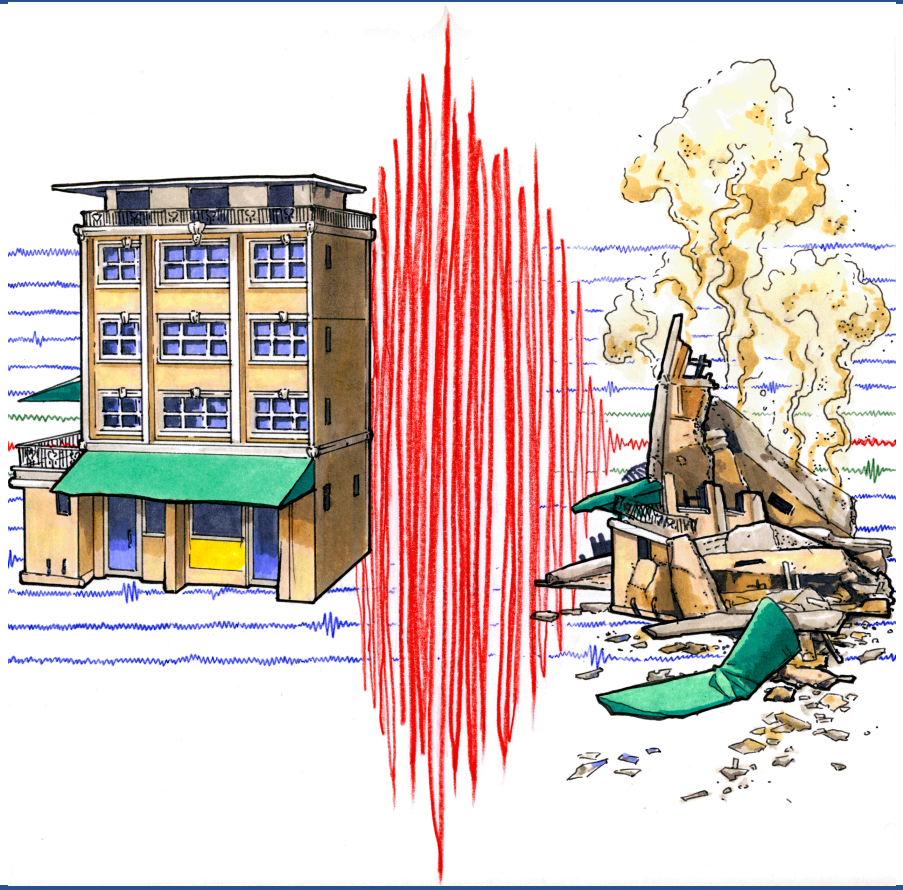
ETH zürich



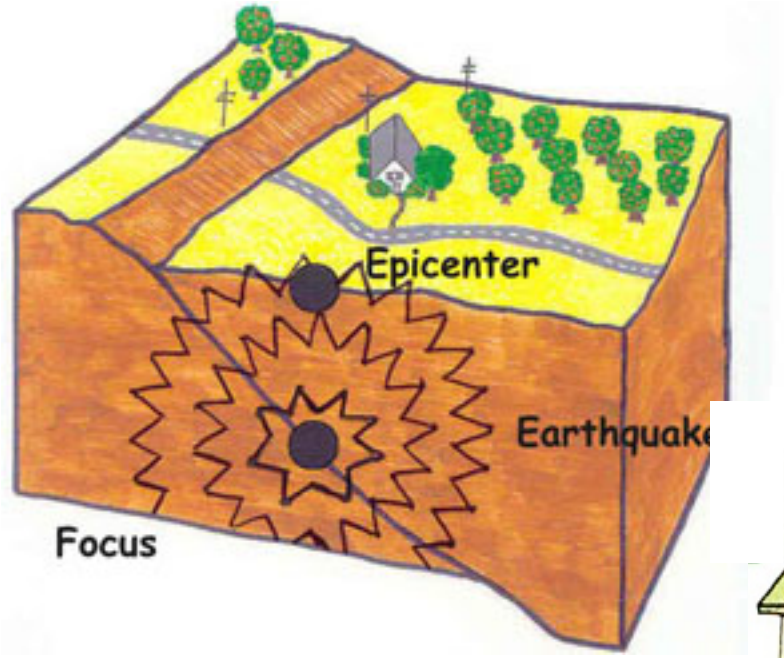
Defeating Earthquakes: How to Build?

Prof. Dr. Bozidar Stojadinovic

Institute of Structural Engineering
Structural Dynamics and Earthquake Engineering Group


DO YOU HEAR A TICKING?
THE BIG ONE
I'LL BE BACK
WAKE UP AND SMELL THE LOOMING DISASTER!
I'M FEELING STRESSED!!!
JUST PRETEND I'M NOT HERE
HEY, YOU!!
YOU ARE GETTING APATHETIC
QUAKE
FAULT

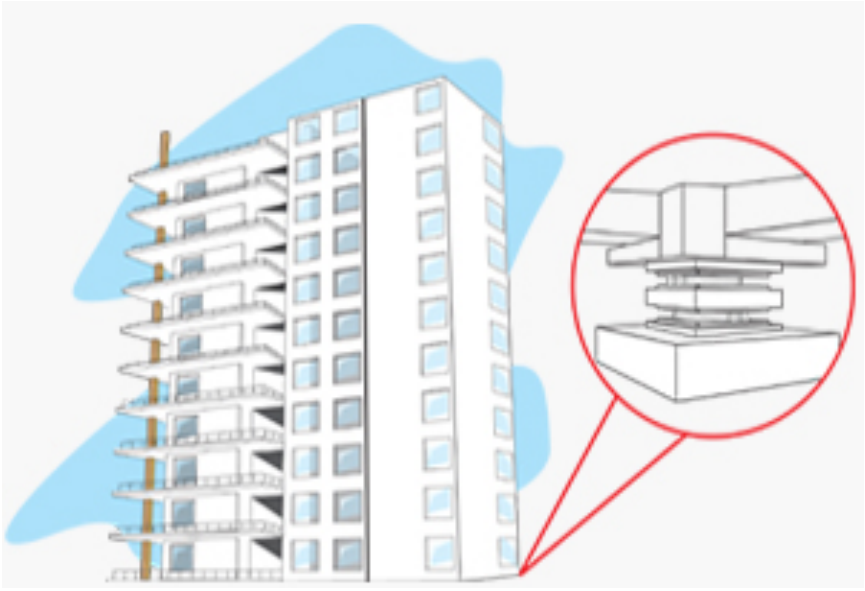
What Happens to Buildings?



http://www.kids-earth-science.com/earthquake-facts.html

Buildings are not Helpless!

- When an earthquake occurs buildings do not necessarily all fall down
- Structures are engineered to resist earthquake forces
- They offer an added layer of protection against natural hazards



http://japanpropertycentral.com

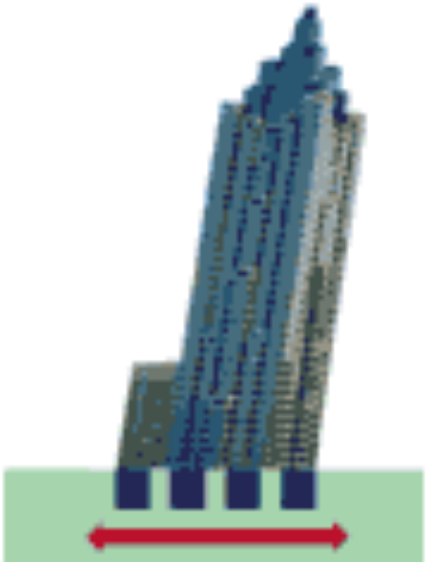
The Physics

- Newton's Second Law:

$$F_i = ma$$

where m = mass of the building

a = ground acceleration

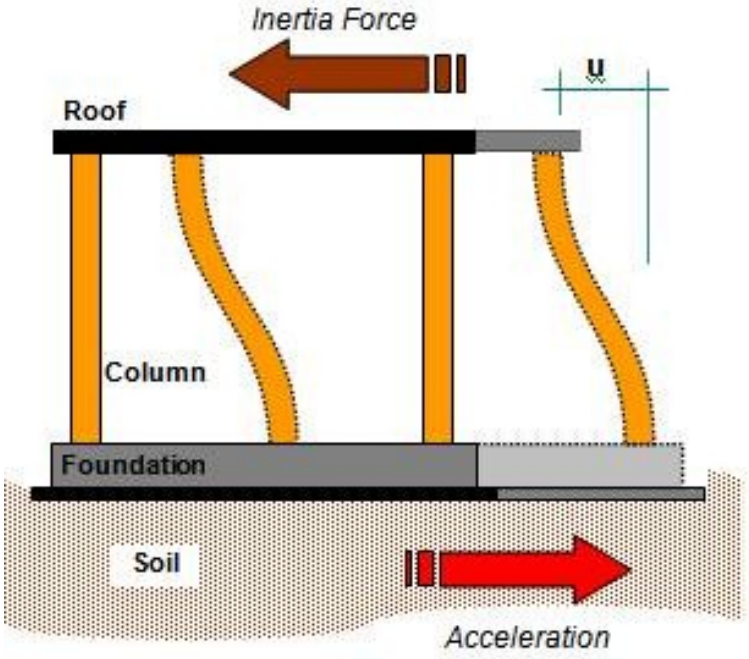


ground acceleration

http://www.exploratorium.edu/

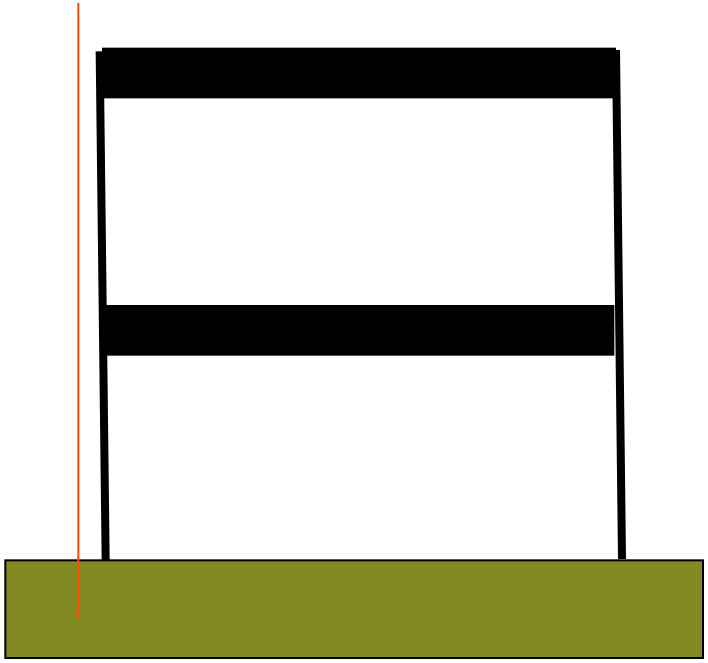
What is really happening?

- F_i is the **inertial** force
  - Created by building's tendency to remain at rest, in its original position, although the ground beneath it is moving

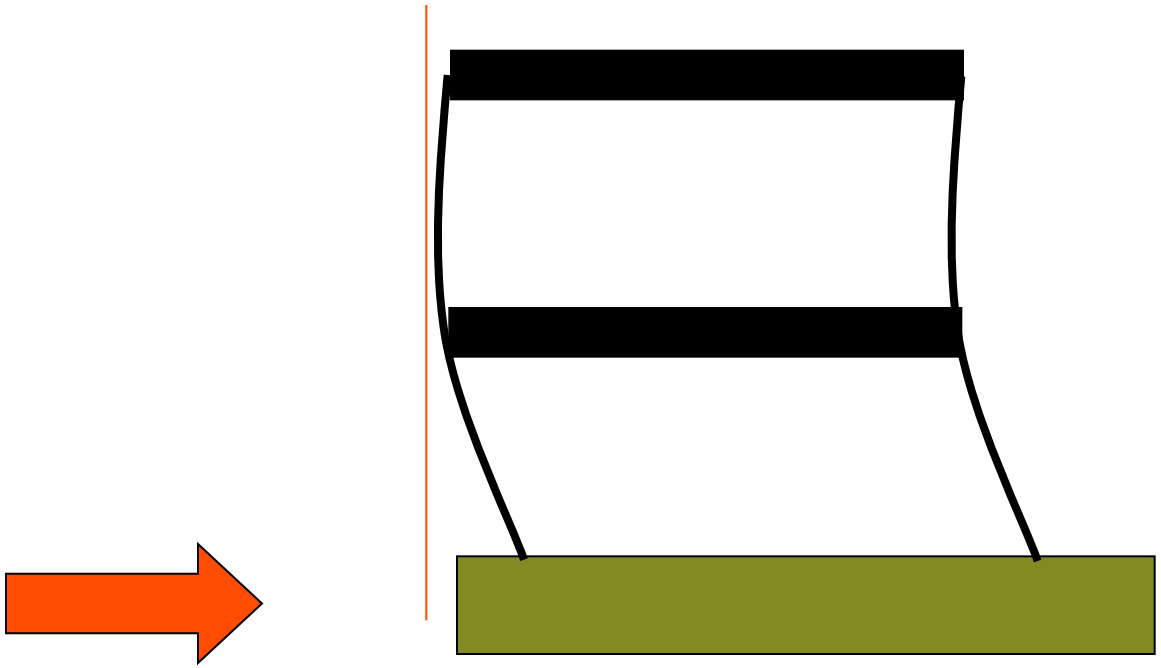


http://theconstructor.org/structural-engg/seismic-effects-on-structures/2704/

How does the building move?

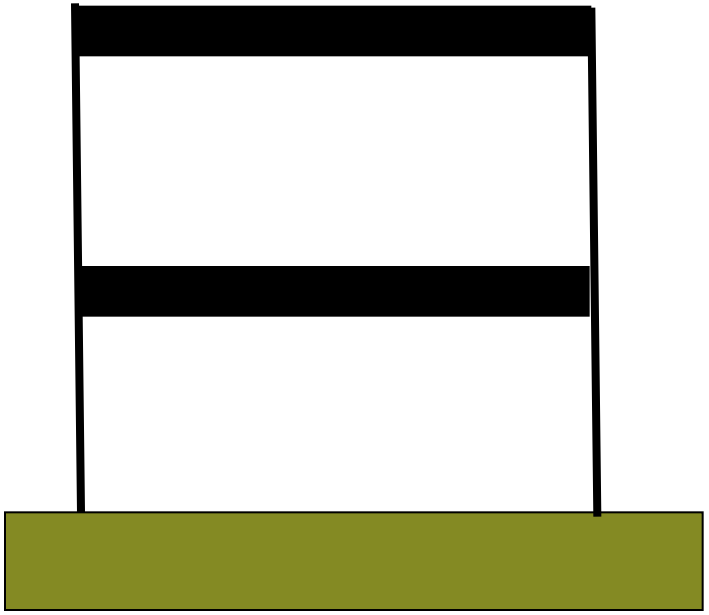


How does the building move?



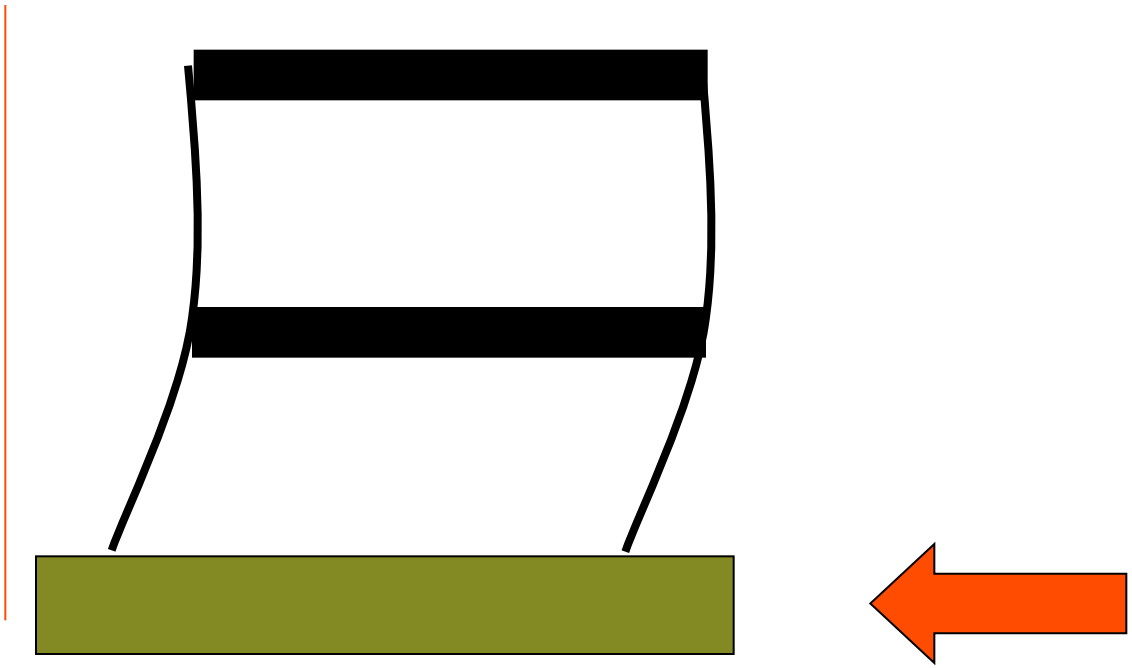
The foundation moves
The columns bend: building resists

How does the building move?



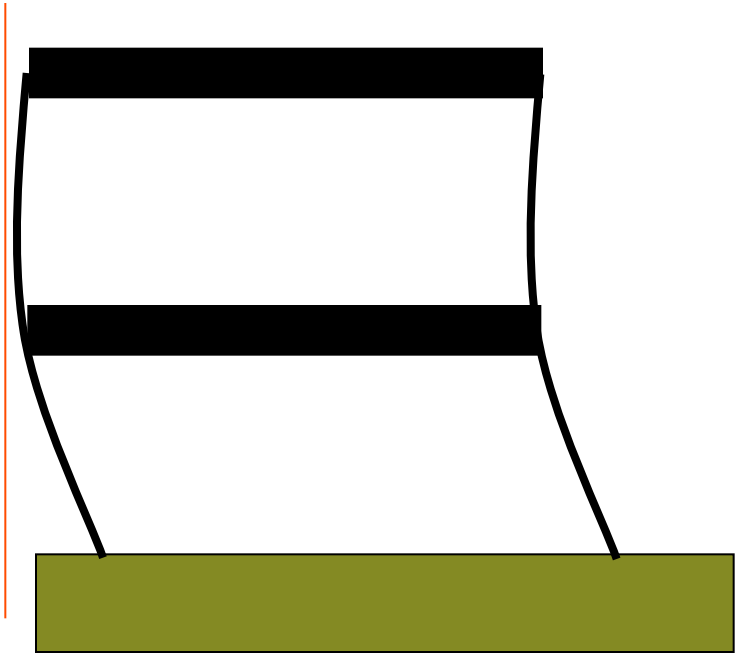
The building catches up to the masses
The floors accelerate…

How does the building move?



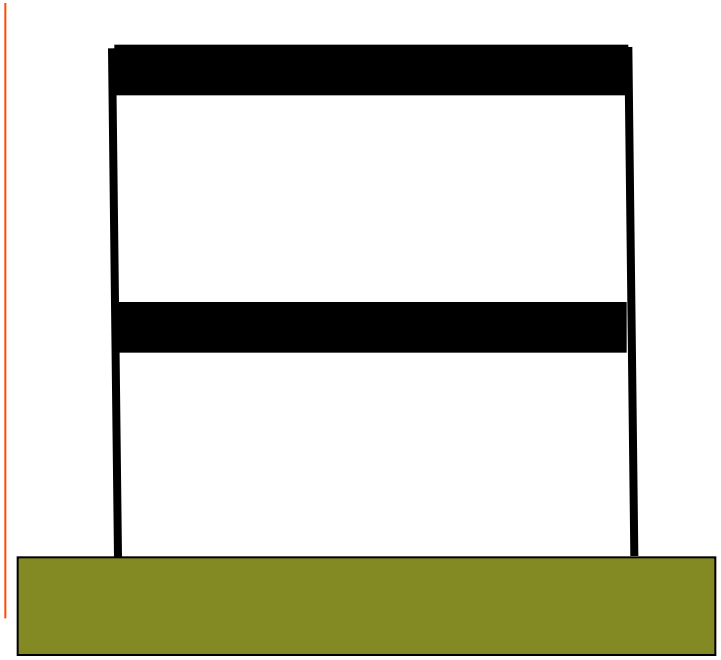
The building overtakes the foundation:
The columns resist motion
The ground moves in the other direction

How does the building move?



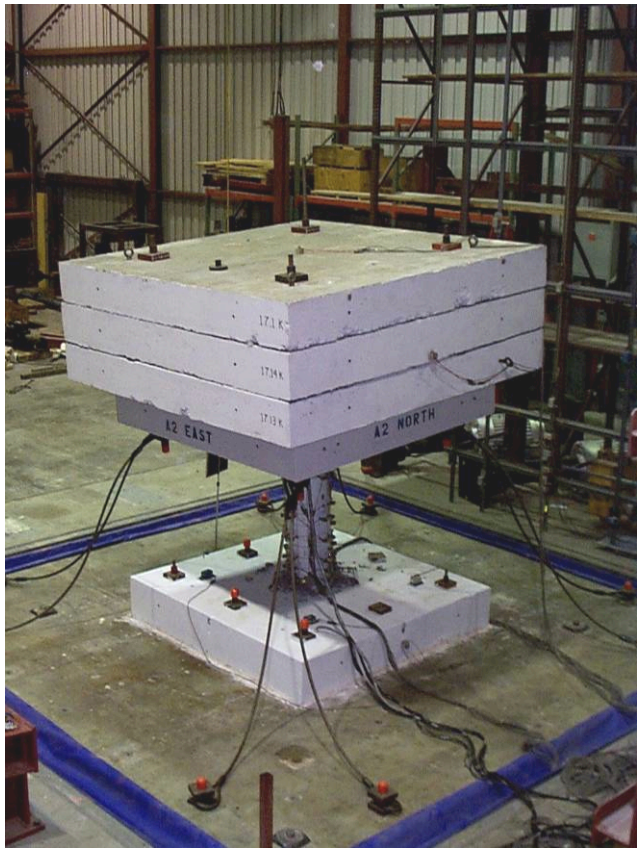
The building sways

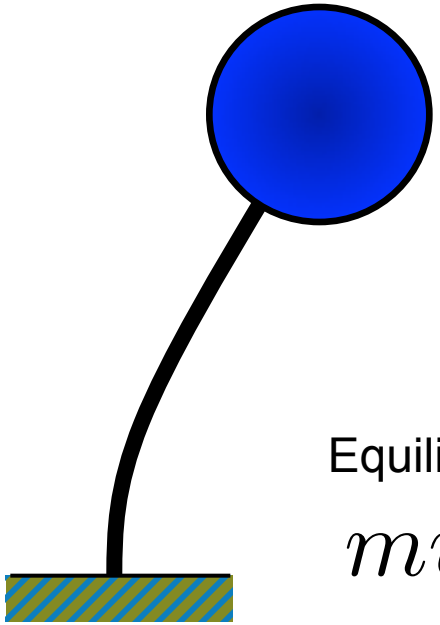
How does the building move?



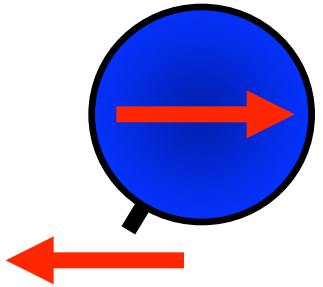
Eventually, the swaying stops

The Math





Inertia force =
ma = mẍ

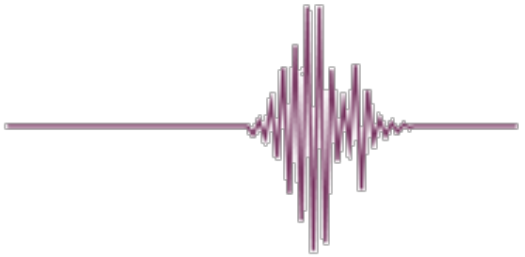


Resisting force = kx

Equilibrium:

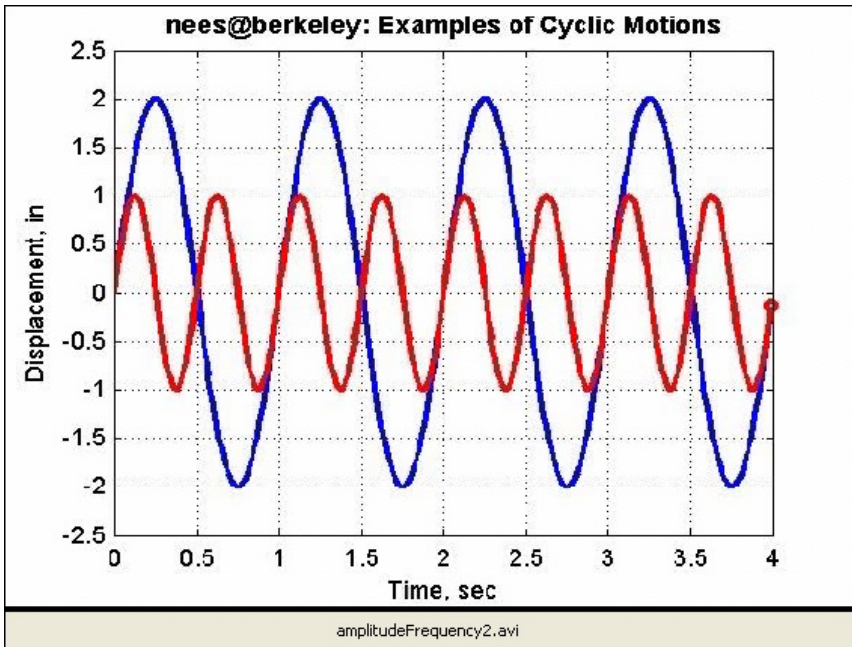
$$m\ddot{u}(t) + ku(t) = 0$$

Solution of this ODE: Vibrations

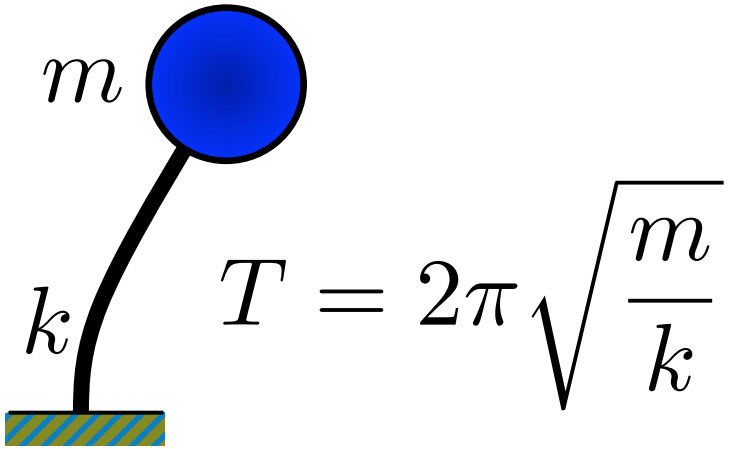


Amplitude and Frequency

Amplitude of a ground motion is a distance from crest to crest.

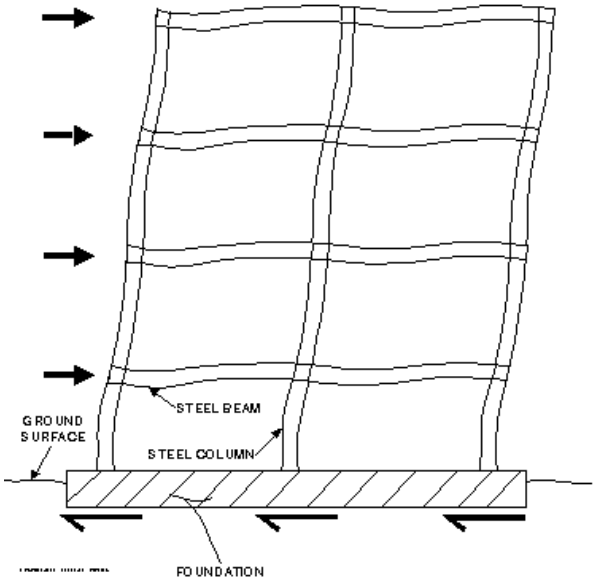


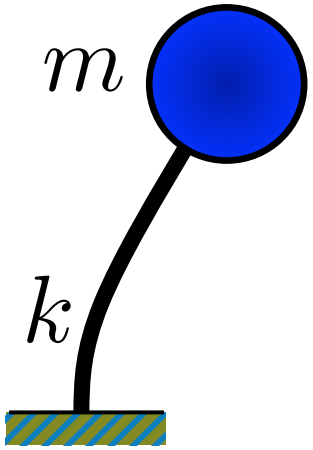
- ***Frequency*** f of a the response:
  - Number of complete vibration cycles the structure makes in one second
- ***Period*** T of the response:
  - Time required for one full cycle of motion.



Models of Buildings

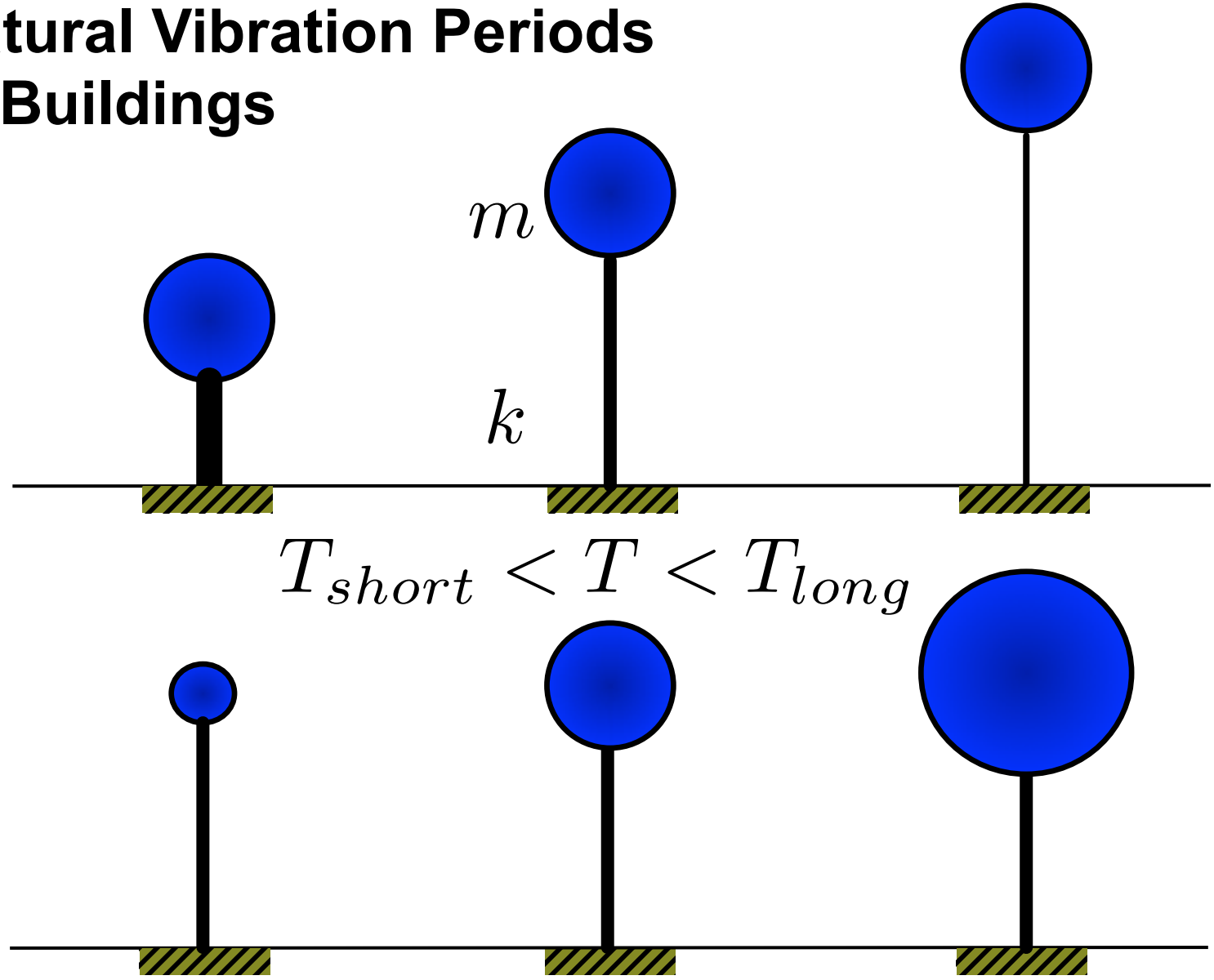
http://www.eversendai.com





Real → Model

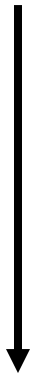
Natural Vibration Periods of Buildings



Natural Vibration Periods of Buildings

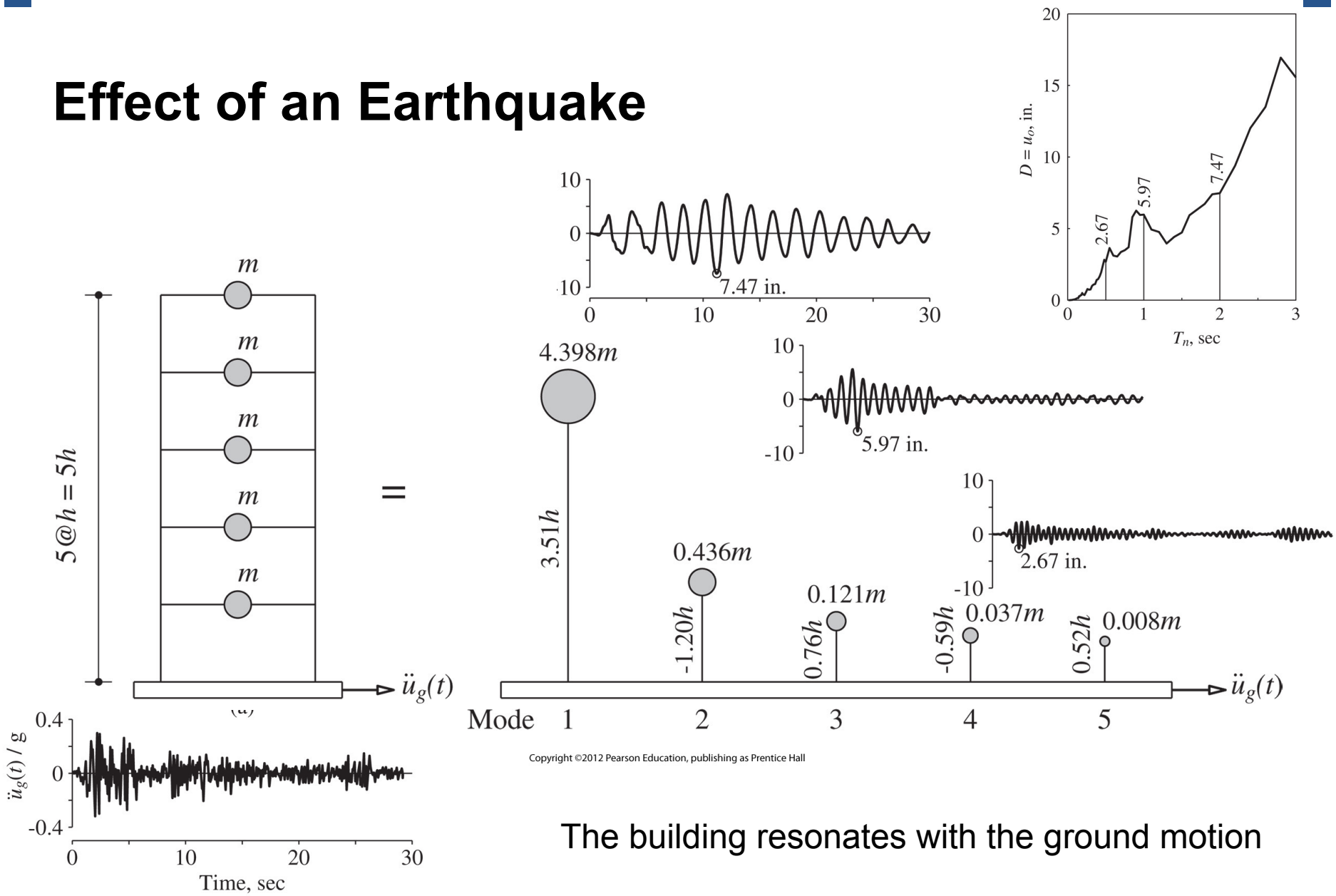
- Each building has its own natural period (frequency)

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	1 cycle/sec
20 story	2.0 seconds	½ cycles/sec
30 story	3.0 seconds	etc.



slower shaking

Effect of an Earthquake



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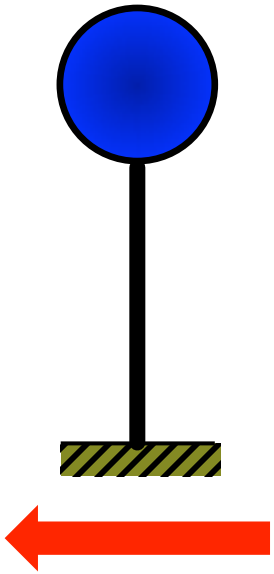
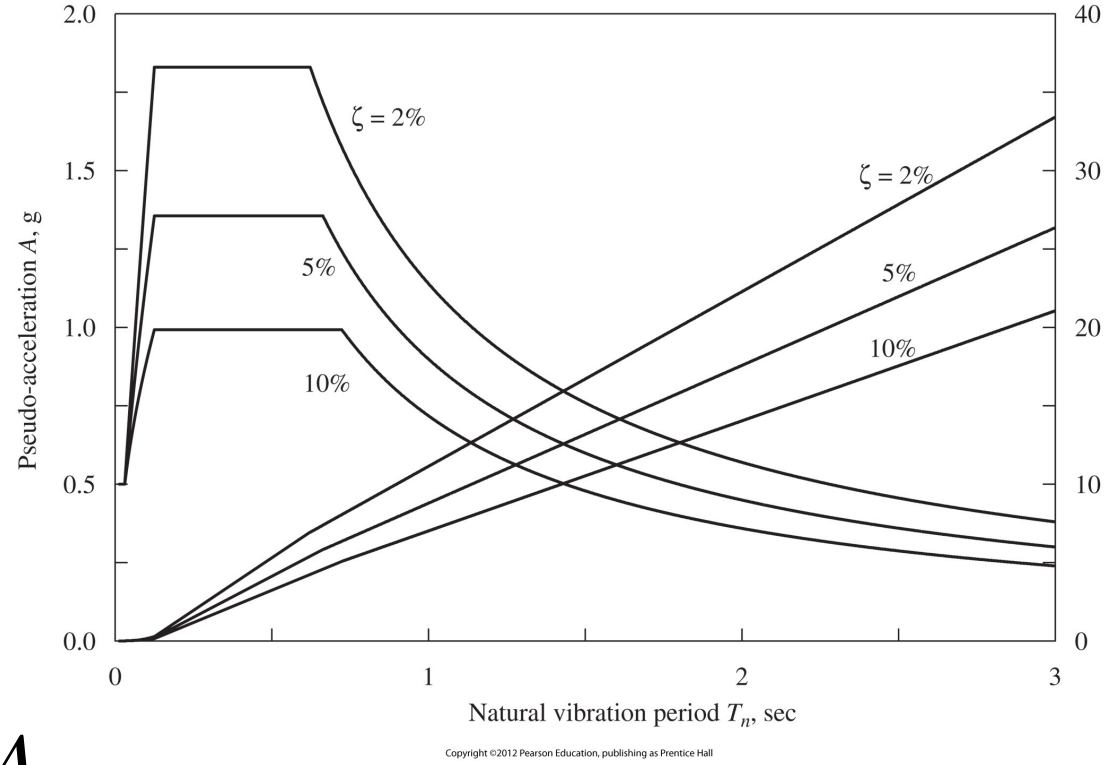
The building resonates with the ground motion

Earthquake Response Spectrum





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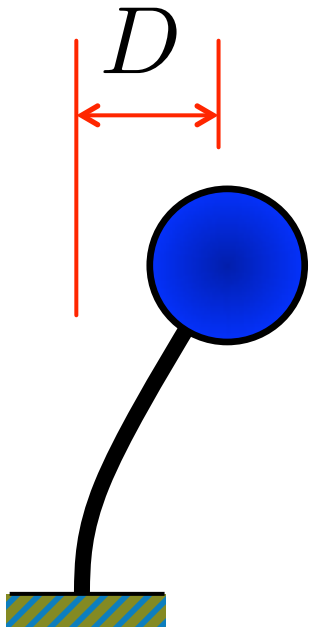
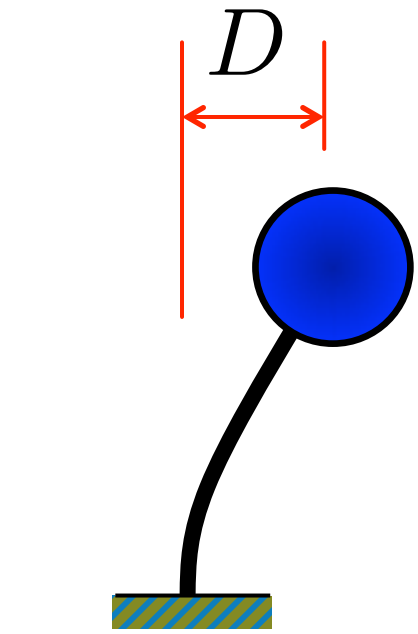


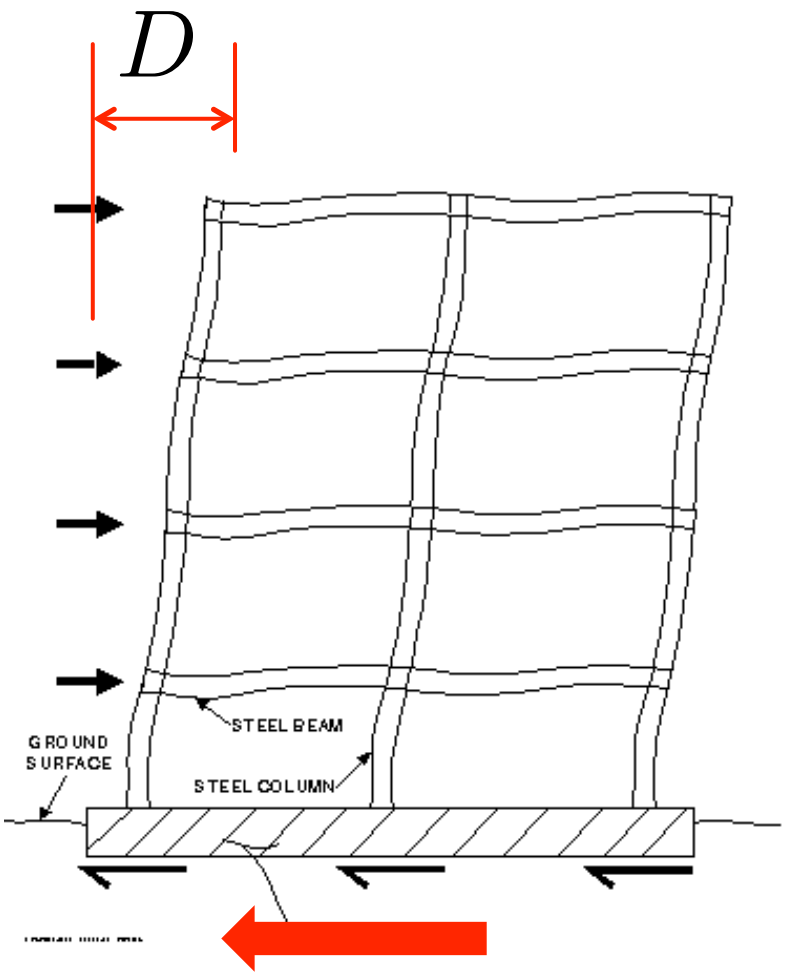
$$V_b = mA$$

Describes the amplification of ground motion excitation in the building

Response of a Building

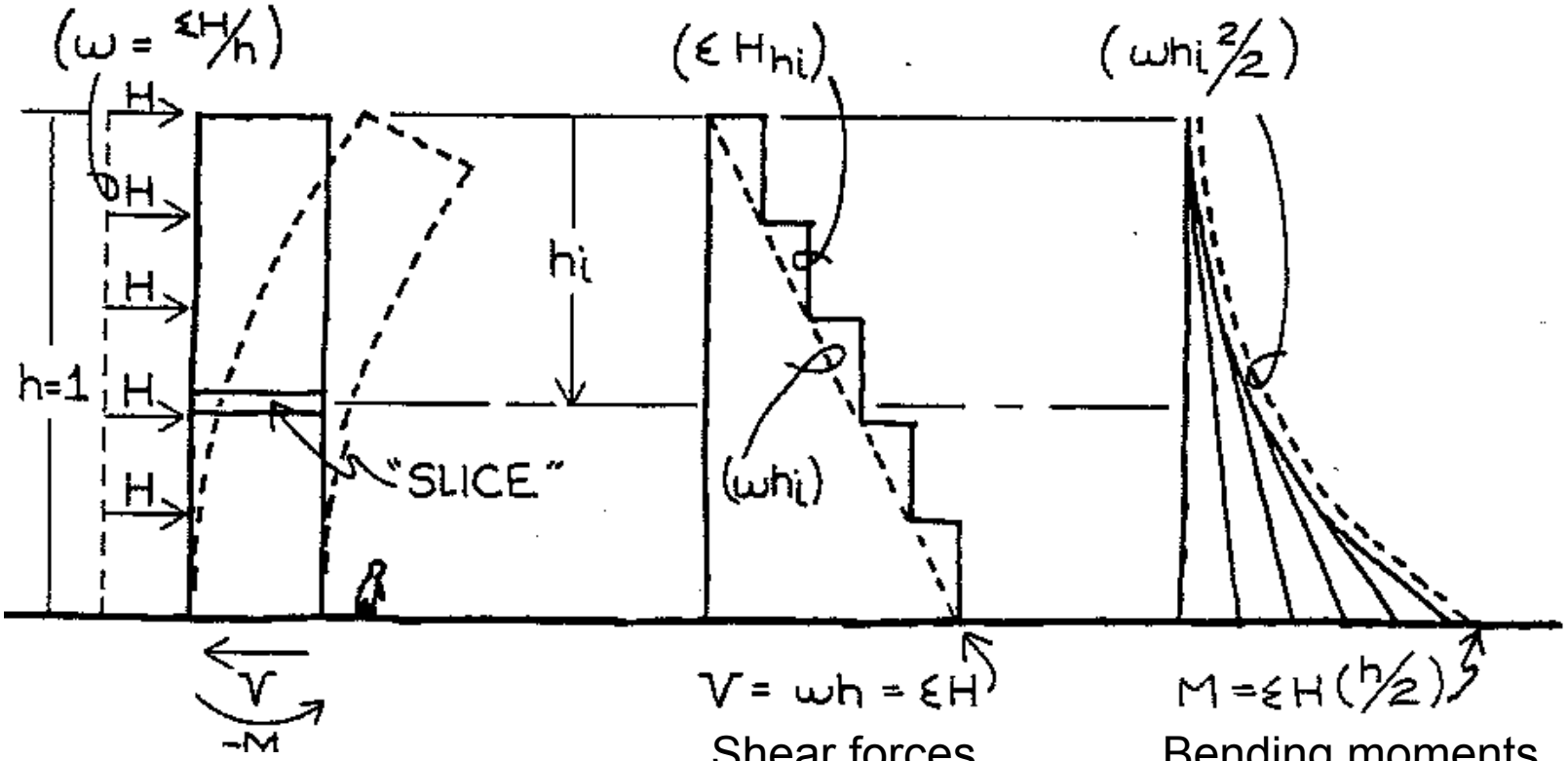


$$V_b = mA$$



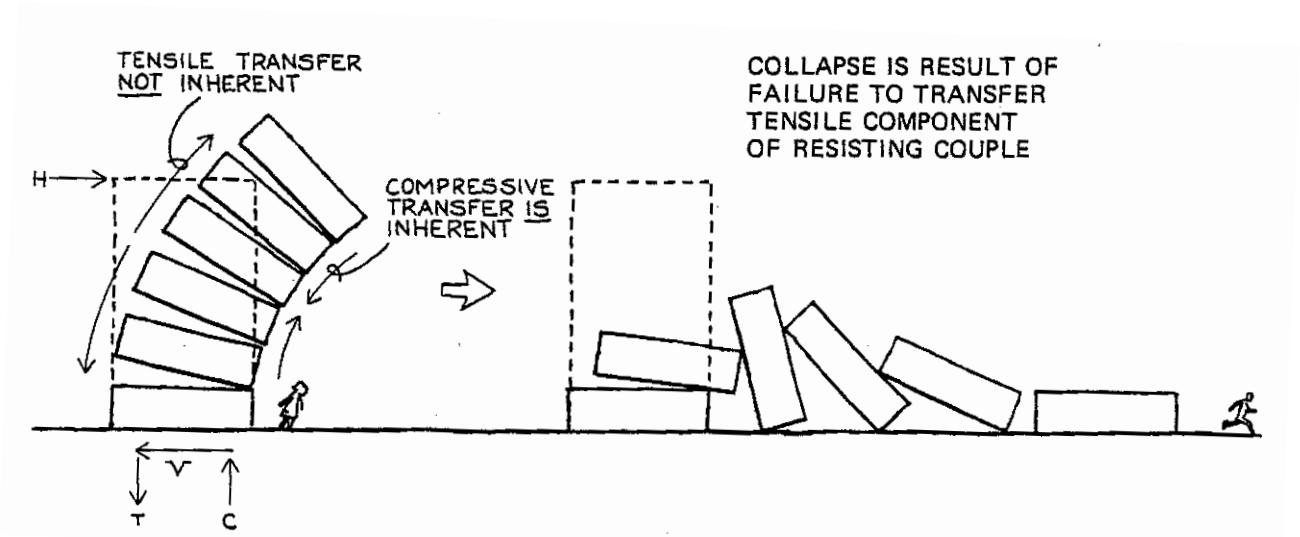
$$V_b = mA$$

Forces and Displacements

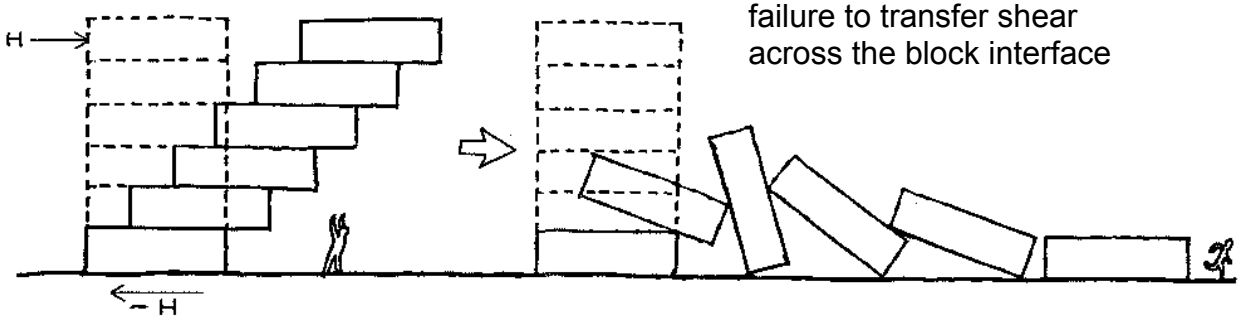


Resistances

Bending



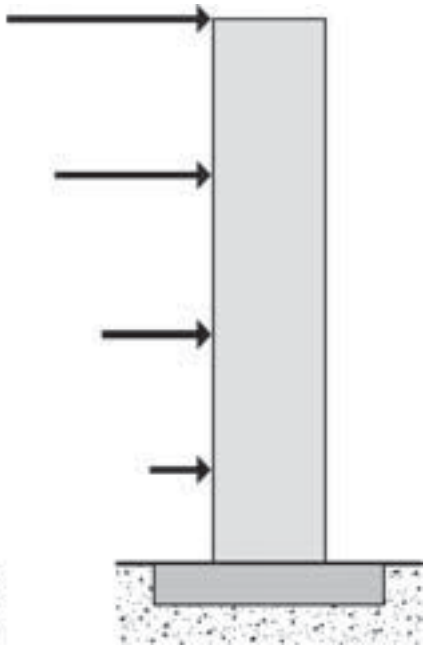
Shear

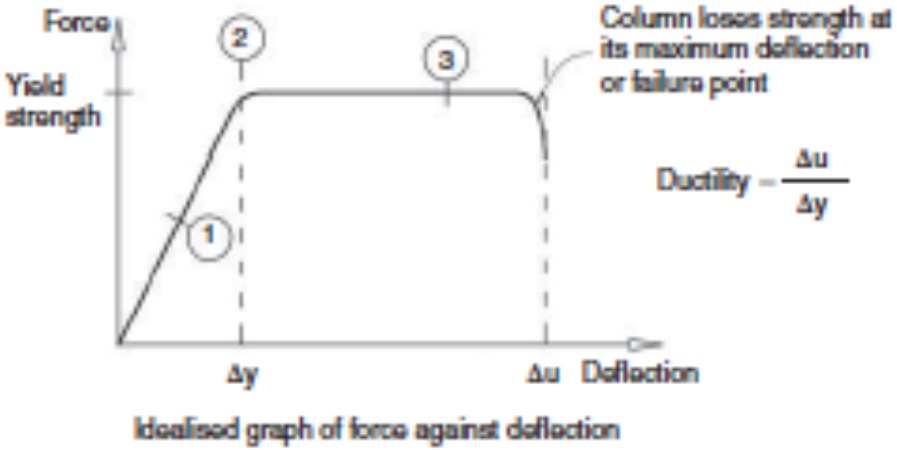


Collapse is result of failure to transfer shear across the block interface

How to Resist Earthquakes?

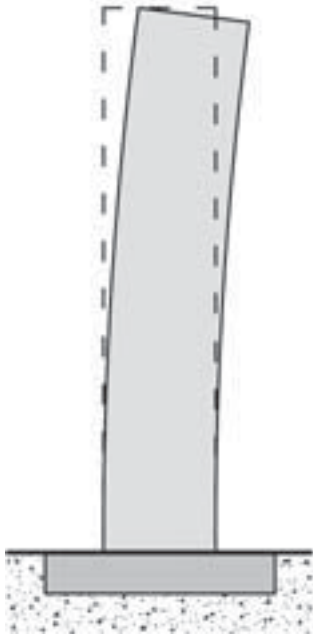
By resisting:
Strength





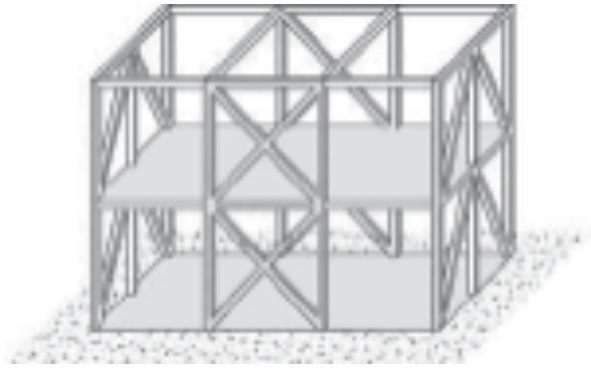
Idealised graph of force against deflection

By giving in:
Deformability



Conventional Structural Systems

Moment frame:
- Deformable
- Ductile
- Strong



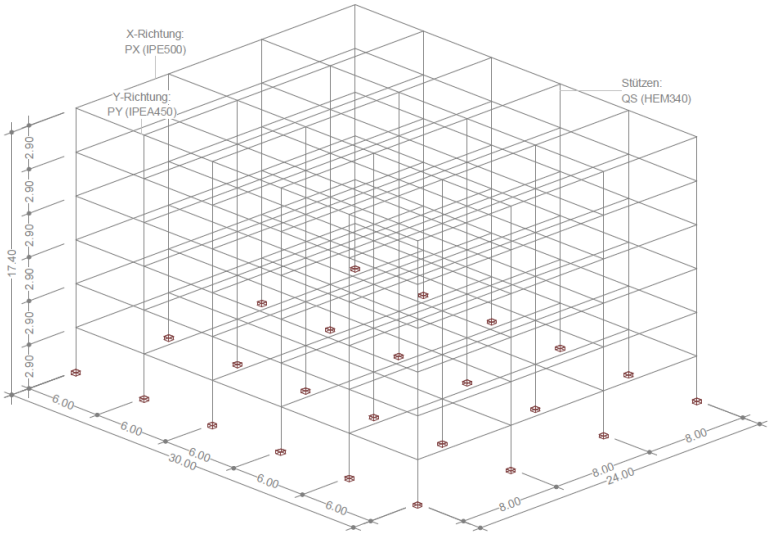
Braced Frame:
- Ductile
- Strong & Deformable

Shear wall
- Strong
- Ductile
- Deformable

Andrew Charleson: “Seismic Design for Acrhitects”, Elsevier, 2008

Seismic Behavior: Moment Frames

- Made of beams and columns with rigid joints

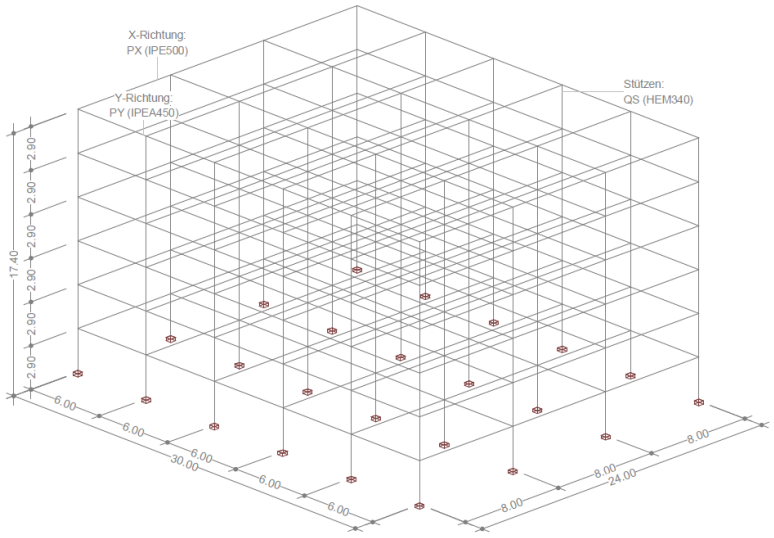


Reinforced Concrete

http://www.nexus.globalquakemodel.org/gem-building-taxonomy/overview/glossary/moment-frame--lfm

Seismic Behavior: Moment Frames

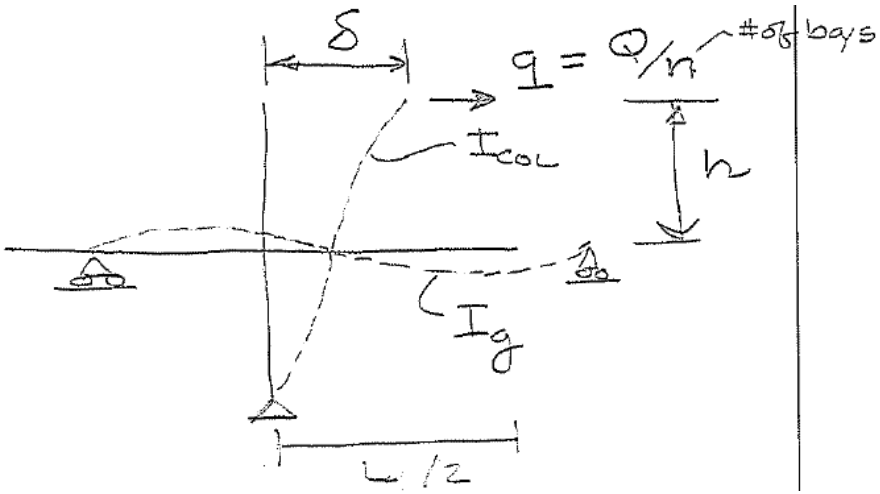
- Made of beams and columns with rigid joints

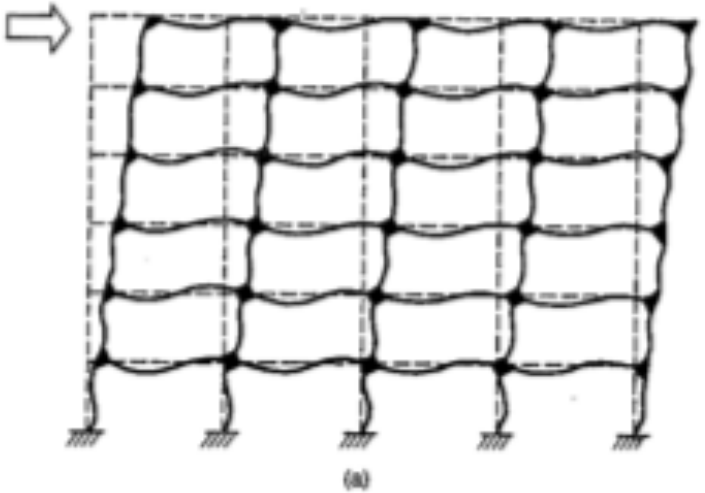


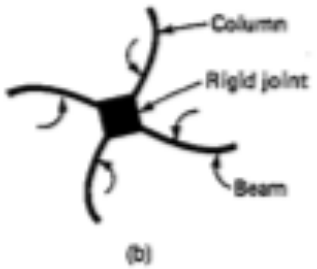
Steel

Seismic Behavior: Moment Frames

- Resist earthquake actions by bending of beams and columns

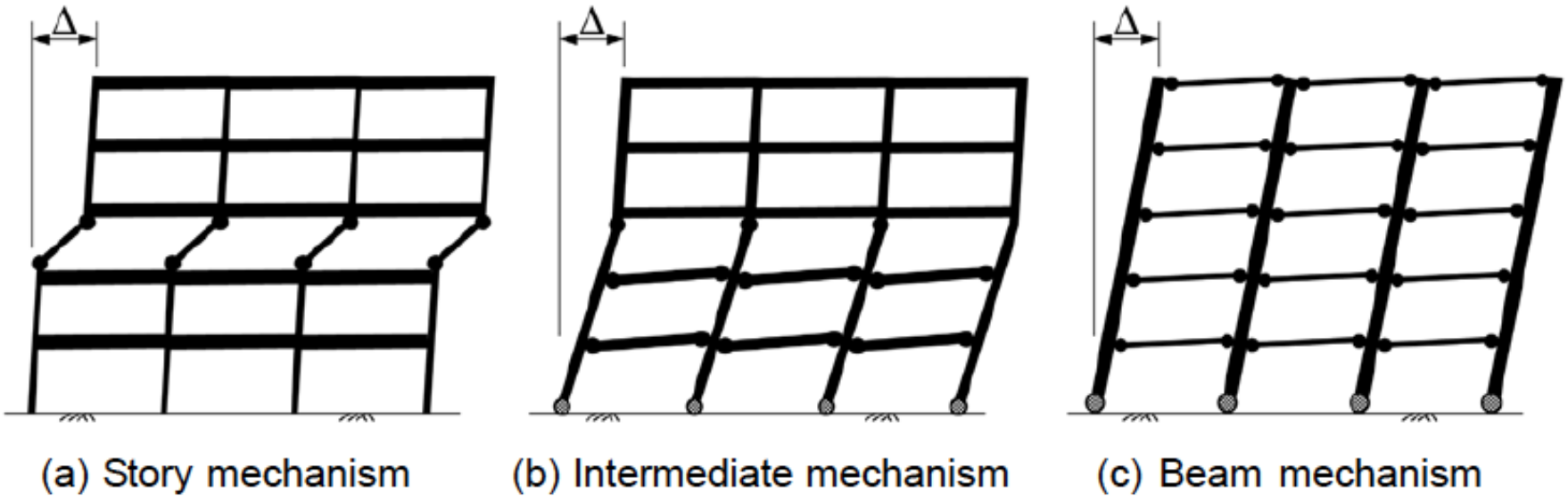






Seismic Behavior: Moment Frames

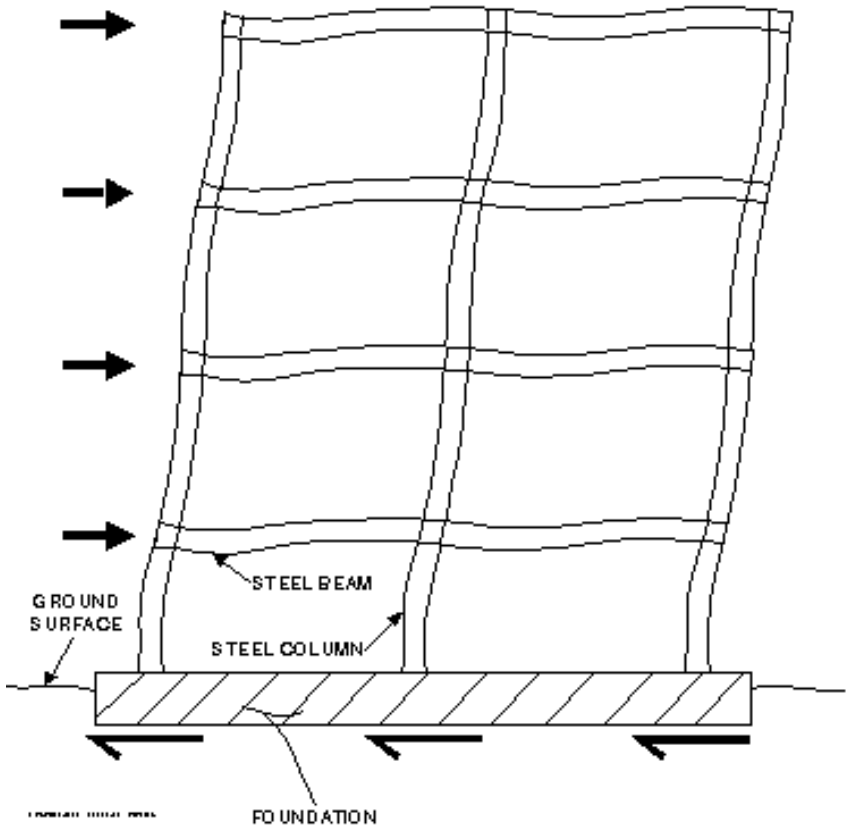
- Deform by relative shear motion of floors



- Promote the beam mechanism by making columns strong

Seismic Behavior: Moment Frames

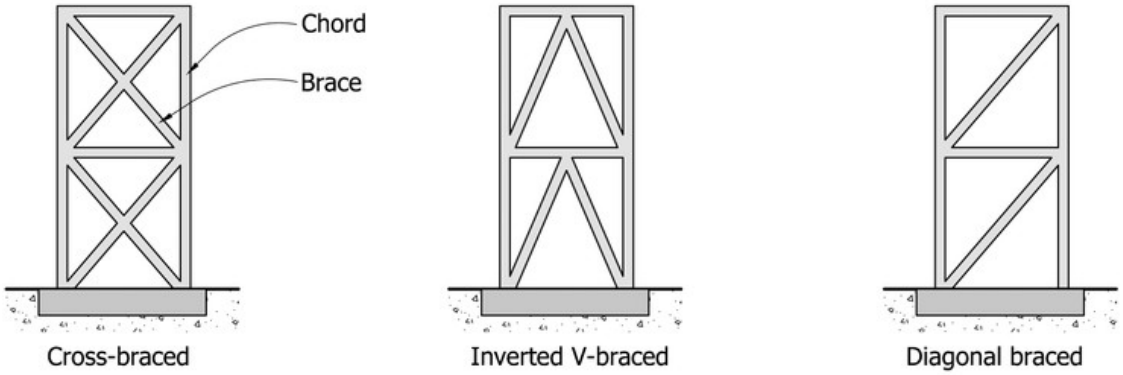
- Deformable:
  - Longer vibration periods
  - Smaller forces
  - Bigger displacements
- Ductile
- Architects like them:
  - Open spaces



Seismic Behavior: Braced Frames

- Made of beams and column and diagonal members: braces

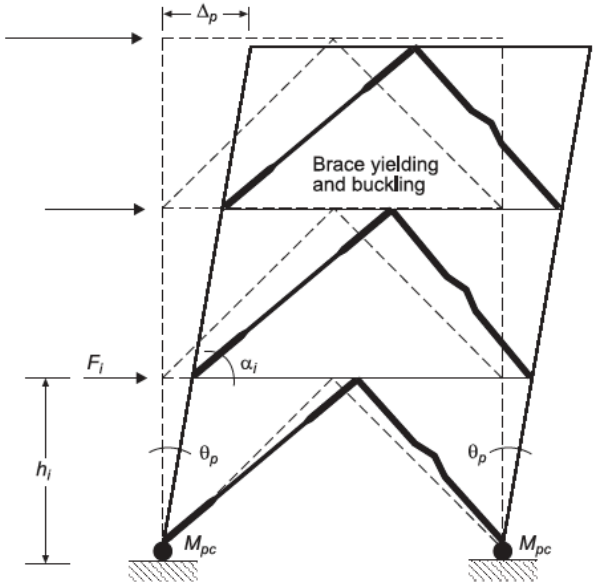
Seismic Behavior: Braced Frames



http://www.nexus.globalquakemodel.org/gem-building-taxonomy/overview/glossary/braced-frame--lfbr

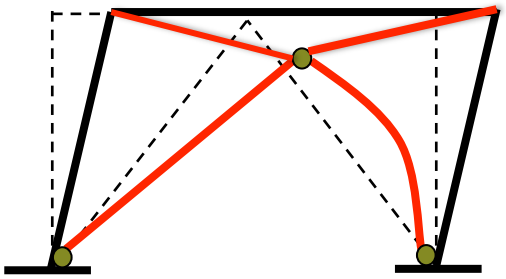
Seismic Behavior: Braced Frames

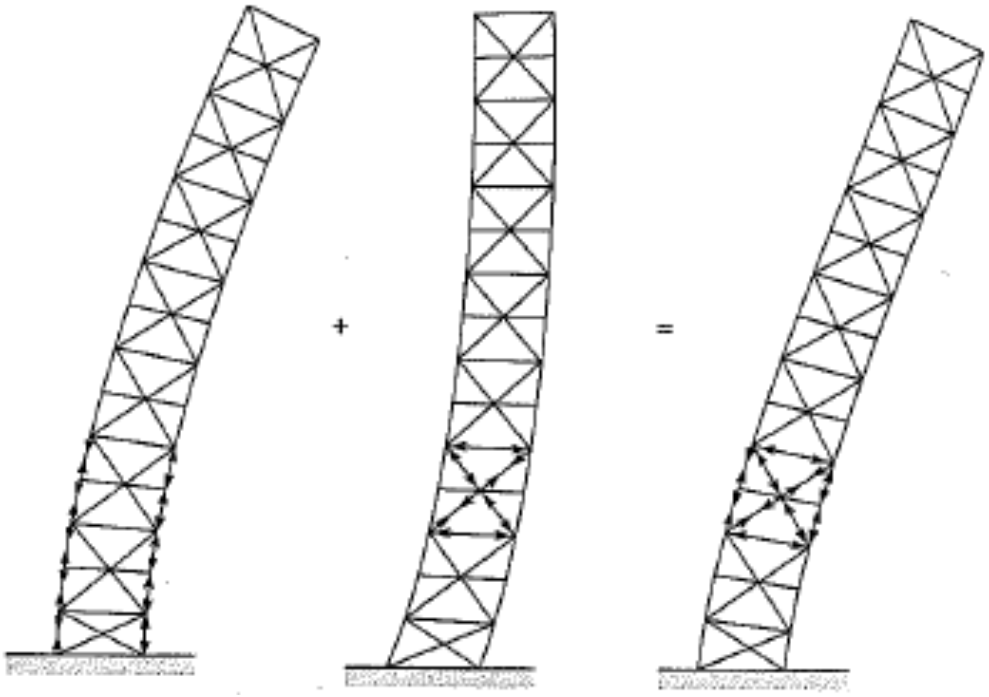
- Braces in moment frames resist the earthquake actions by tension and compression



Seismic Behavior: Braced Frames

- Deform as hybrid system:
  - Shear of the floors
  - Cantilever bending of the columns

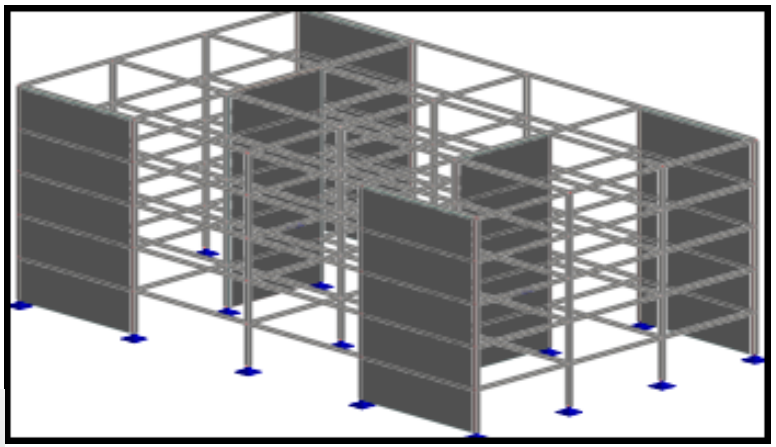




Seismic Behavior: Braced Frames

- Strong & Deformable:
  - Moderate vibration periods
  - Larger forces
  - Moderate displacements
- Ductile, but not as much as moment frames
- Both architects and engineers like them:
  - Open spaces
  - Good structural behavior

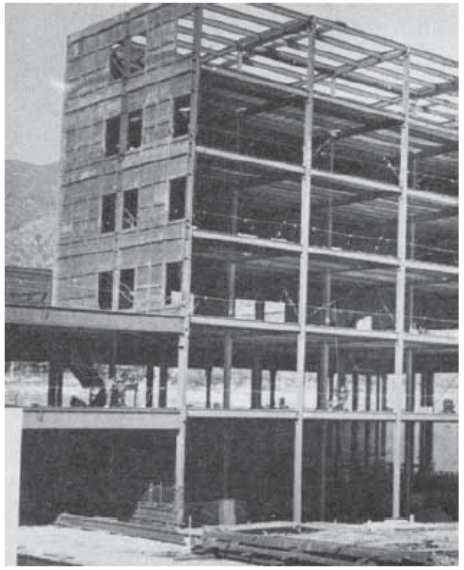
Seismic Behavior: Shear Walls



Reinforced concrete

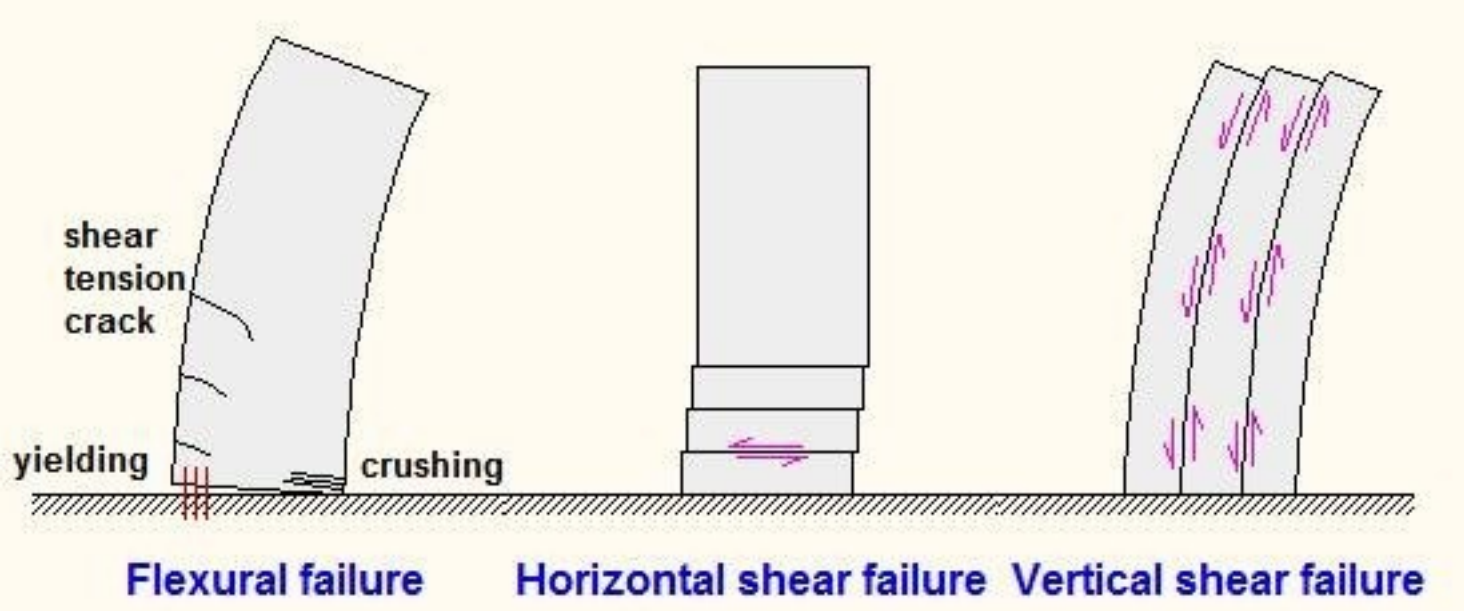
Masonry

Steel



Seismic Behavior: Shear Walls

- Resist earthquake actions by cantilever bending and shear resistance



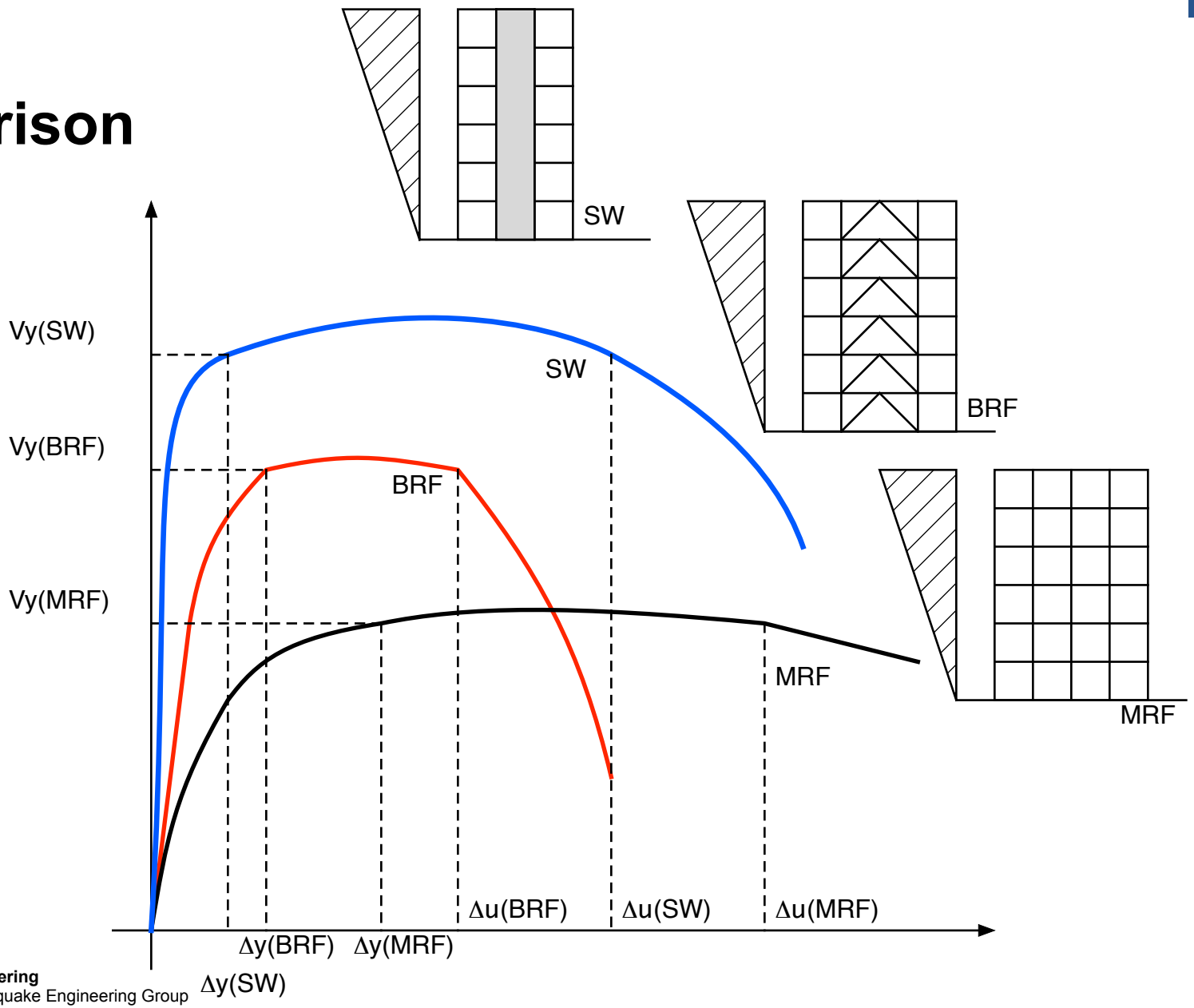
http://theconstructor.org/structural-engg/analysis-of-shear-walls/6243/

Seismic Behavior: Shear Walls

- Strong:
  - Short vibration periods
  - Large forces
  - Small displacements
- Ductile
- Engineers like them:
  - Good structural behavior

http://www.nexus.globalquakemodel.org/gem-building-taxonomy/overview/glossary/wall--lwal

Comparison

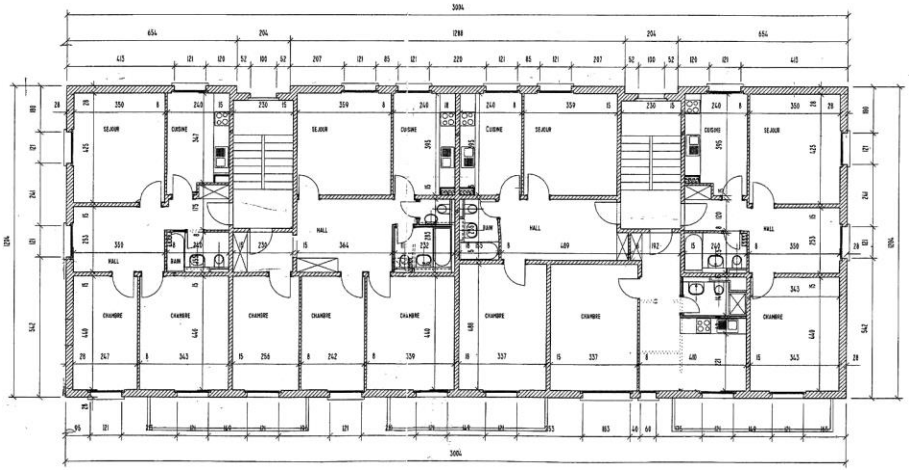

SW
BRF
MRF
Vy(SW)
Vy(BRF)
Vy(MRF)
SW
BRF
MRF
Δu(BRF)
Δu(SW)
Δu(MRF)
Δy(BRF)
Δy(MRF)
Δy(SW)

Typical Swiss Building

- Unreinforced masonry shear wall building

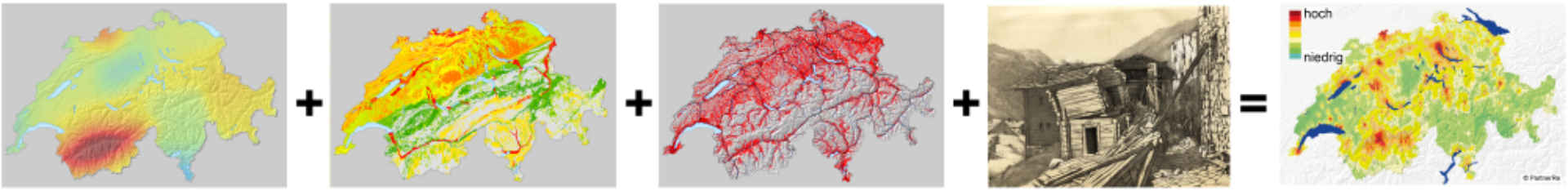
- Strong, but not very deformable
- Not ductile

- Life-Safe in expected earthquakes
- Present an increased risk

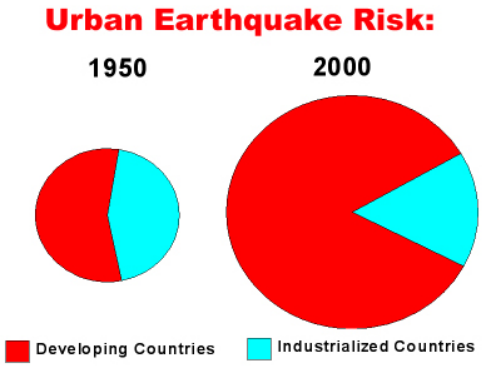


What is Seismic Risk?

- Integral of hazard exposure, vulnerability and values



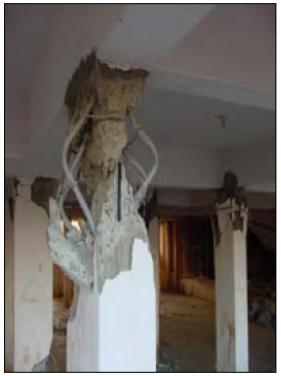
- How much can we loose?



http://www3.ntu.edu.sg/wssi/goals.html

http://www.seismo.ethz.ch/eq_swiss/haz_risk/index_EN

Structural Damage



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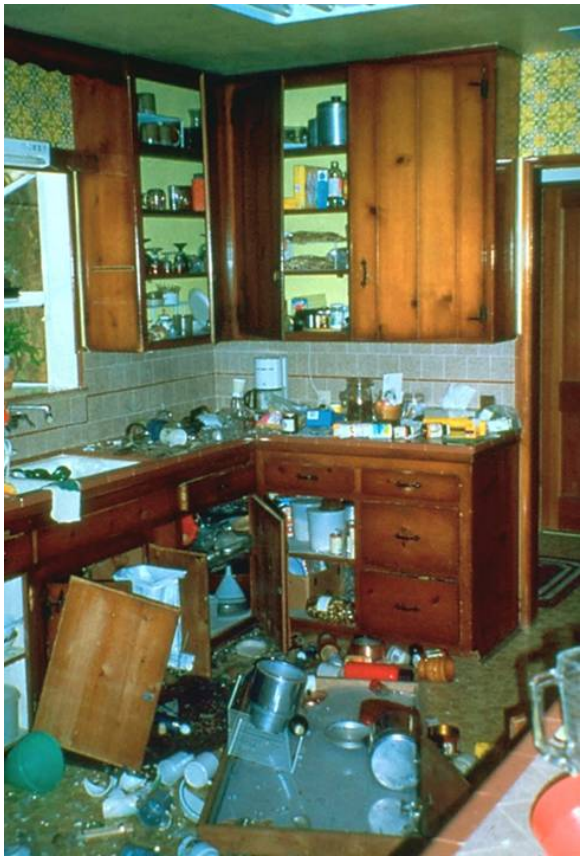
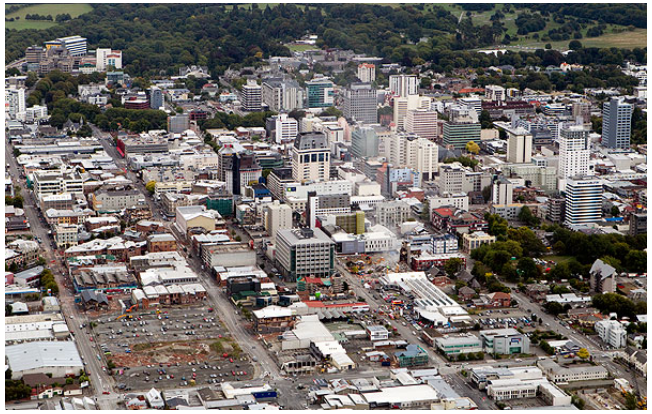
Non-Structural Damage



Communities at Risk

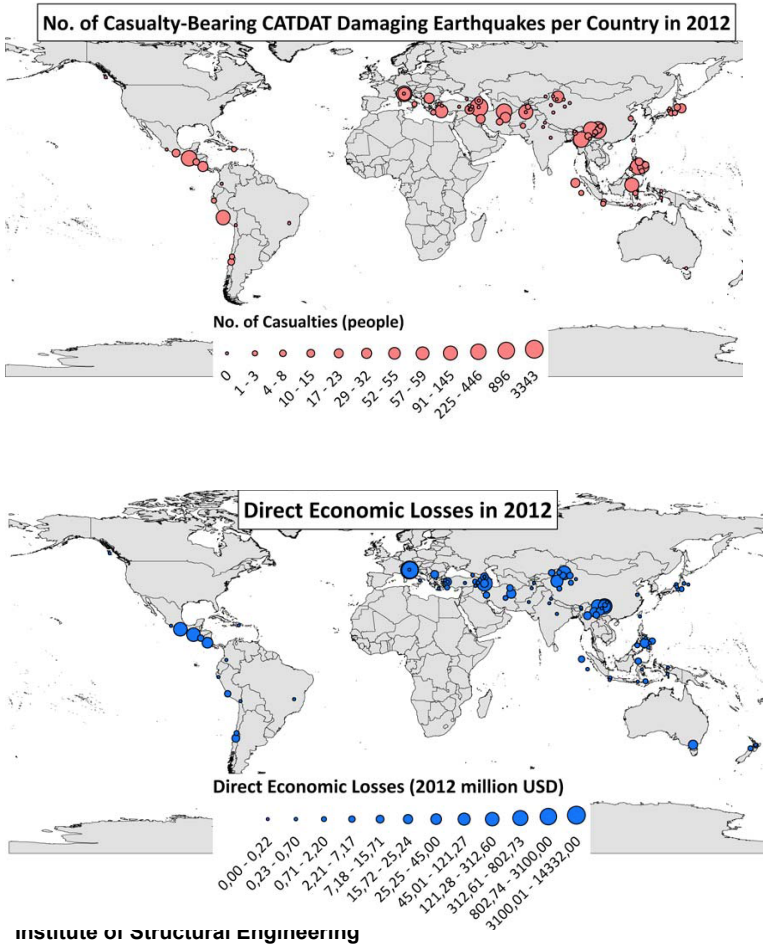


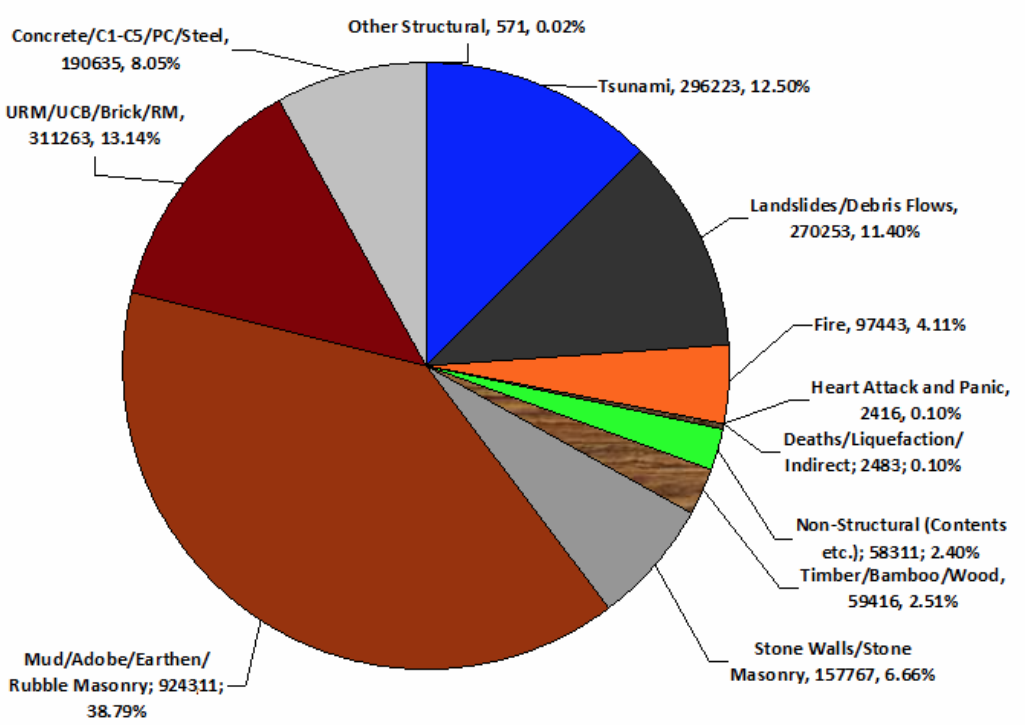
Community

- An entity that has geographic boundaries and shared fate
- Composed of interacting:
  - Built
  - Natural
  - Social
  - Economic

  environments

How Much can we Loose?

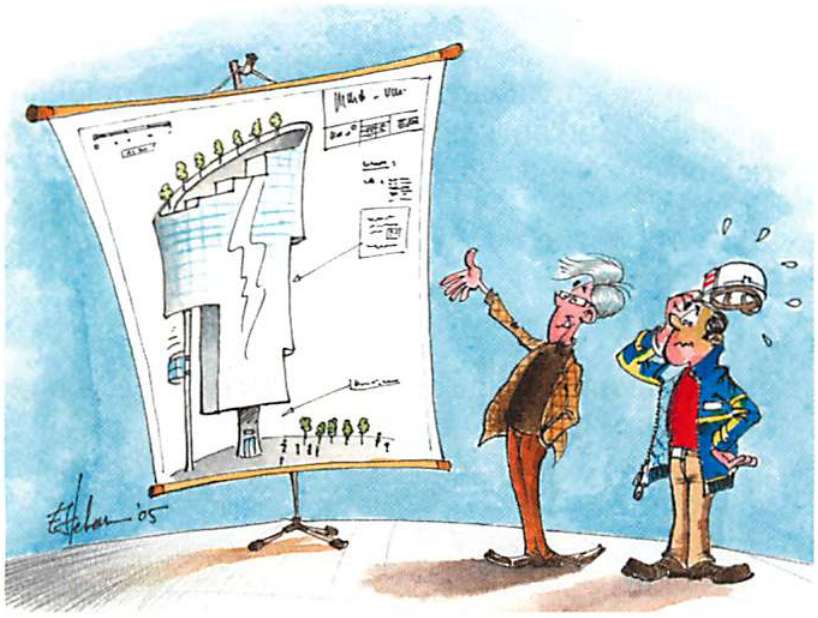




http://earthquake-report.com/2013/01/07/damaging-earthquakes-2012-database-report-the-year-in-review/

What can we do?

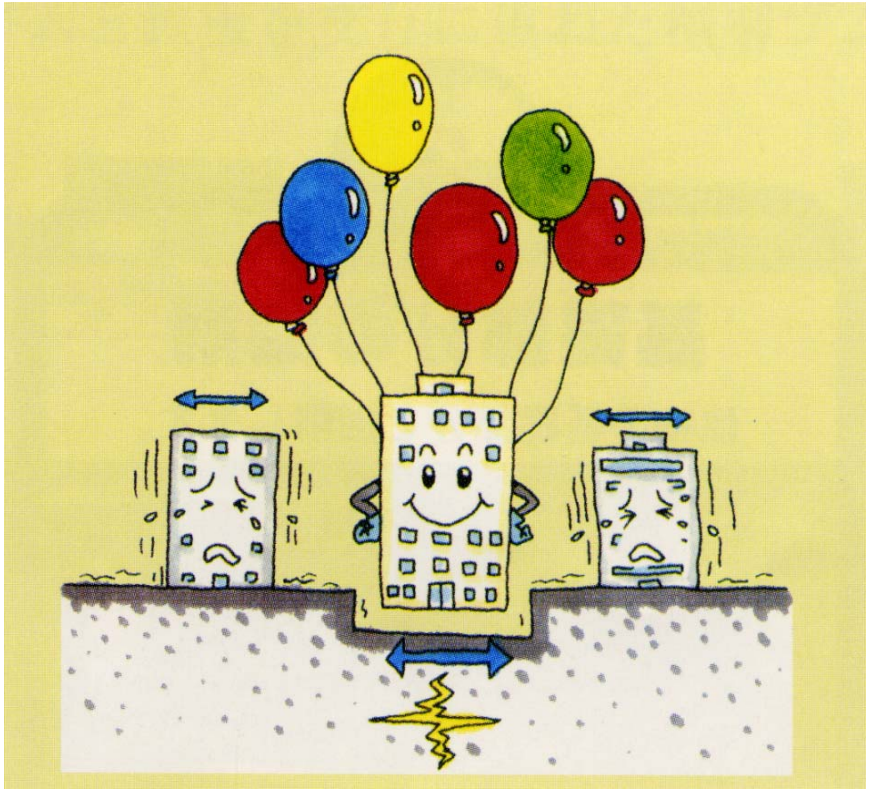
- Engineer structures for better seismic performance
- Prepare communities for earthquakes (and other natural hazards)
- Build a resilient society



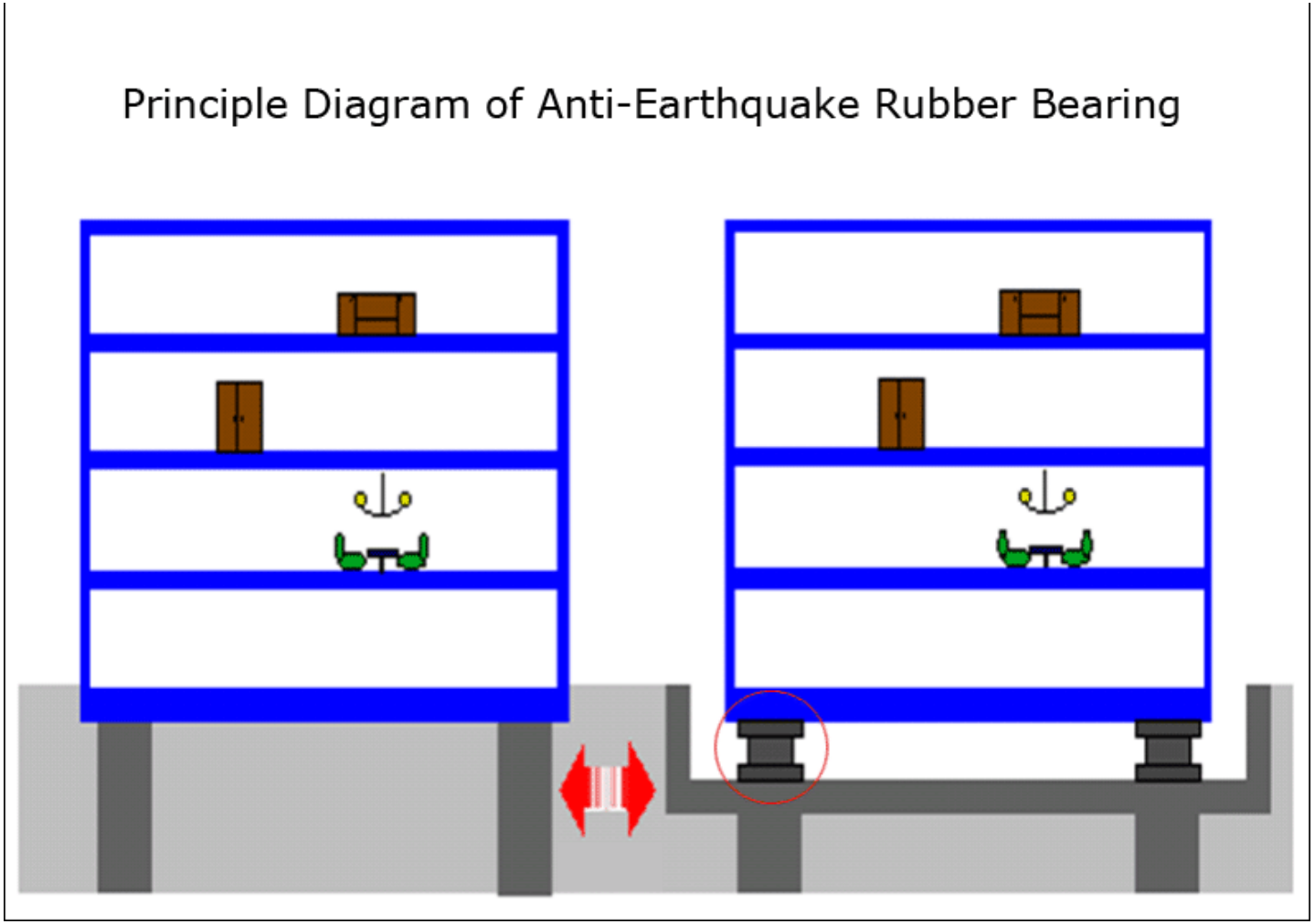
Architekt und Ingenieur: «Nein, so nicht!» (Zeichnung E. Rosales)

New Structural Systems for Better Seismic Performance

- Reduce seismic risk by modifying the dynamic response of structures:
  - De-couple the structure from the ground
  - Reduce motion of the structure
  - Reduce forces and accelerations
- Seismic isolation devices
- Damping devices



Seismic Isolation



Seismically Isolated Structures
San Francisco City Hall

1906

1994

Seismic isolators

Retrofitted Structural Systems for Better Seismic Performance

Strengthening systems

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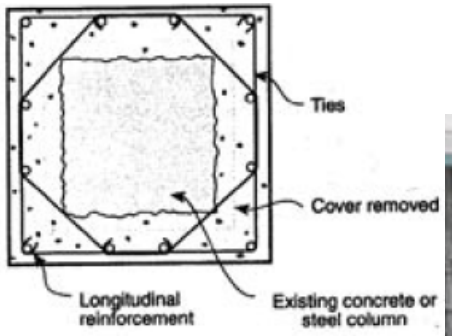
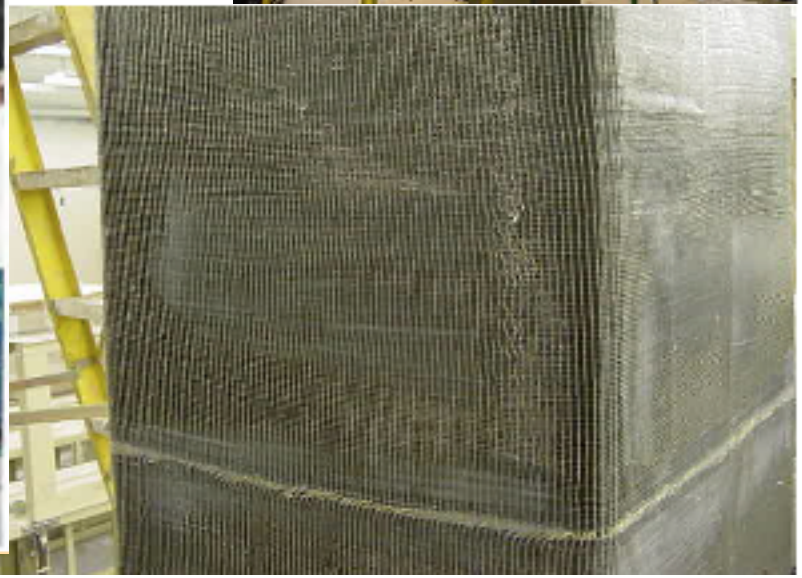
Retrofitted Structural Systems for Better Seismic Performance





Strengthening elements

Retrofitted Structural Systems for Better Seismic Performance

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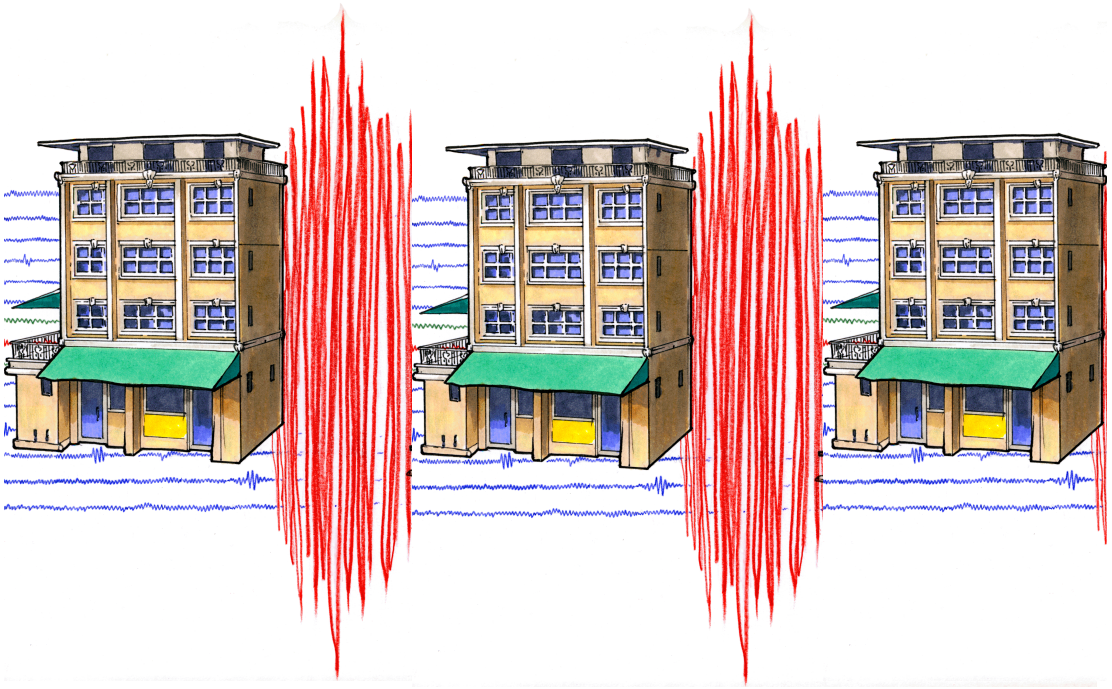
Community Preparedness
Emergency Services

Community Preparedness: Education

Community Preparedness: Education

Community Preparedness: Long-term Planning

ETH zürich



Build to Defeat Earthquakes!

Thank you.

Prof. Dr. Bozidar Stojadinovic

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