Earthquake Mitigation for Hospitals Workshop

Part 3 – Structural Vulnerability

Building Structural Vulnerability to Earthquakes

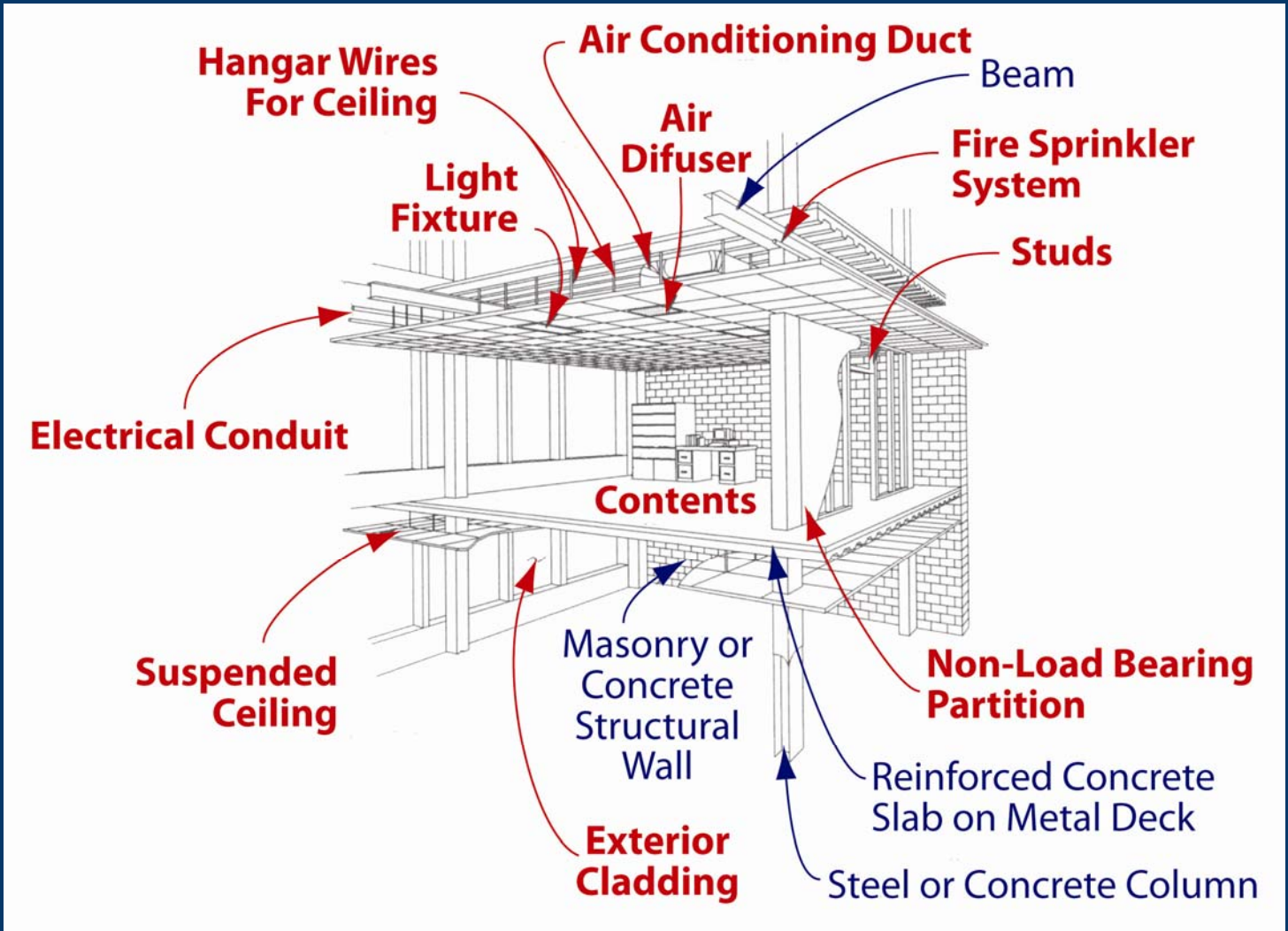
RISK = f(HAZARD, VULNERABILITY)

Risk is a function of both the potential hazard (seismic ground motion) and vulnerability (lack of seismic preparedness in structural and nonstructural systems)

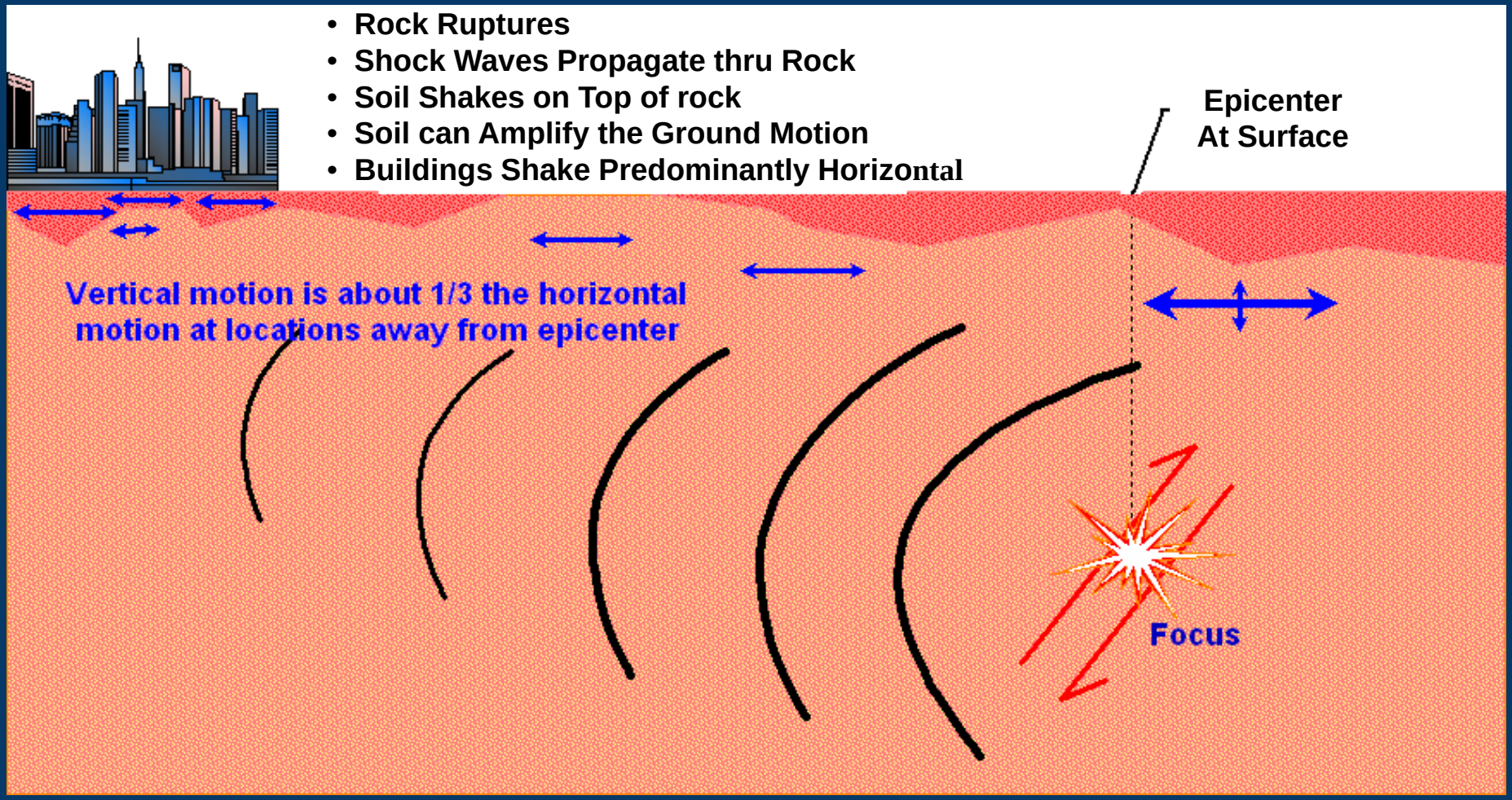
Section Outline

- Building response to earthquake ground shaking
- Effect of building type, age, configuration, regularity on performance
- Pounding between buildings
- Examples of structural damage
- Implications of building response to nonstructural performance

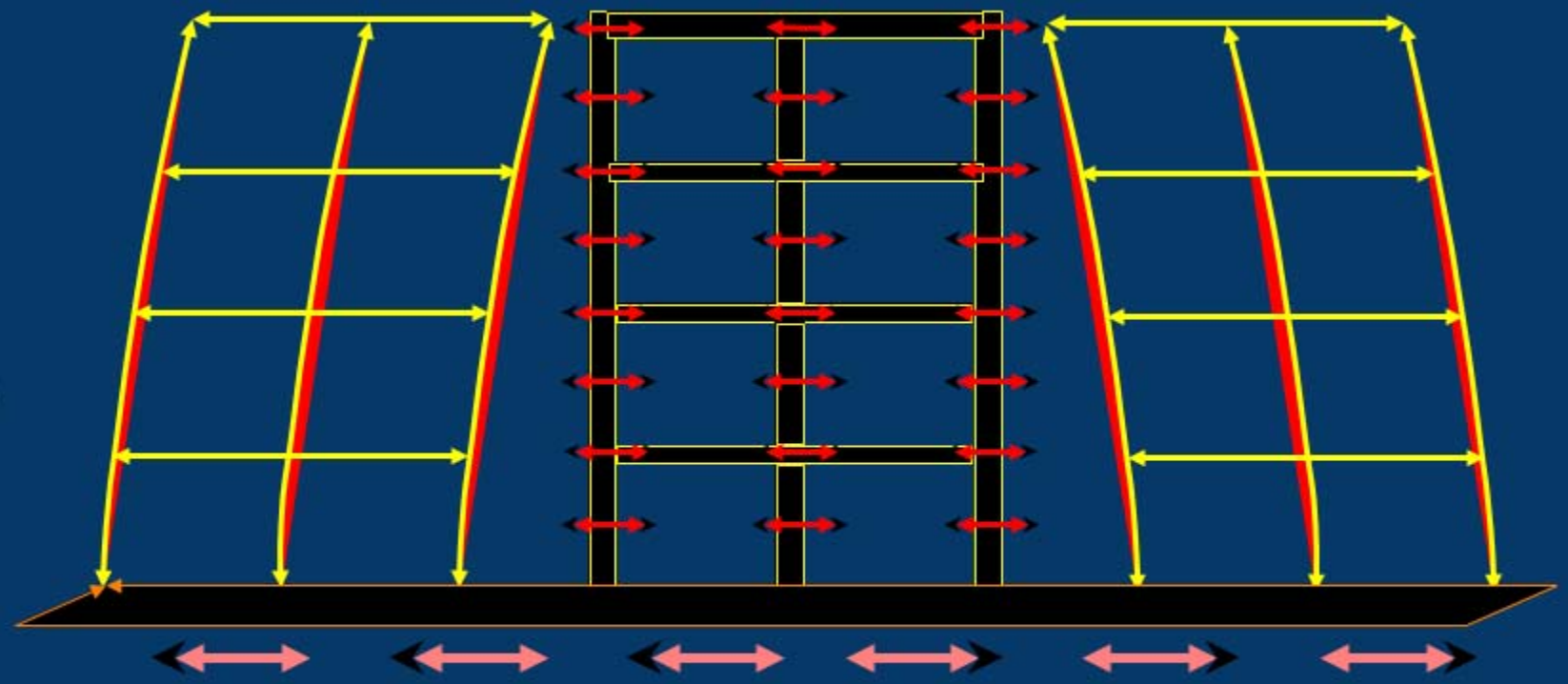
Structural & Nonstructural Components



Building Response to Earthquake Ground Shaking

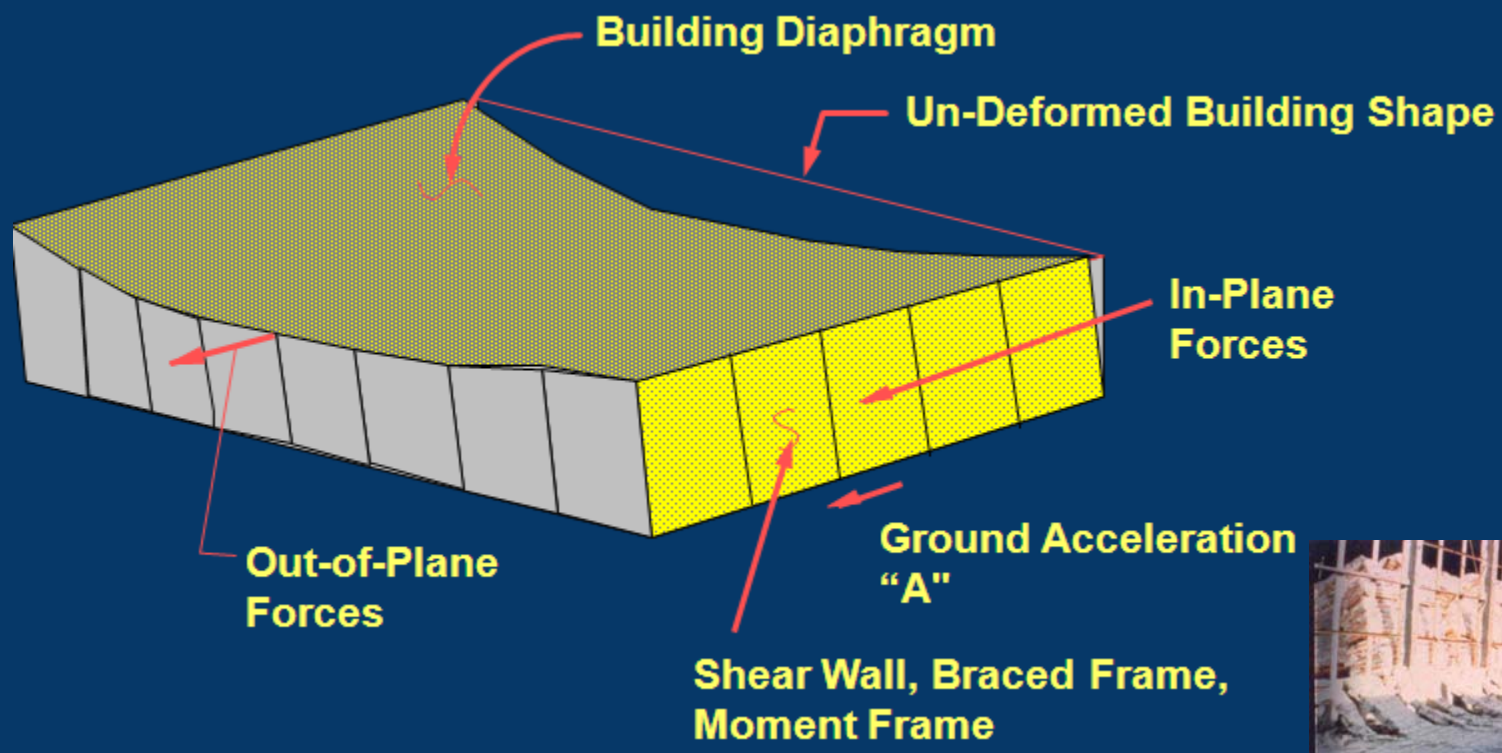


Earthquake Loads on Buildings

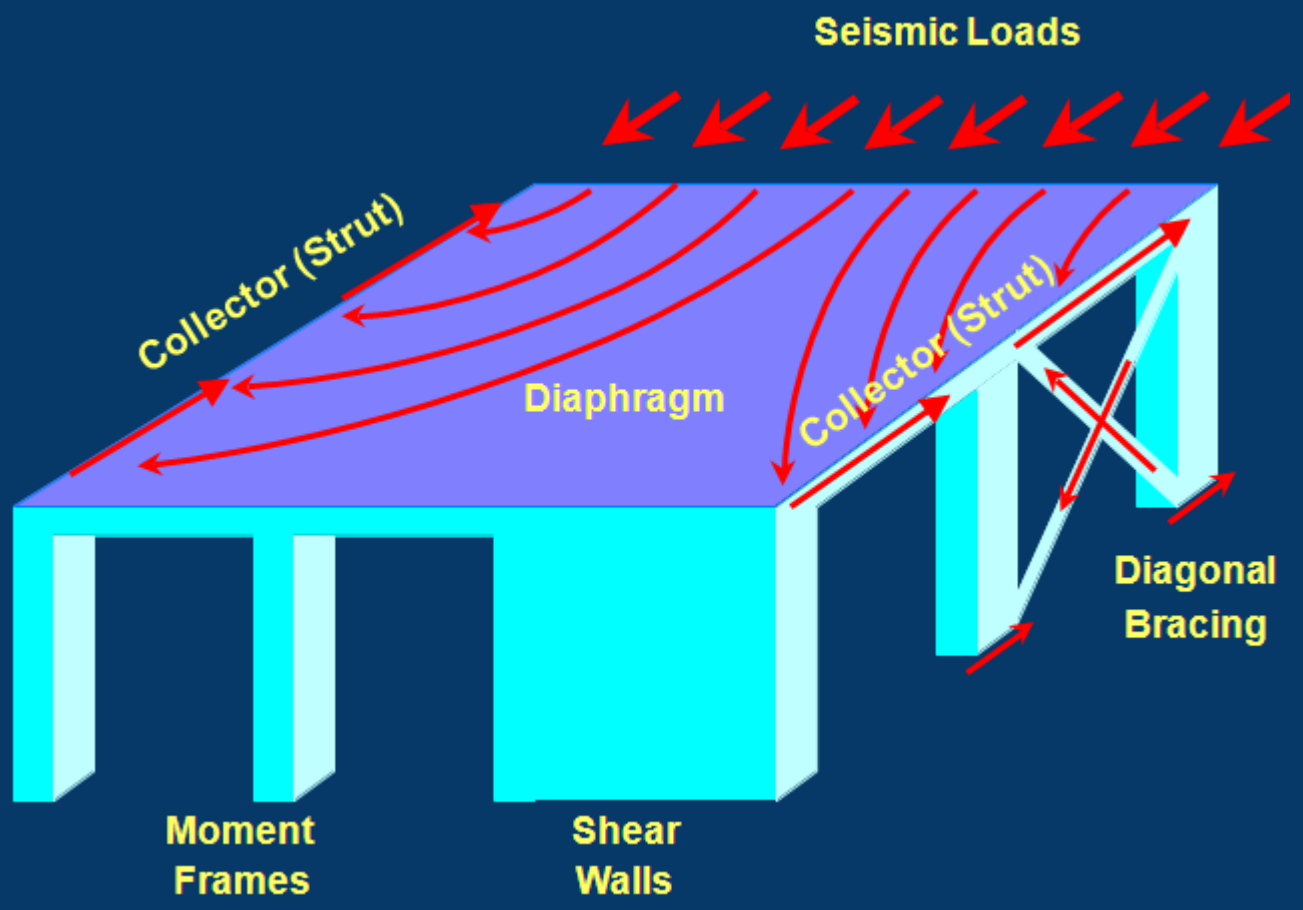


Ground Shakes Primarily In Both Horizontal Directions
Bottom Of Building Moves with Ground
Top Of Building Tries to Follow

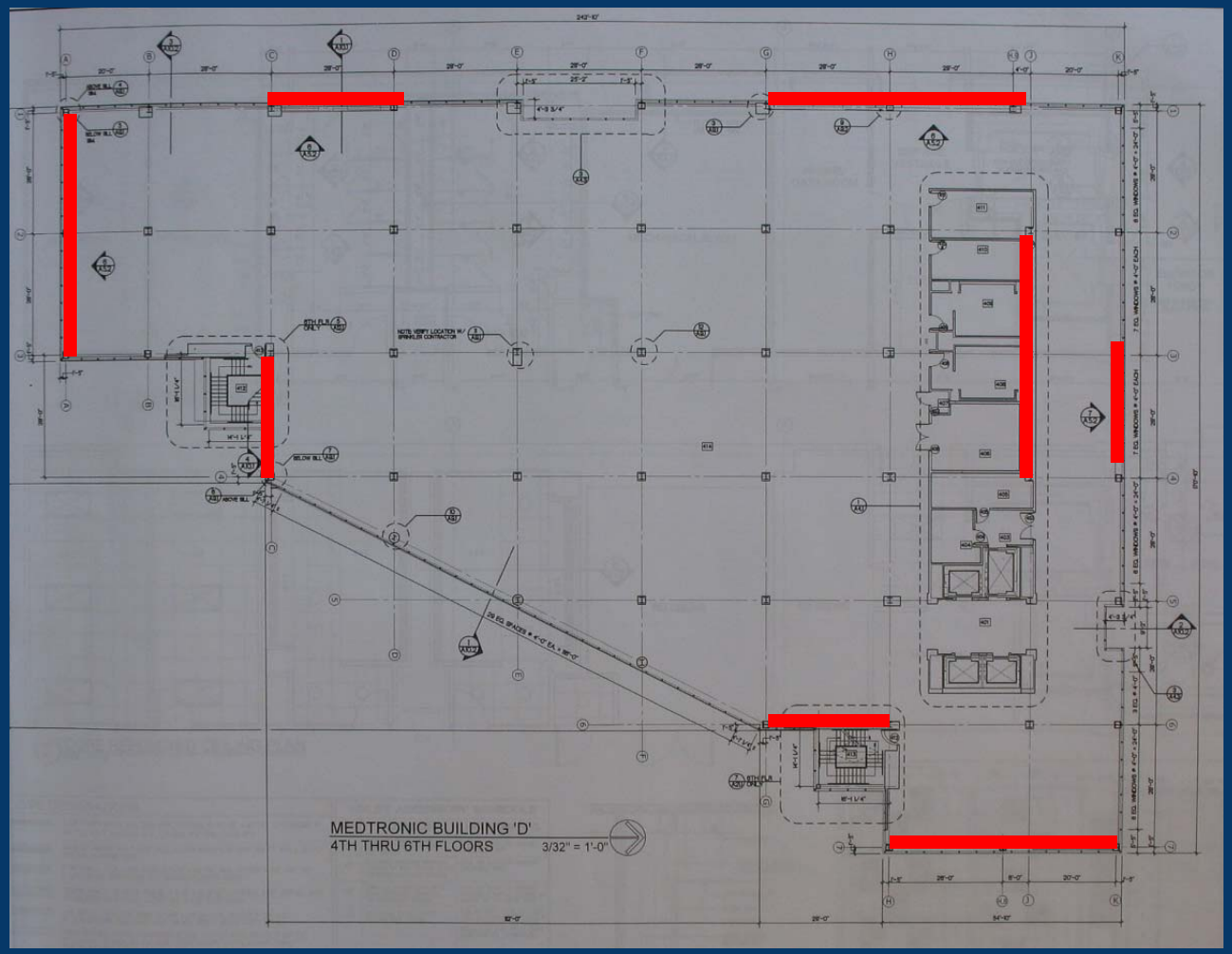
Earthquake Response of Structures

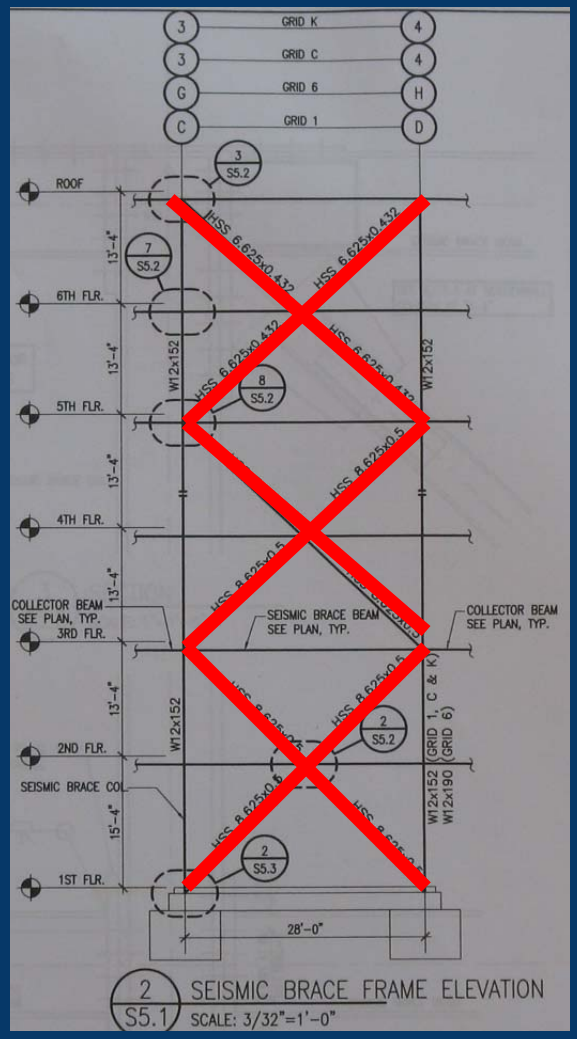


Building Lateral Force Resisting Systems – Key to Good Performance

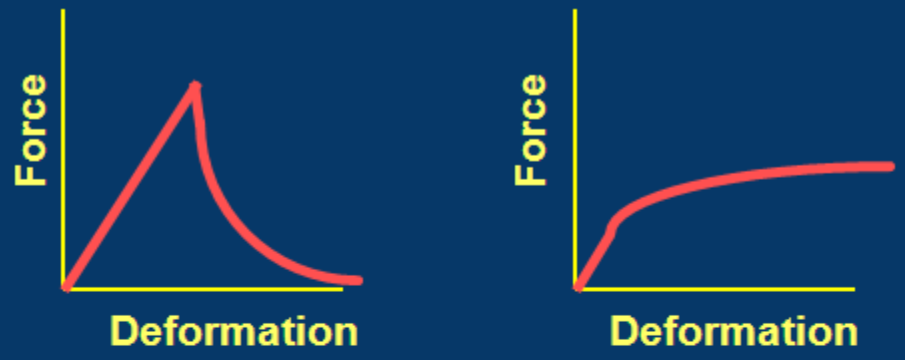


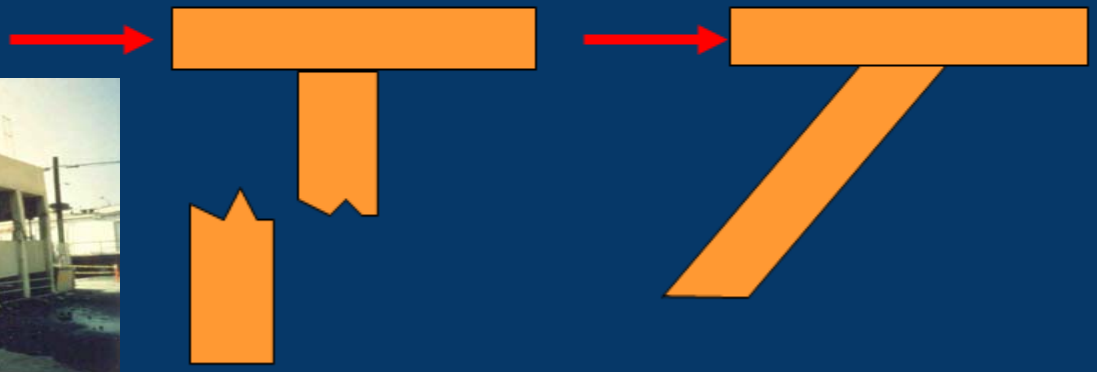
Lateral Force Resisting System





Strength & Ductility

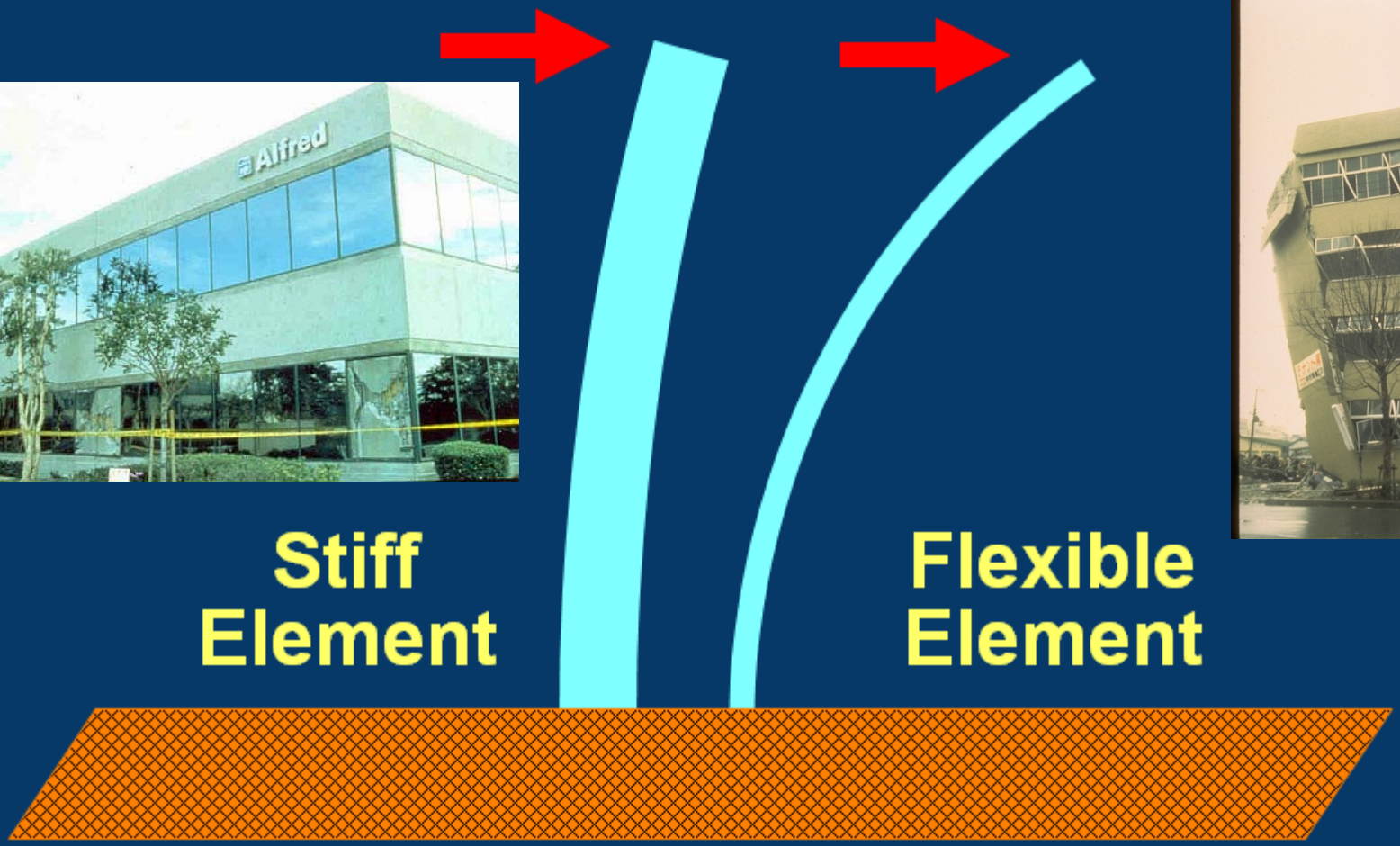




Analogy: Chalk

Rubber

Building Stiffness



Other Performance Predictors

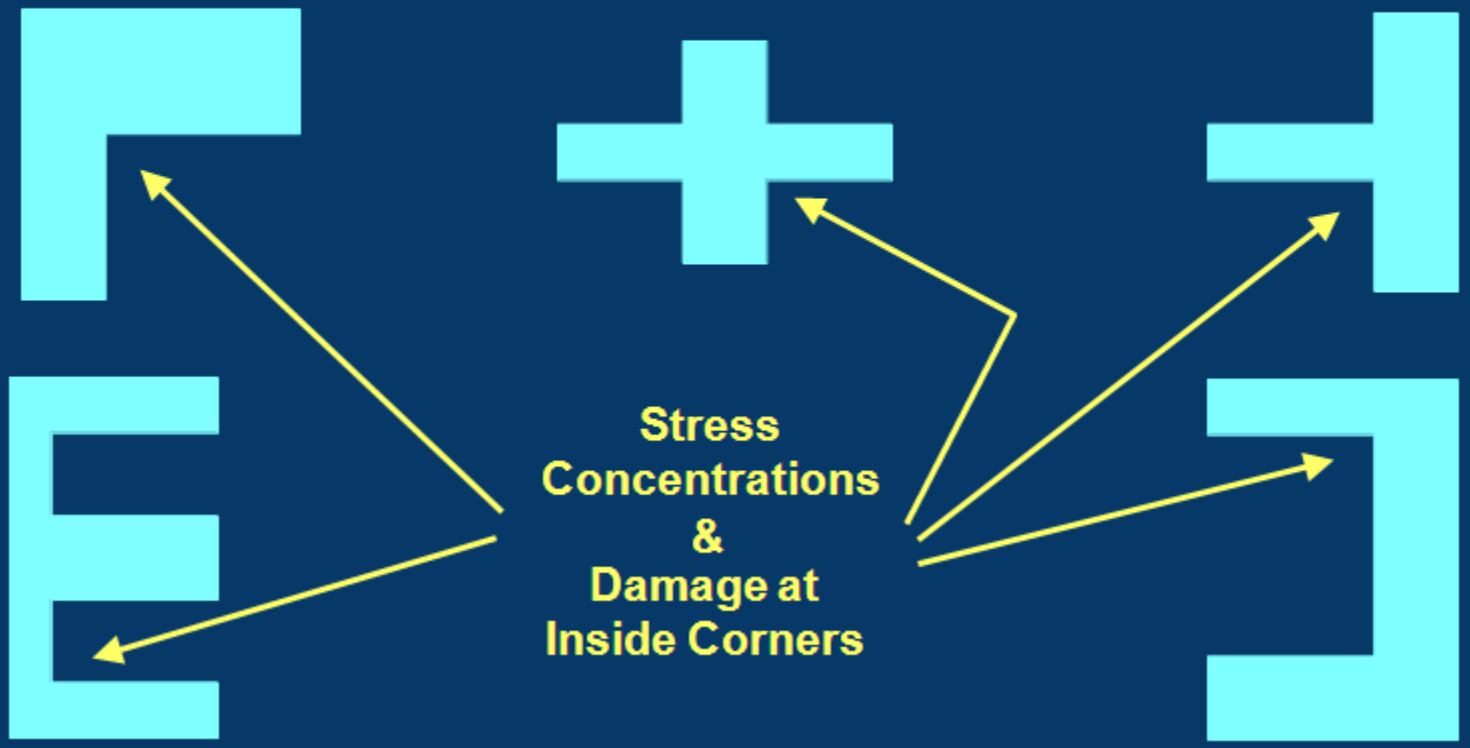
- Structure Type:
  - Unreinforced Masonry
  - Concrete Shear Wall
  - Concrete Frame
  - Concrete Frame with/ infill Shear Walls
  - Steel Frame
  - Steel Frame with/ infill Shear Walls
  - Steel Braced Frame
  - Precast Concrete Frame

Performance Predictors (Cont.)

- Building Age:
  - Governing building code (seismic design)
  - Seismic provisions enforcement
  - Materials used in construction
  - Advances in technology
  - Quality of construction
  - Deterioration with age

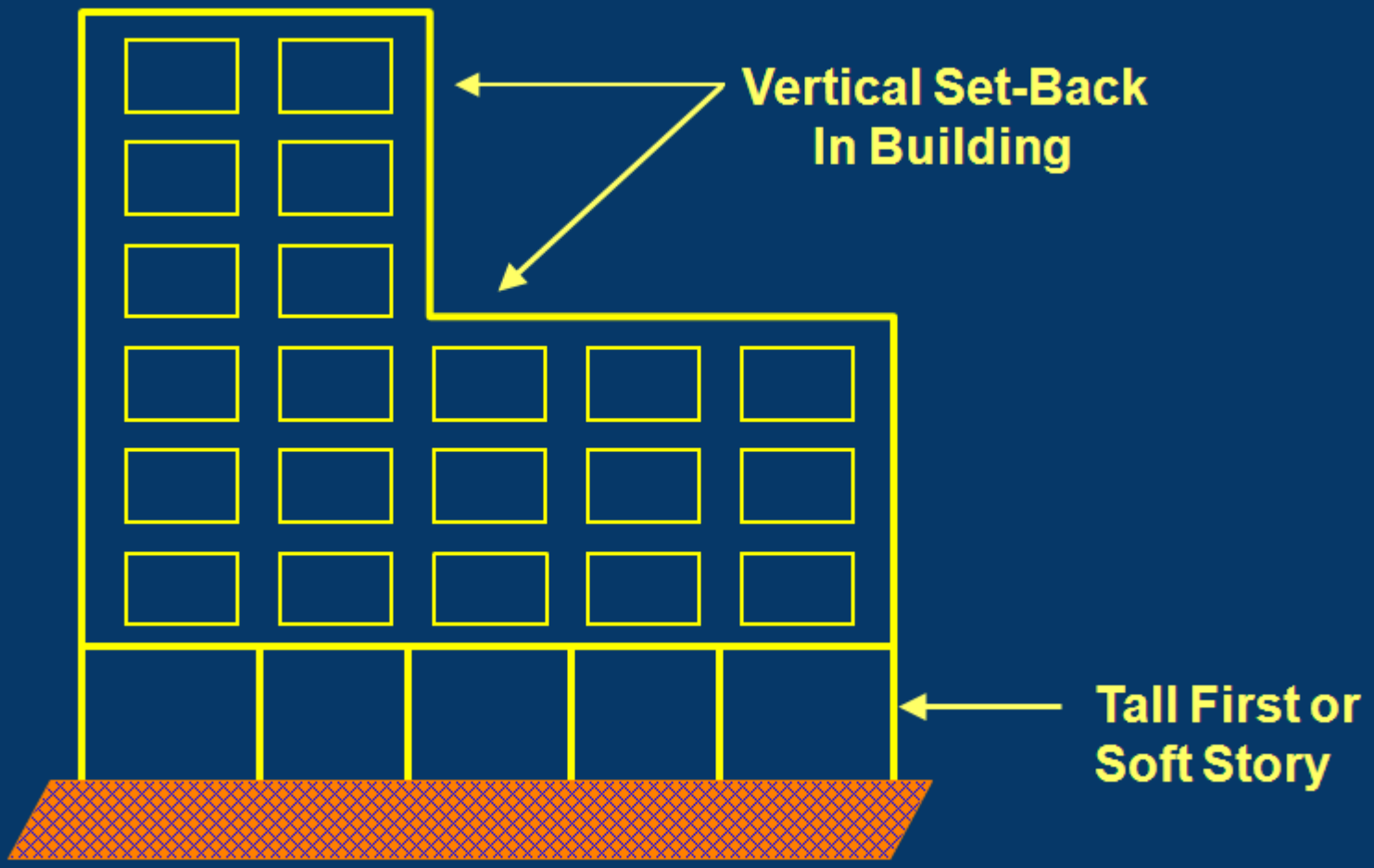
Performance Predictors (Cont.)

- Structure Configuration:
  - Plan irregularities



Plan Irregularities

Building Vertical Irregularities



Vertical Irregularities

Vertical Irregularities

Diaphragm Discontinuities

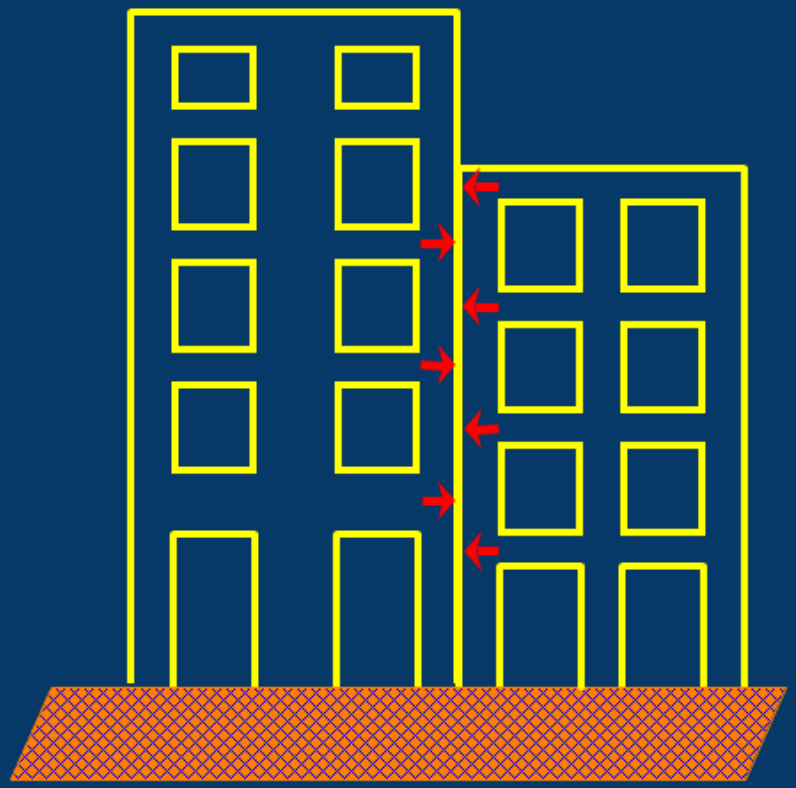
Stiffness Irregularity

- Soft Story:
  - Typically occurs at the first story
  - Desired architectural effect is tall open lobby or entry areas
  - Story stiffness significantly different than adjacent stories

Soft Story

Building Adjacency (Pounding)

- Inadequate building separation
- Floors & roofs do not align



Building Pounding

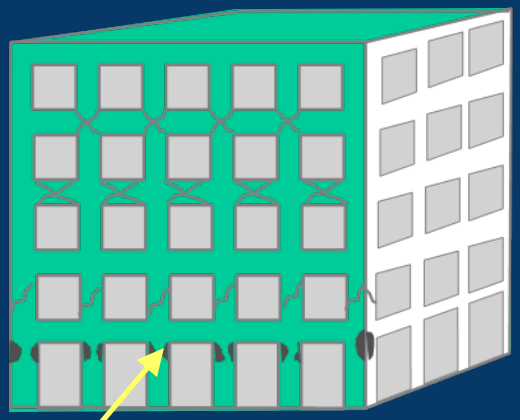
Building Differential Displacement

Building Damage

Unreinforced Masonry Building Damage

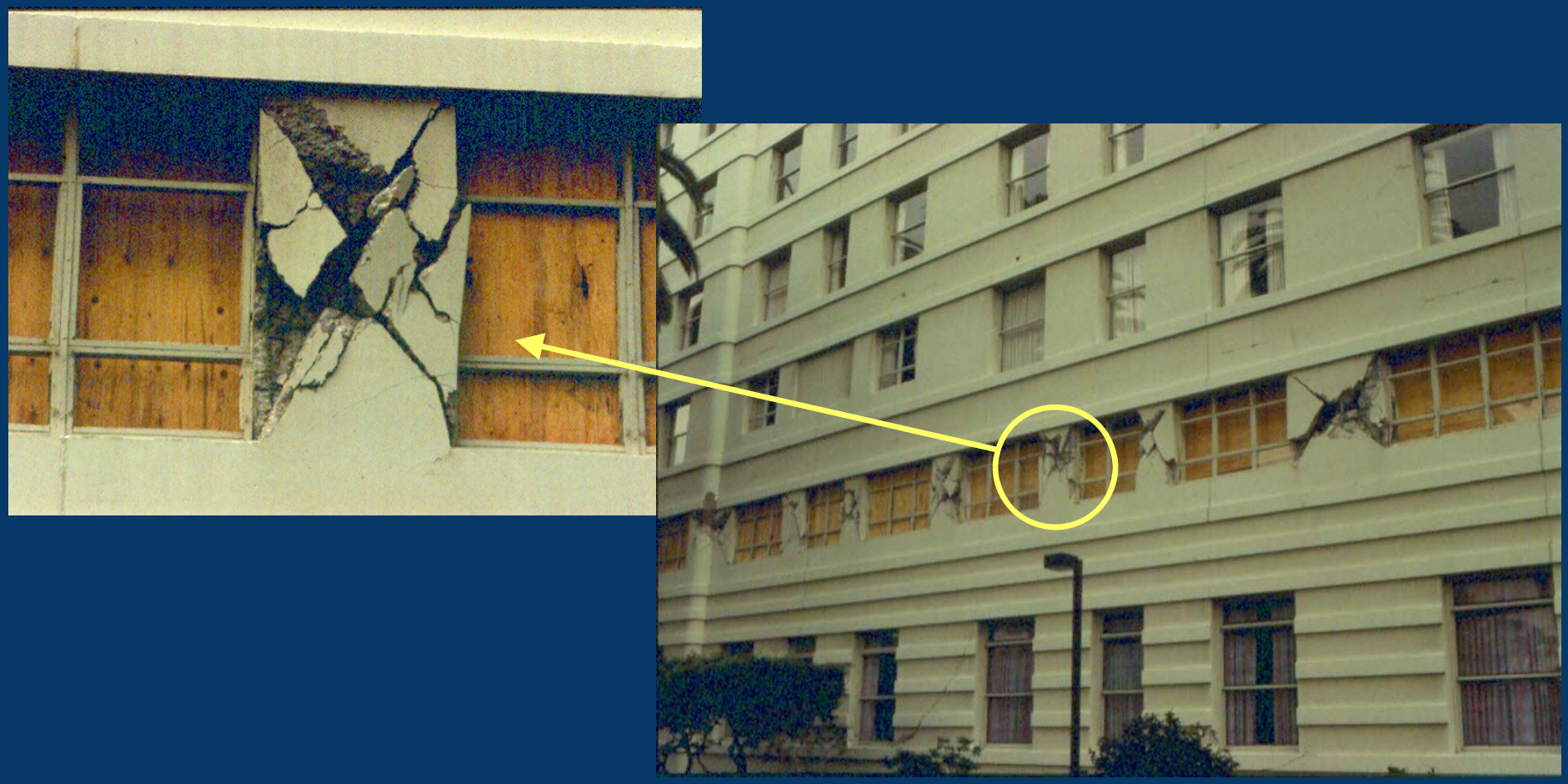
Unreinforced Masonry Damage

Concrete Frame Building Damage



Typical "X" cracking patterns

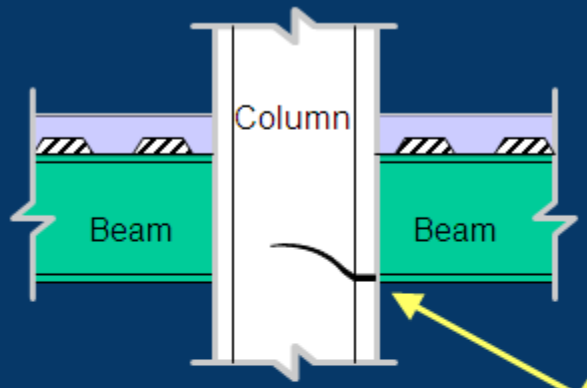
Concrete Frame Building Damage



Concrete Frame Building Damage

Concrete Frame – Olive View Hospital

Steel Frame Building Damage



Flange & Web Fracture

Steel Frame Building Damage

Precast Concrete Frame Damage

Building Pounding Damage

Building Damage can be Subtle

Generalized Building Structure Earthquake Performance

Decreasing Vulnerability

Stiff Structures	Flexible Structures
Unreinforced Masonry (Brick)	Concrete Precast Frame (Parking Garages)
Concrete Frame with URM Infill	Concrete Moment Resisting Frames
Concrete Tilt-Up	
Steel Frame w/URM Infill Shear Walls	
Reinforced Masonry	Steel Moment Resisting Frames
Concrete Shear Wall	Light Metal Frame Buildings
Steel Braced Frames	Wood Frame Buildings

Implications of Building Response on Nonstructural Component Performance

- Nonstructural Performance Dependent upon:
  - Level of ground shaking
  - Response of the building structure
  - Flexibility or stiffness of the building structure
  - Seismic design and detailing of nonstructural components, equipment, & systems; e.g., are the seismic restraints compatible with expected building response – stiff or flexible building structure?

PLAY SHAKE TABLE VIDEO