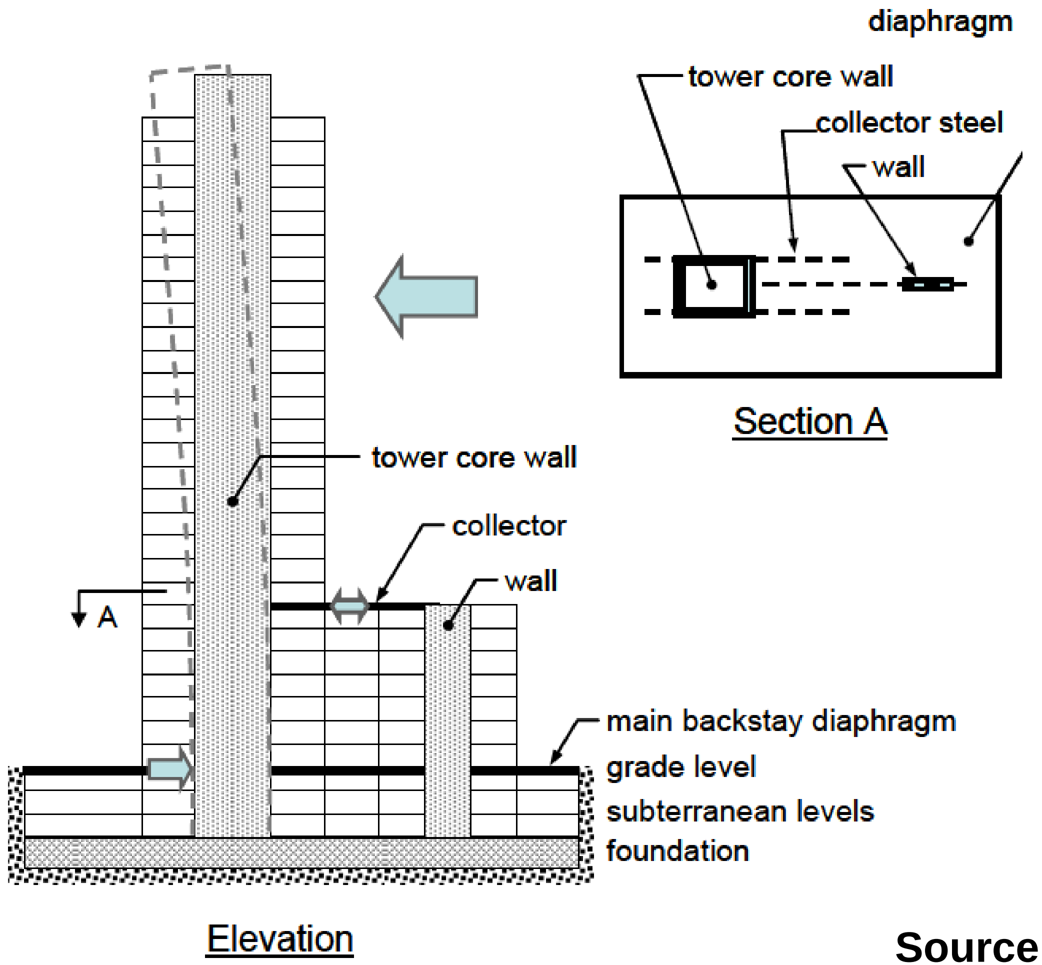




Collector




**Source: NEHRP Seismic Design Technical Brief No. 3**

# Backstay Effect

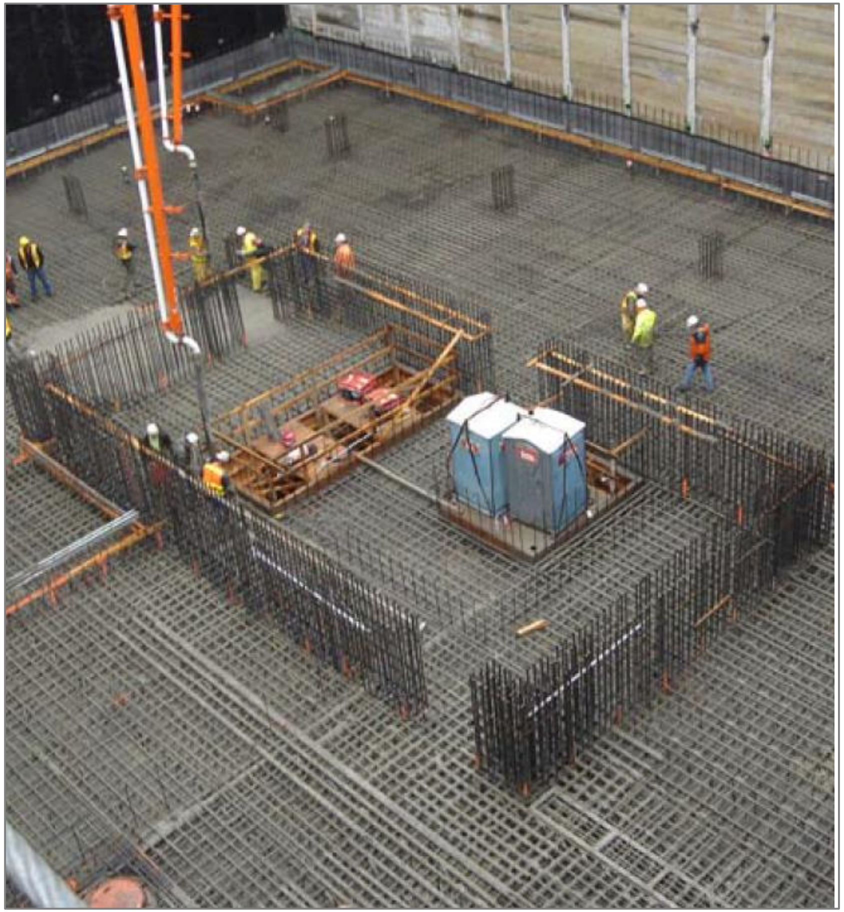



Source: PEER/ATC 72-1

# Backstay Effect

- PEER/ATC 72-1 mentions in details about podium diaphragm modeling and backstay effects.
  - **Case 1: Upper bound backstay effect**
    - *Provide upper-bound estimate of forces in the back stay load path and lower-bound estimate of forces in foundation below the tower.*
  - **Case 2: Lower bound backstay effect**
    - *Provide lower-bound estimate of forces in the back stay load path and upper-bound estimate of forces in foundation below the tower.*

# Mat Foundation



**Shear Reinforcement in Mat**

**Source: NEHRP Seismic Design Technical Brief No. 7**

# Thank You