Response of Buildings during Earthquakes

Why do buildings do the things they do?

Underlying Physics

- Newton's Second Law

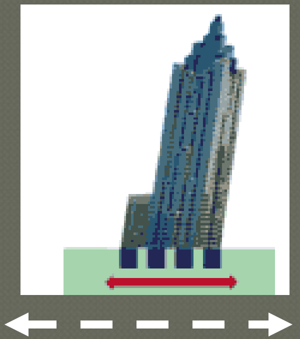
$$F = ma$$

where m = mass of building

a = acceleration of ground

Question:

What do the physics tell us about the magnitude of the forces that different types of buildings feel during an earthquake?

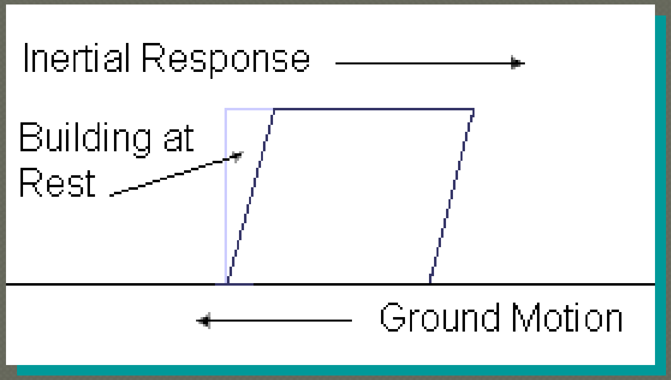


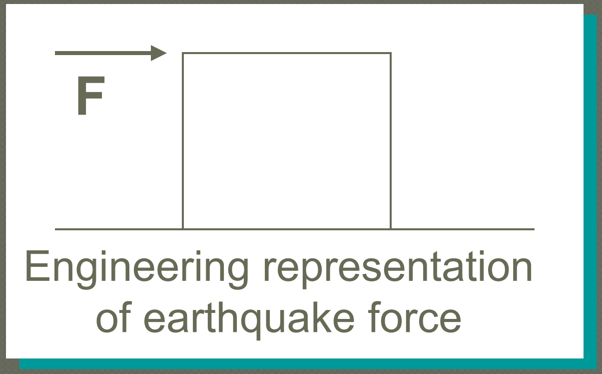
ground acceleration

Animation from www.exploratorium.edu/faultline/engineering/engineering5.html

What is really happening?

- **F** is known as an **inertial** force,
  - created by building's tendency to remain at rest, in its original position, although the ground beneath it is moving

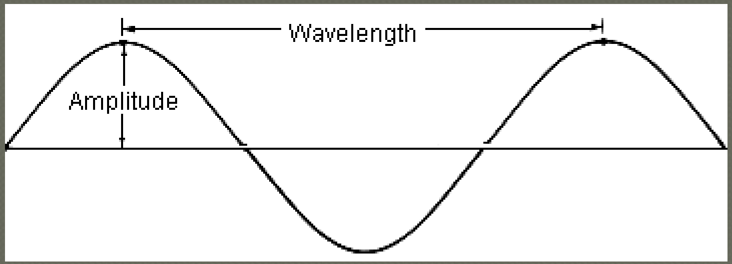


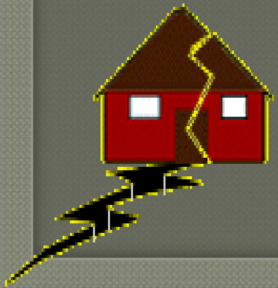


Period and Frequency

- **Frequency (f)** = number of complete cycles of vibration per second
- **Period (T)** = time needed to complete one full cycle of vibration

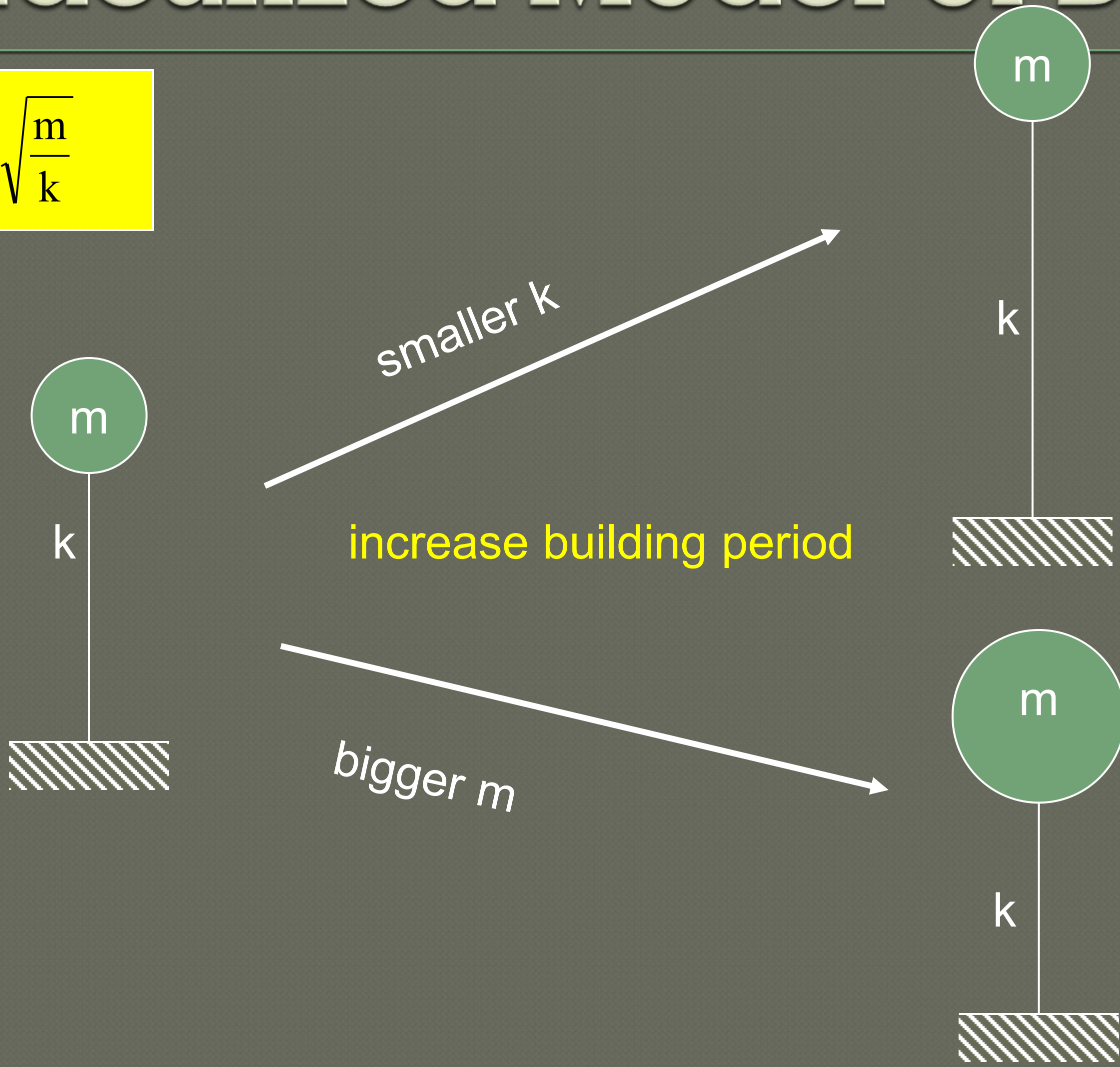
$$T = 1 / f$$





Idealized Model of Building

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



Natural Period of Buildings

- Each building has its own natural period (frequency)

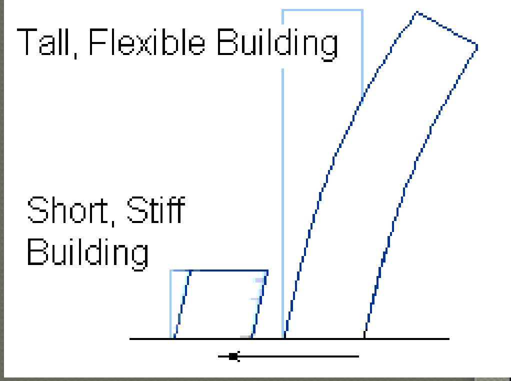
Building Height	Typical Natural Period	Natural Frequency
2 story	0.2 seconds	5 cycles/sec
5 story	0.5 seconds	2 cycles/sec
10 story	1.0 seconds	?
20 story	2.0 seconds	?
30 story	3.0 seconds	?

slower shaking

Resonance

- Resonance = frequency content of the ground motion is close to building's natural frequency
  - tends to increase or **amplify** building response
  - building suffers the greatest damage from ground motion at a frequency close or equal to its own natural frequency

- Example: Mexico City earthquake of September 19, 1985
  - majority of buildings that collapsed were around 20 stories tall
  - natural period of around 2.0 seconds
  - other buildings, of different heights and different natural frequencies, were undamaged even though located right next to damaged 20 story buildings

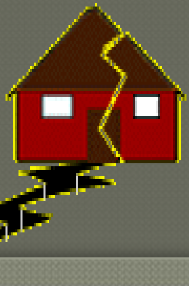


What affects building performance & damage?

- Shape (configuration) of building:
  - Square or rectangular usually perform better than L, T, U, H, +, O, or a combination of these.
- Construction material: steel, concrete, wood, brick.
  - Concrete is the most widely used construction material in the world.
  - Ductile materials perform better than brittle ones. Ductile materials include steel and aluminum. Brittle materials include brick, stone and unstrengthened concrete.
- Load resisting system
- Height of the building: (i.e. natural frequency)
- Previous earthquake damage
- Intended function of the building (e.g. hospital, fire station, office building)
- Proximity to other buildings
- Soil beneath the building
- Magnitude and duration of the earthquake
- Direction and frequency of shaking

Proximity to Other Buildings - Pounding

- Buildings are so close together that they repeatedly hit each other during an earthquake
- Can cause collapse of frame buildings

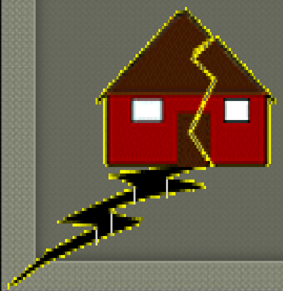


http://nsmp.wr.usgs.gov/data_sets/20010228_1/20010228_seattle_pics.html

Key Factor in Building Performance

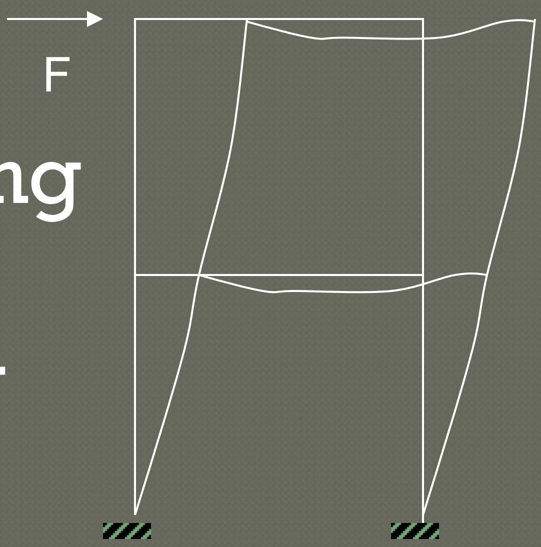
Good connections

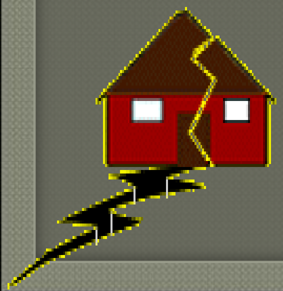
- Need to transfer loads from structural elements into foundation and then to ground



Building Systems: Frames

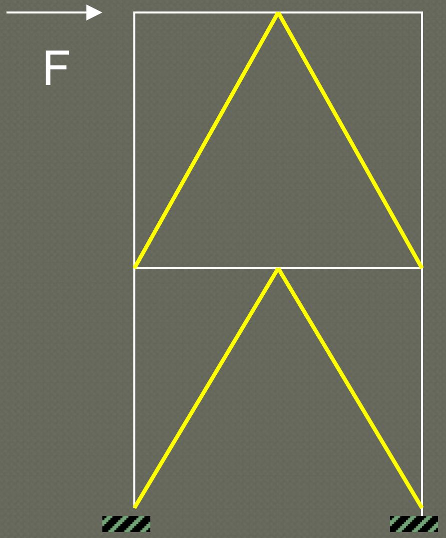
- Frame built up of beams and columns
  - Steel
  - Concrete
- Resists lateral load by bending of beams and columns
- Provides lots of open interior space
- Flexible buildings





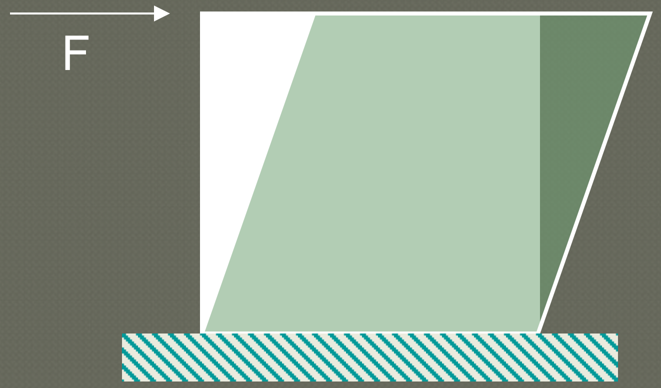
Building Systems: Braced Frame

- Braces used to resist lateral loads
  - steel or concrete
- Damage can occur when braces buckle
- Stiffer than pure frame



Building Systems: Shear Walls

- wall elements designed to take vertical as well as in-plane horizontal (lateral) forces
  - Concrete buildings
  - Wood buildings
  - Masonry buildings
- resist lateral forces by shear deformation
- stiffer buildings

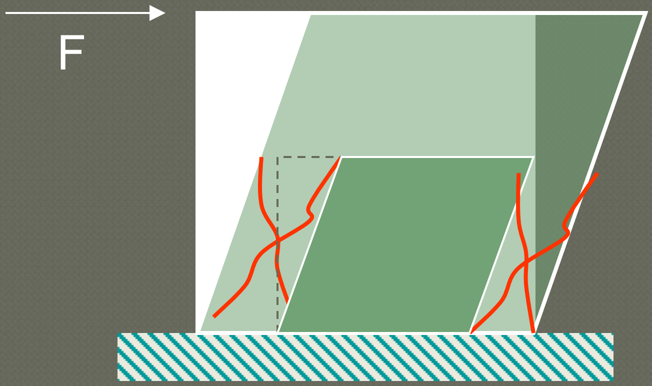


Shear Deformation

Building Systems: Shear Walls

- Large openings in shear walls
  - a much smaller area to transfer shear
  - resulting large stresses cause cracking/failure

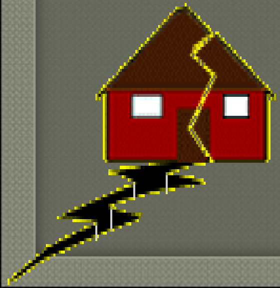
West Anchorage High School, 1964



Cracking around openings

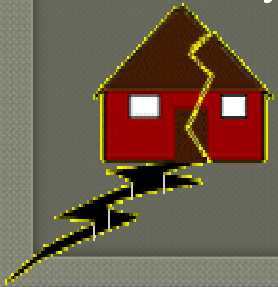
Wood Frame Construction

- Most houses and low rise apartments in California, some strip malls
- Shear wall type construction
- Light weight (except if has clay tile roof)
- Generally perform well in earthquakes
- Damage often consists of cracked plaster and stucco



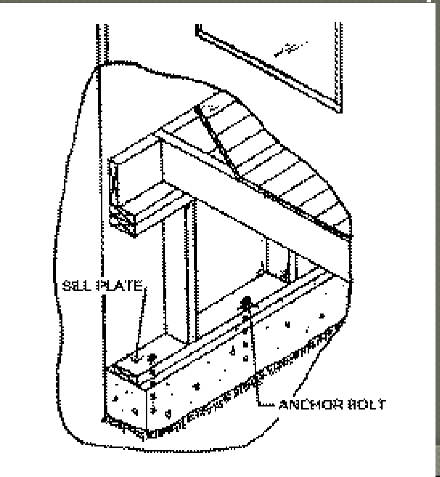
Wood Frame Damage

Chimneys collapse



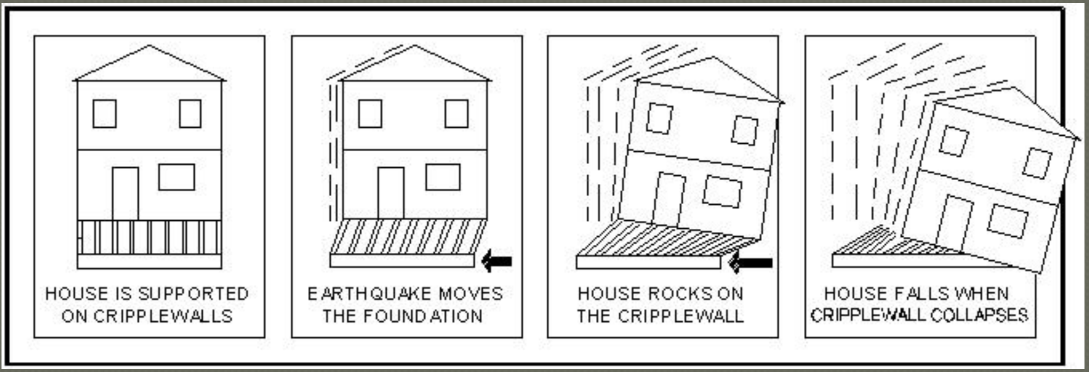
generally don't collapse because have many interior walls

Slide off foundation – generally pre-1933 because bolting inadequate



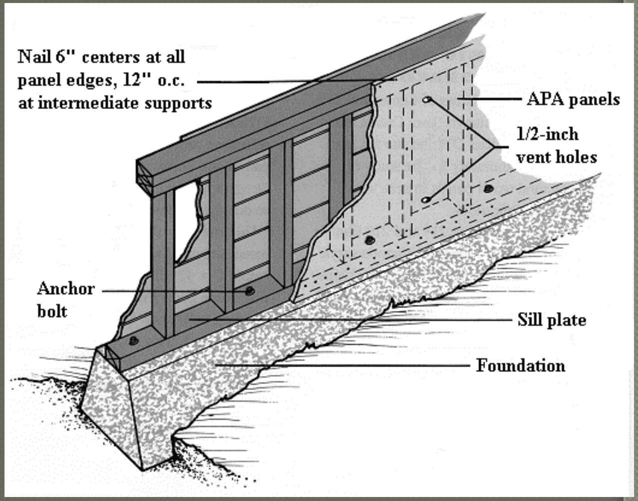
Wood Frame Damage – Cripple Wall Failure

the problem



short walls that connect foundation to floor base - common in houses built before 1960

the fix



the damage

Soft First Story

Occurs when first story much less stiff than stories above

Typical damage – collapse of first story

Tuck Under Parking

Typical apartment building with tuck under parking

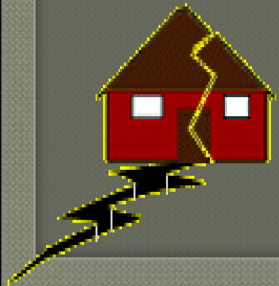
Retrofit can include installation of a steel frame to limit the deformation of first floor

Unreinforced Masonry (URM)

- Built of heavy masonry walls with no reinforcing
  - anchorage to floors and roof generally missing
  - floors, roofs and internal partitions are usually of wood
  - older construction – no longer built
- Typical damage
  - Walls collapse and then roof (floors) come down
  - Parapets fall from roof

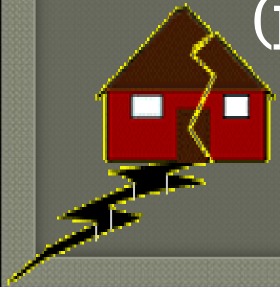
Tilt-up Construction

- Shear wall load resisting system
- Quick and inexpensive to build
- Warehouses (Costco), industrial parks
- Typical damage
  - Walls fall outward, then roof collapses



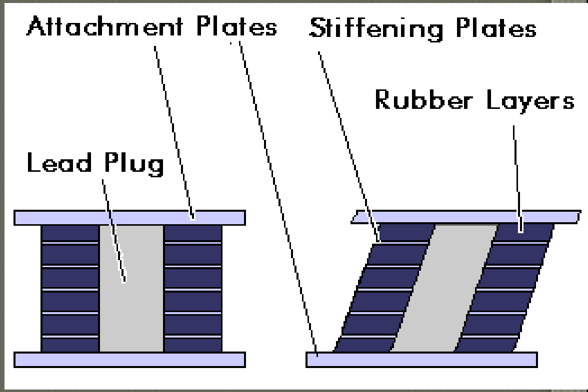
Mobile Home

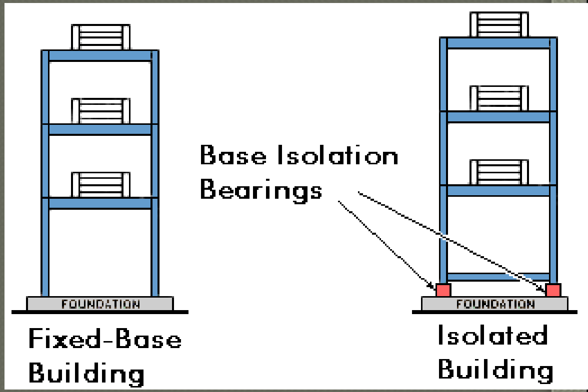
- Factory-built dwelling (lightweight)
  - built of light-weight metal construction or a combination of a wood and steel frame structure
- Typical damage
  - jacks on which the coach is placed tip, and coach falls off some or all of its supports.
  - jacks to punch holes through the floors of the coach
  - usually stays in tact
  - mobile home becomes detached from utilities (possible fire)

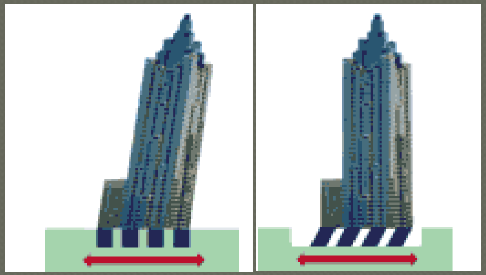


Base Isolated Buildings

- Supported by a series of bearing pads placed between the building and its foundation
- Most of deformation in isolators and acceleration of the building is reduced = less damage





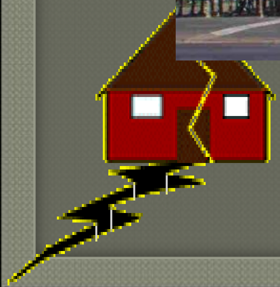


not isolated isolated

Bay Area Base-Isolated Buildings

U.S. Court of Appeals, San Francisco
Survived 1906 earthquake
(seismic retrofit 1994)

San Francisco City Hall
Steel frame with stone exterior
(seismic retrofit 1994)



Non Structural Issues

Good connections of non-structural building contents with building


THANK YOU !!