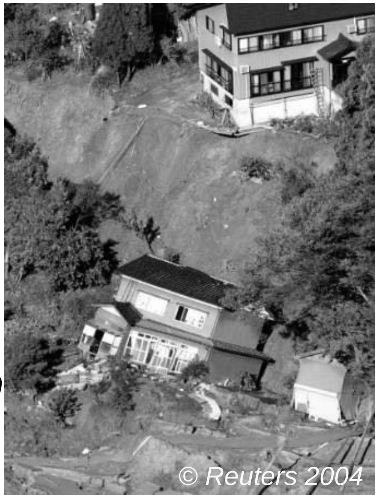
APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS
ARCH 631
DR. ANNE NICHOLS
FALL 2013

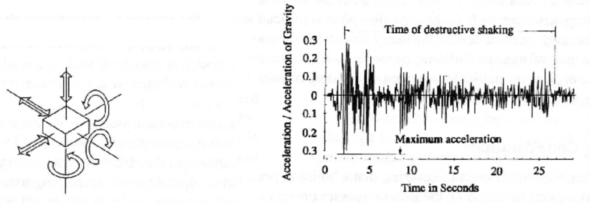
lecture
sixteen

seismic design



Earthquake Design

- dynamic vs. static loading
  - amplification of static affect
  - time duration
  - acceleration & velocity



a) Possible ground movements—normally accelerations in the horizontal plane are the largest and most significant.

b) Typical accelerogram data: North-south component of ground acceleration recorded for the 1940 El Centro, California, earthquake (recorded 4 mi. from the causative fault on deep alluvium).

Earthquake Design

- hazard types
  - surface fault ruptures
  - ground failures
  - tsunamis (sea waves)

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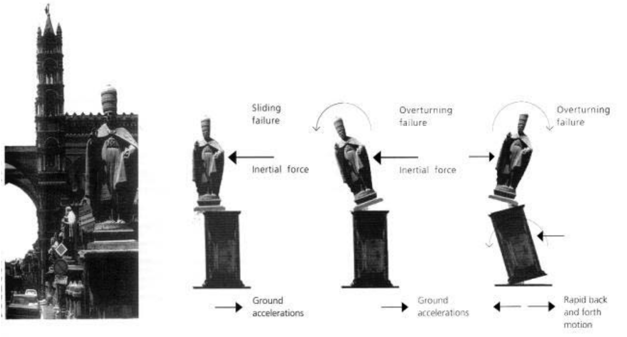
Earthquake Design

- hazard types: ground shaking



Statue in front of the cathedral of Palermo, Sicily

Lateral ground motions associated with earthquakes cause inertial forces to develop that are dependent on the weight of the structure. Sliding failures can occur.

The lateral ground motions can also cause a sculpture to overturn. The magnitude of the overturning effect depends on the weight of the sculpture and its height above the ground.

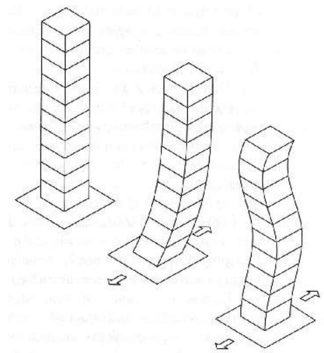
Back and forth ground motions can cause different parts of the sculpture to move in different directions. Overturning or cracking of elements can consequently occur.

Earthquake Design

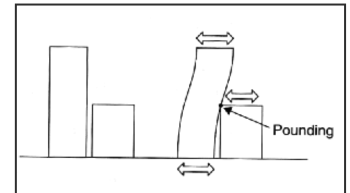
- *fundamental considerations*
  - *building configuration*
    - *symmetry with respect to mass*
  - *stiffness or vibration control*
    - *symmetry with respect to lateral resistance mechanisms*
    - *member sizes, rigidity, braces, dampers*
  - *anchorage of parts and components*
    - *seismic joints*
  - *"tie the building together"*

Earthquake Design

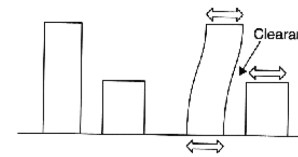
- *building response*



(c) Typical vibration modes for a tall building subjected to varying horizontal ground accelerations.



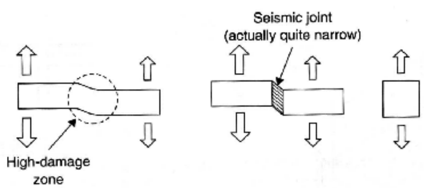
(a) Small separation—not desirable.



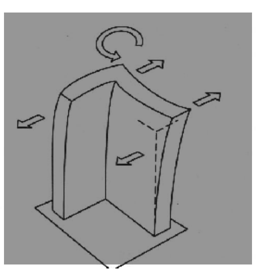
(b) Large separation—preferred.

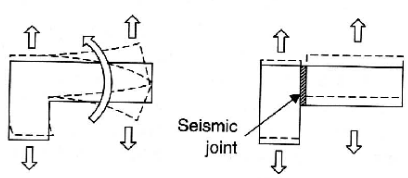
Earthquake Design

- *building response*
  - *seismic joints*
  - *L, T, H shapes bad*



(a) Not desirable. (b) Preferred.





Earthquake Design

- *building response*
  - *center of mass*
    - *ex.:*

$$\bar{x} = \frac{\Sigma W_{NS} x}{\Sigma W_{NS}}$$

  - *center of rigidity*
    - *ex. (R = 1/ δ):*

$$r_E = \frac{\Sigma R_y x}{\Sigma R_y}$$

  - *torsion (eccentricity)*

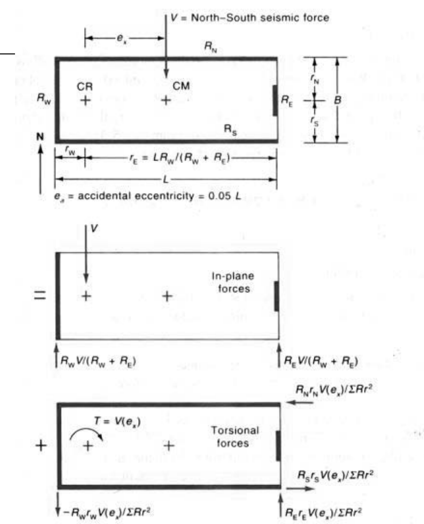
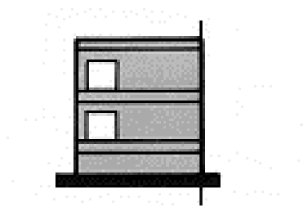
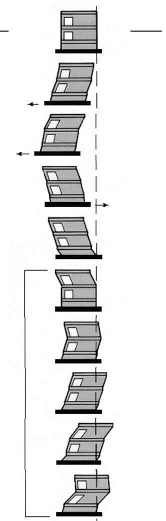


Fig. 5-33. Torsional effects

Low-Rise Response

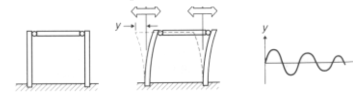
- lateral ground movement
- drift

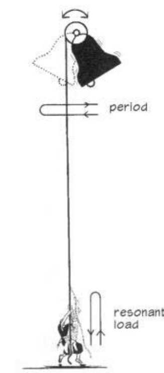




Frequency and Period

- natural period of vibration





  - avoid resonance
  - hard to predict seismic period
  - affected by soil
  - short period
    - high stiffness
  - long period
    - low stiffness

"To ring the bell, the sexton must pull on the downswing of the bell in time with the natural frequency of the bell."

Earthquake Design

- codes
  - purpose is to provide a simple uniform method of determining potential earthquake forces in any location with enough accuracy to ensure a safe and economical building design
  - National Earthquake Hazards Reduction Program (NEHRP)
  - evaluate structural response (spectrum) to earthquake (motion vs. time)

Earthquake Design Loads

- derived from W & amplification factors
- at base of structure:

$$V = {ZICW}/{R_W}$$

  - Z, zone
  - I, importance (1.0 – 1.5)
  - C, stiffness related to period of vibration
  - R_W, response modifications for building type (1.25 – 8)
- distribution per floor
  - simple vs. tall - $W_x h_x / \sum Wh$

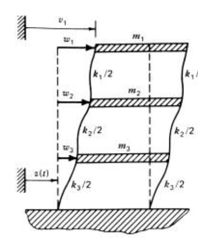


Figure 20.9. Multistory building subjected to earthquake excitation.

Earthquake Design Loads (ASCE-7)

- at base of structure: $$V = C_S W$$
  - W, usually dead load but can include some live load
  - C_s, seismic design coefficient

$$C_S = \frac{S_{DS}}{(R/I)} \text{ but not greater than } \frac{S_{D1}}{T(R/I)}$$

  - S_{DS}, short period design spectral response acceleration
  - S_{D1}, one second design spectral response acceleration
  - R, response modification factor
  - I, importance factor
  - T, building period
  - S_1, mapped one-second spectral acceleration

Earthquake Design Loads (ASCE-7)

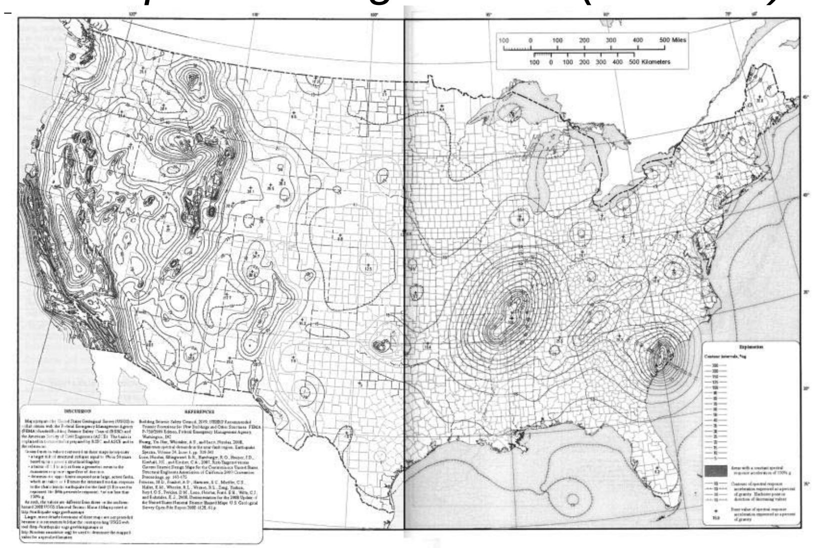


FIGURE 1613.3.1(1)
RISK-TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTION RESPONSE ACCELERATIONS FOR THE CONTERMINOUS UNITED STATES OF 0.2-SECOND SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

Earthquake-Resistant Structures

- absorb energy input from ground motion
- pins can't, rigid frames can
  - energy goes into forming plastic hinges (ductility)
  - continuous
  - steel, timber or reinforced concrete

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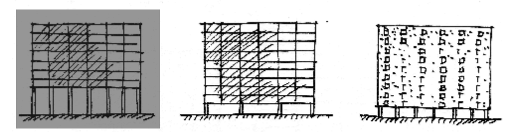
- redundancy helpful
- use rigid diaphragms
- horizontal members fail before verticals

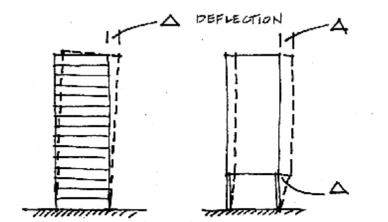
Earthquake Design

- soft first stories
  - problematic



(a) High Story (b) Reduced Story Strength (c) Heavy Cladding on Superstructure

Figure 3.21 Building Types with Soft First Story



(a) Deflection of Structure with Uniform Stiffness (b) Deflection of Structure with Rigid Superstructure

Figure 3.22 Deformation of a Building with Soft First Story

  - ground level story weaker than those above
    - usually higher
    - reduced strength in vertical elements
    - significantly increased mass above

Earthquake Design

- *want <u>horizontal elements</u> to fail before vertical elements do*

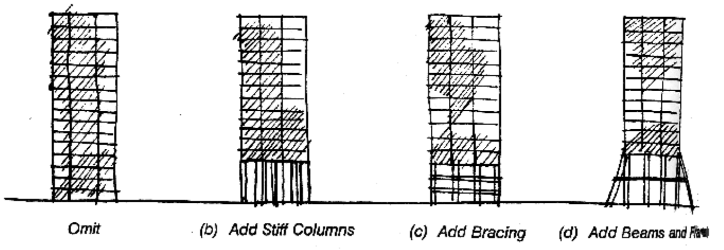
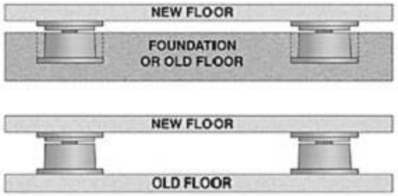


Figure 3.23 *Solutions to the Soft First Story Problem*

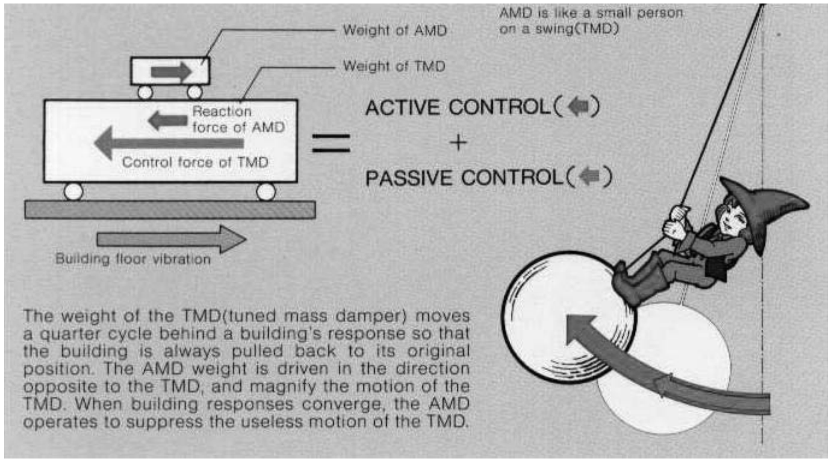
Earthquake Design

- *passive base isolation*
  - *low stiffness layer between foundation and structure*



Earthquake Design

- *tuned mass damping systems*



Earthquake Design

- *dampers*
- *elastomer bearings*
  - *neoprene or rubber*
- *sliding systems*
- *friction pendulum systems*

Sendai Mediatheque, Japan, 2011

Architectural Considerations

Video – Buildings at Risk