Seismic Principles for Museums and Collections: Buildings

Dr. Elwin C. Robison

National Endowment for the Humanities
Utah Humanities
Ideas in Action
Utah Division of Arts & Museums

Introduction

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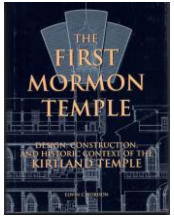
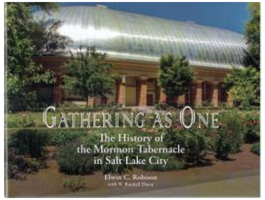
BSCE Brigham Young University
MA & PhD Cornell University

Books:
Architectural Technology Up To the Scientific Revolution, MIT Press, gen. ed. Robert Mark, 1994.

The First Mormon Temple: Design, Construction, and Historic Context of the Kirtland Temple, BYU Press, 1997.

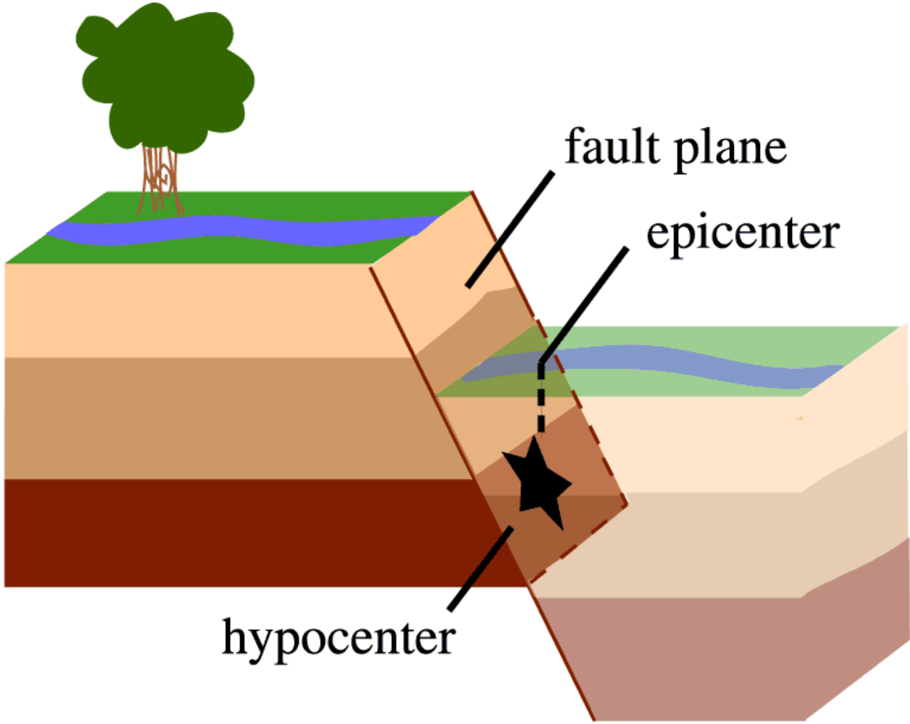


Gathering as One: The Mormon Tabernacle in Salt Lake City, BYU Press, 2014.



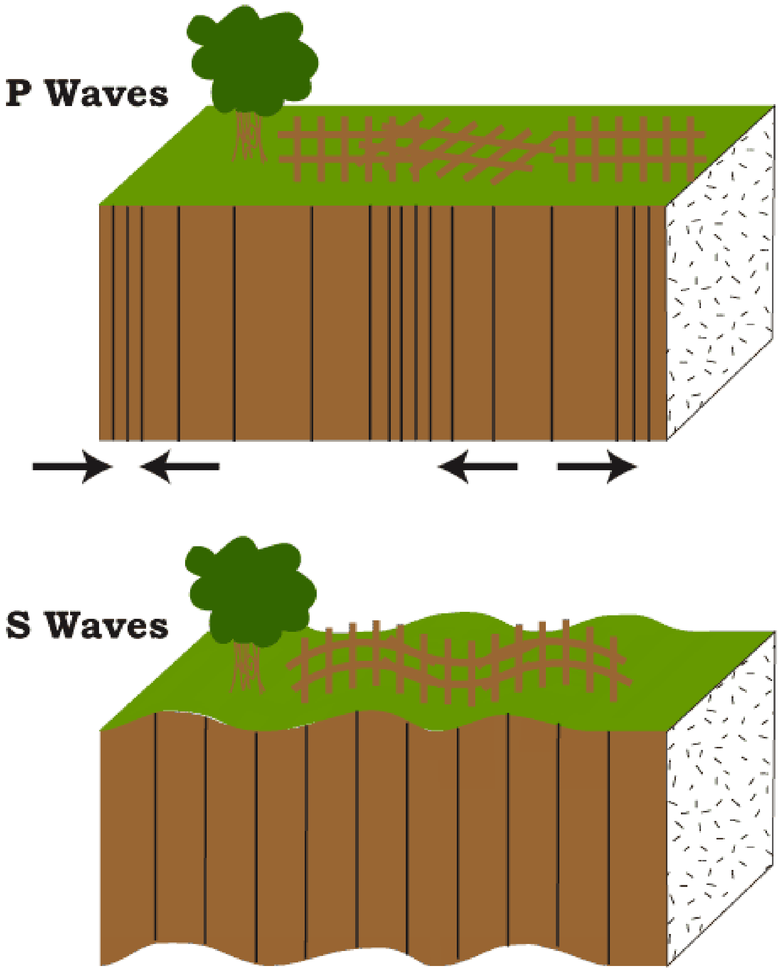
What is an earthquake?

- When two blocks of earth slide past one another.
- The slip plane is referred to as a fault.



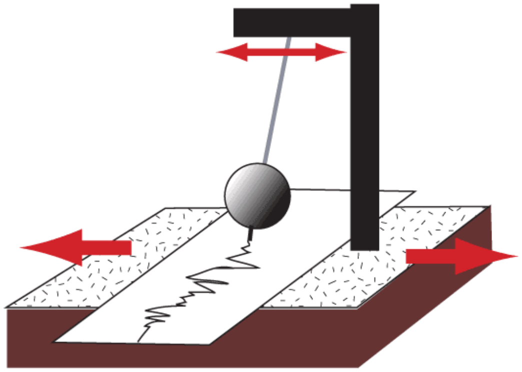
P waves and S waves

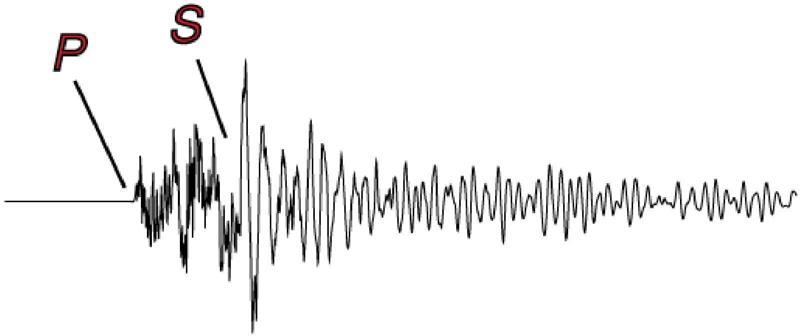
- Earthquakes produce P waves and S waves.
- One can think of P waves like lightening, and S waves as thunder.
- P waves move back and forth and travel more quickly through the earth, but are not as strong.
- S waves move side to side and can be very strong.



Early Earthquake Warning (EEW)

- P waves arrive first, leaving several seconds before the more damaging S waves arrive.
- The ShakeAlert system is used in CA, WA, OR to send out alerts via cell phone.
- Can provide several seconds warning so that building occupants can take cover or take other protective measures that only require a few seconds.
- Utah not part of system yet.





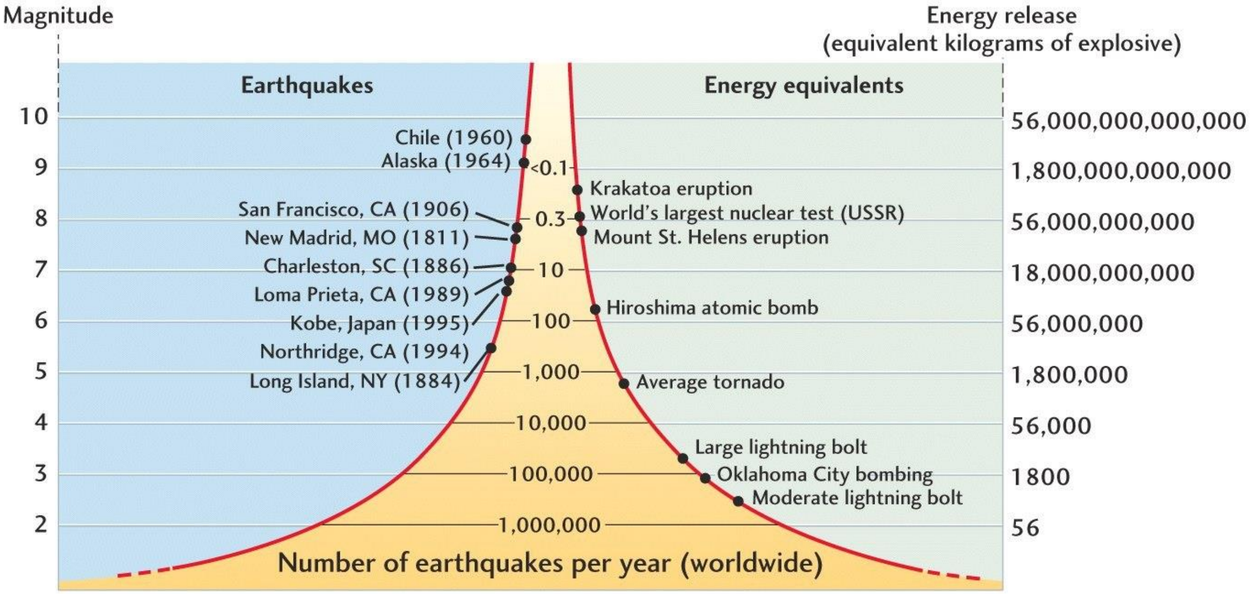
What is the Richter scale?

- Charles Richter 1909-85
- Used logarithmic scale to ‘rate’ earthquakes, giving a simple way to communicate the intensity or potential for damage.

COLLECTIONS PRESERVATION

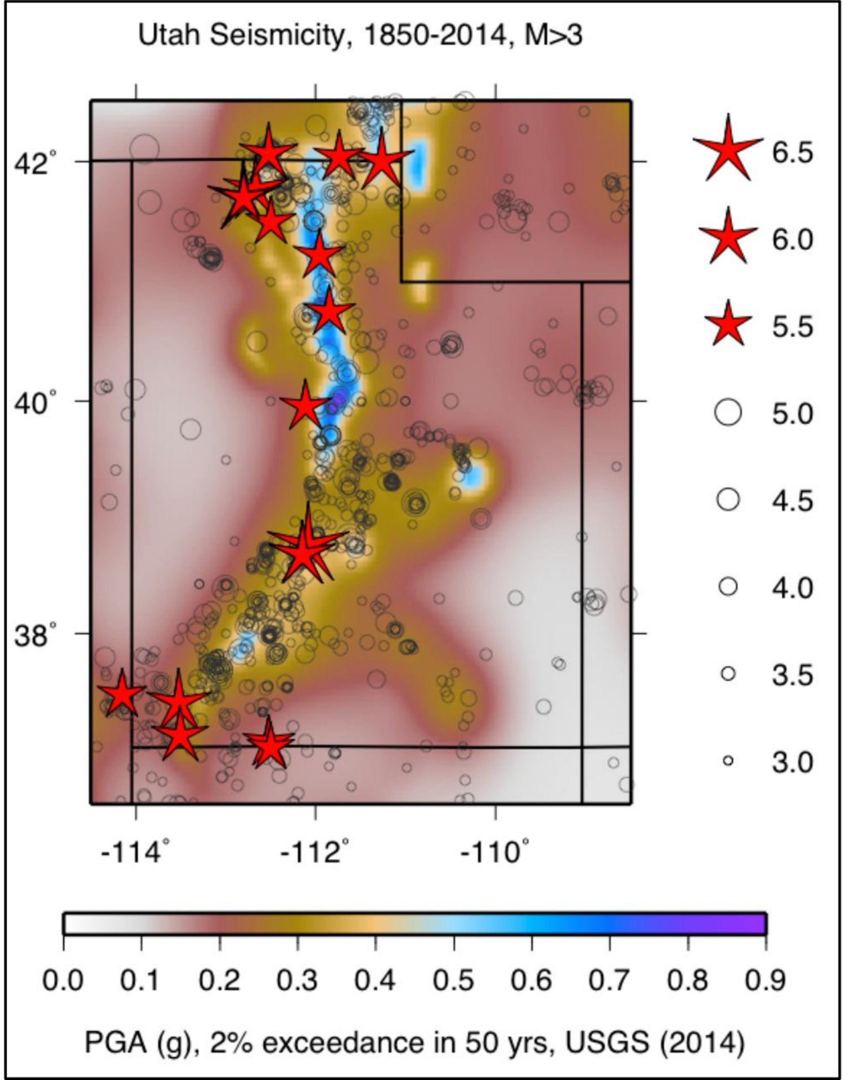
What is a logarithmic scale?

- Each number represents an order of magnitude, i.e., each number on the scale is 10 times more powerful
- While the difference between 2.5 and 3.0 is modest (because the curve is relatively flat), the difference between 7.0 and 7.2 is great.



Seismic Risk Assessment

- Seismic risk is judged by past history.
- Which each major earthquake comes a new assessment of risk.
- Forces used by engineers in calculations also change as more is learned.
- It is likely that today’s calculation will be obsolete in a few years.

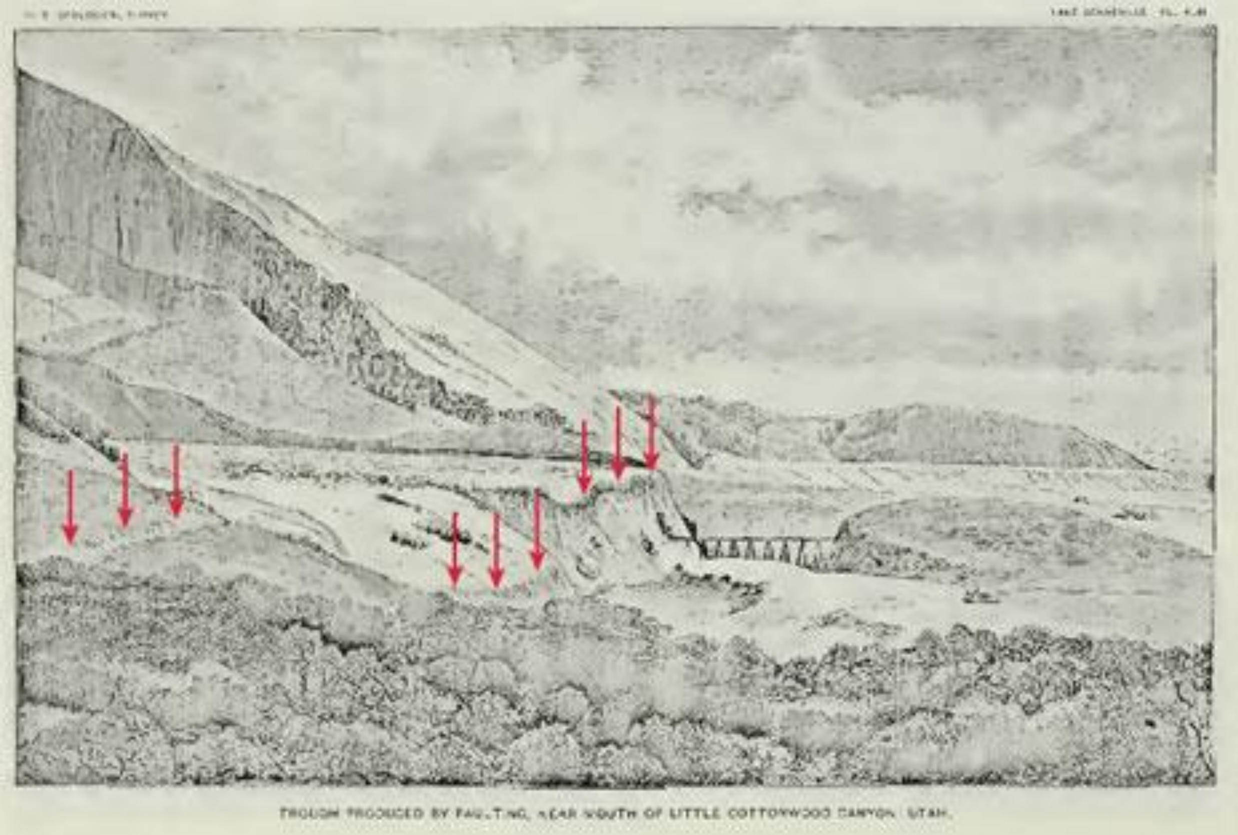


Scarps

- An example of an exposed scarp from the 1983 Bora Mountain, Idaho earthquake.
- Six feet was added to the height of the scarp.

Scarps

- Scarps from past earthquakes are visible along the Wasatch Front.
- You have probably driven past them but did not notice.



Little Cottowood Canyon scarp

- Scarp near the mouth of Little Cottonwood Canyon in 1901.

Little Cottonwood Scarp today

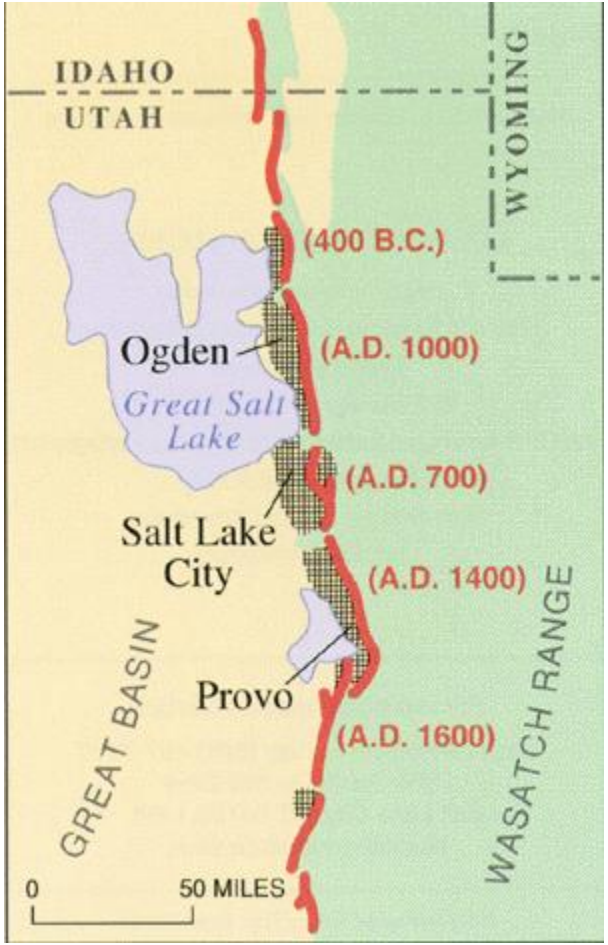
- Guess where everyone wants to build their house (great views over the valley)

Trenches through scarps

- By trenching through scarps, archaeologists and geologists can measure the height of the scarp (giving the approximate magnitude of the earthquake) and the approximate date by comparing the ages of artifacts on each side of the scarp.

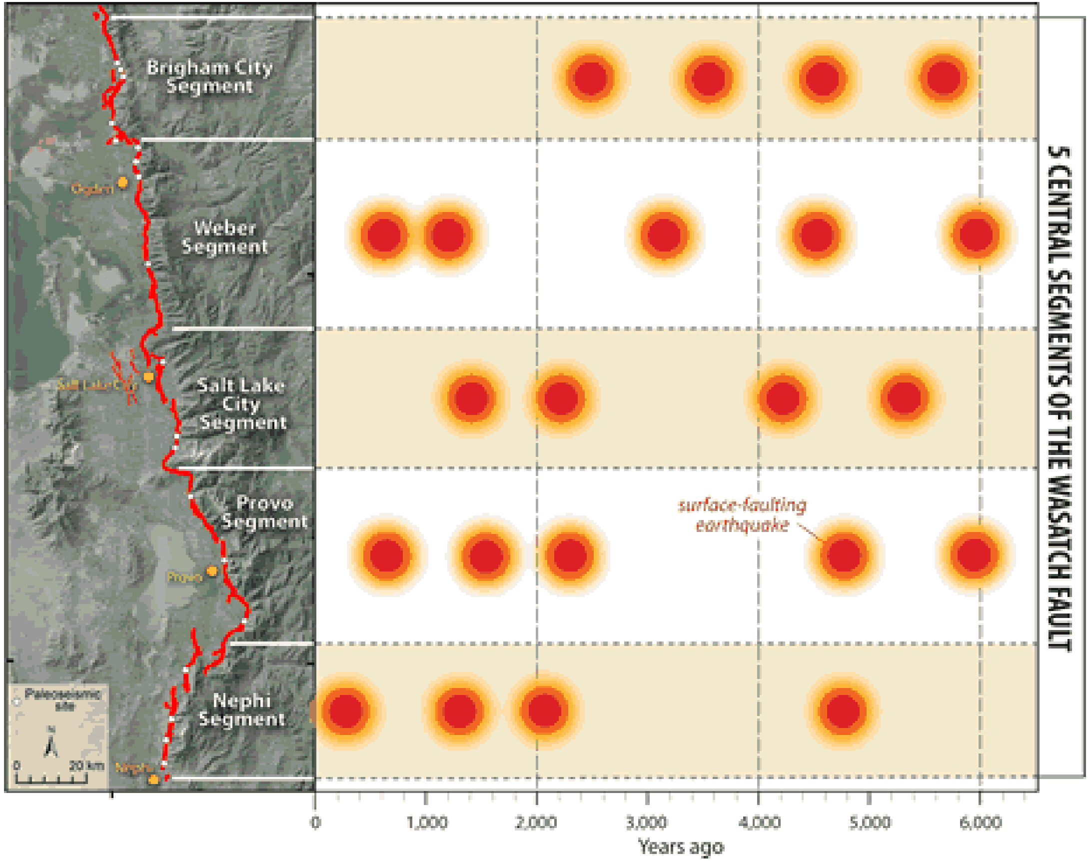
Utah Seismic History

- Utah seismic history has been mapped by geologists looking at scarps—where faults have caused a break in the soil surface.



Frequency?

- When will the next big earthquake happen?
- Note that the Brigham City and Salt Lake City segments of the Wasatch fault have gone long periods without activity.
- Breathe easier if you are near the Nephi segment (but there is no guarantee).



Structural Design for Earthquakes

- US codes are based on the American Society of Civil Engineers publication #7
- The aim is not to make buildings ‘earthquake proof,’ but rather to protect occupants.
- It would be prohibitively expensive to build structures that would meet an ‘earthquake proof’ standard.
- The ideal would be to have a heavily damaged building without catastrophic failure.

Structural Design for Earthquakes

- Calculations for seismic forces are based on the category of building.

- Category I. Low hazard to human life (barns, agricultural buildings).
- Category II. Most buildings.
- Category III. High occupancy buildings with 300 or more occupants, most schools.
- Category IV. Essential facilities, such as hospitals, police and fire stations, utilities.

Structural Design for Earthquakes

- Seismic forces are determined by:
  - Distance to the fault.
  - Soil characteristics (soft clays can shake like a bowl of jelly)
  - Frequency of shaking.
- ASCE has mapped conditions and assigned coefficients for seismic force calculations.
- A sample report for Temple Square is to the right. These data are then used to calculate the forces in term of the percentage of ‘g’, the force of gravity.

REPORT SUMMARY

Site Information

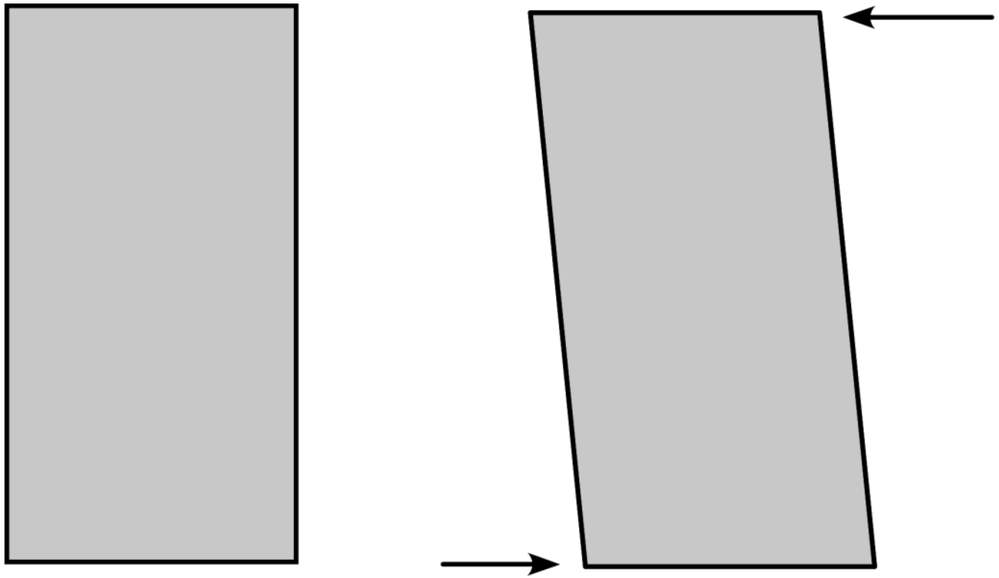
Address:	*Temple Square - W South Temple, Salt Lake City, ,*
Elevation:	4334 ft (NAVD 88)
Lat:	40.77044
Long:	-111.8919
Standard:	ASCE/SEI 7-22
Risk Category:	III
Soil Class:	Default

Seismic Data

S_S	1.66
S_1	0.57
S_{MS}	1.74
S_{M1}	1.25
S_{DS}	1.16
S_{D1}	0.83
T_L	8
PGA_M	0.73
V_{S30}	260
Seismic Design Category	D
Note	Where values of the multi-period 5%-damped MCER response spectrum are not available from the USGS Seismic Design Geodatabase, the design response spectrum shall be permitted to be determined in accordance with Section 11.4.5.2

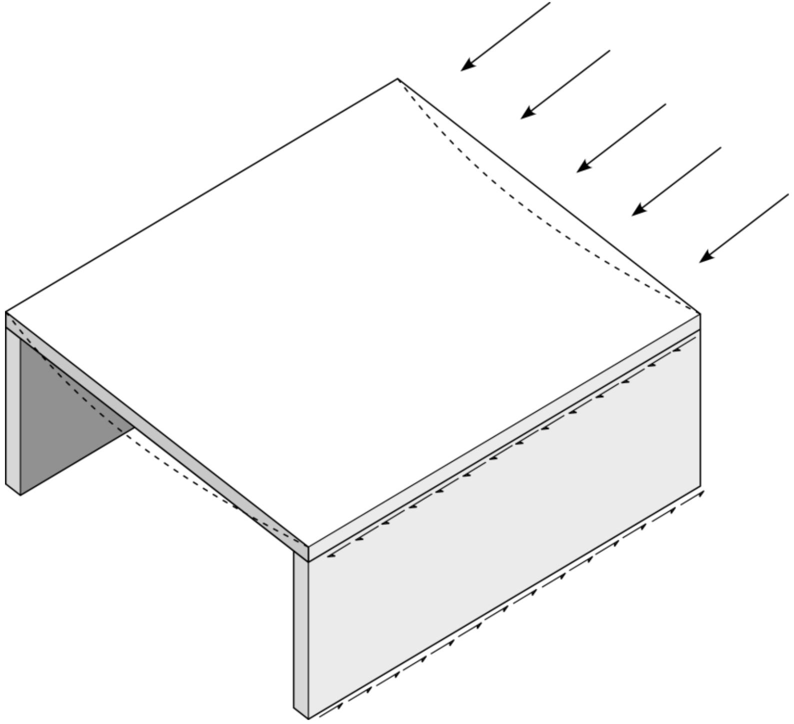
Some Engineering Principles

- A shear wall resists deformation into a parallelogram when subjected to lateral (sideways) forces.
- Shear walls can be:
    - Reinforced concrete (very strong)
    - Plywood (lightweight)
    - Reinforced masonry (strong)
    - Drywall (not very strong)
    - Unreinforced masonry (not very strong)



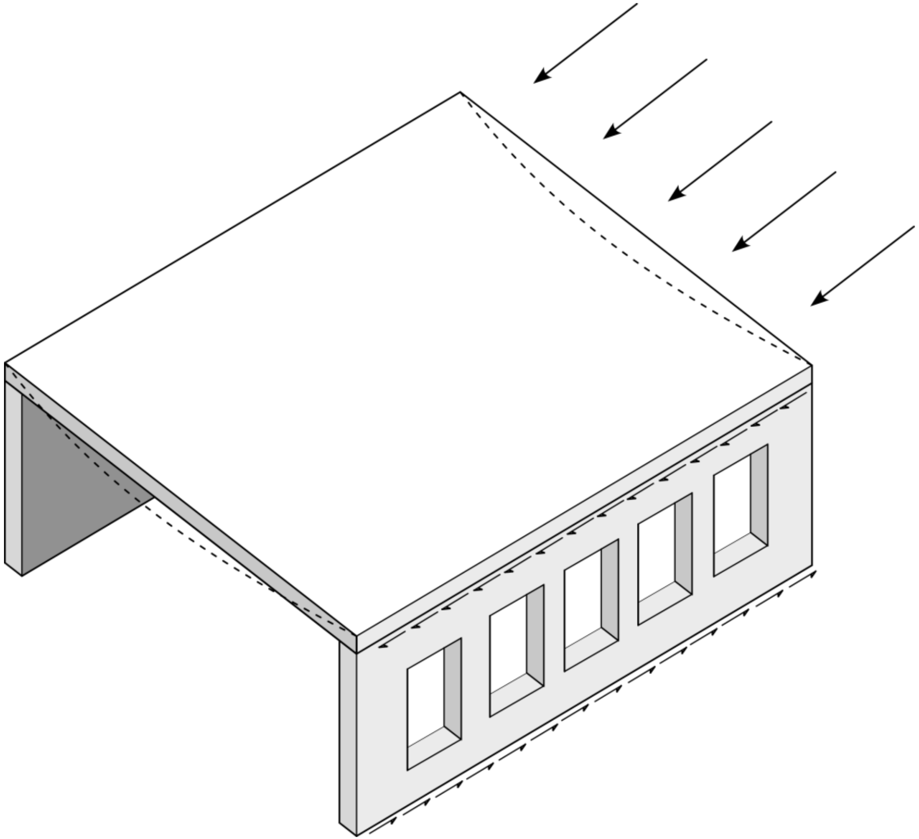
Some Engineering Principles, cont.

- If an earthquake shakes a building, the horizontal roof or floor acts as a horizontal diaphragm, transferring the force to the shear walls.
- Long, uninterrupted shear walls are stronger.



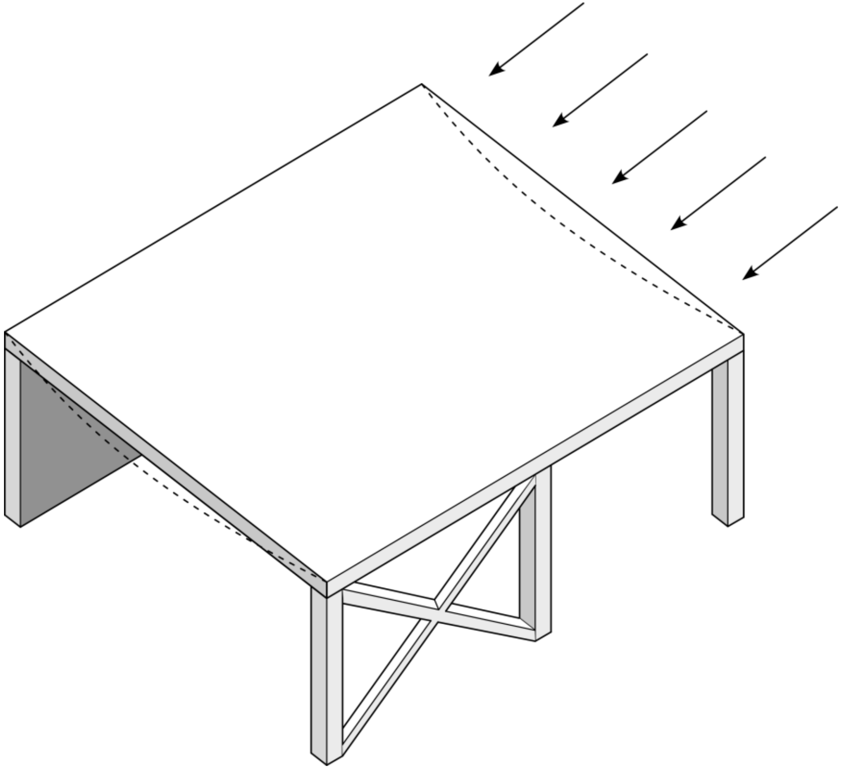
Some Engineering Principles, cont.

- If the shear walls are perforated by openings, the capacity of the shear wall is reduced.
- In the diagram to the right, the number of openings and closeness of spacing of the openings greatly reduces the capacity of the shear walls.



Some Engineering Principles, cont.

- Sometimes engineers opt for X-braces when many openings are desired.



Some Engineering Principles, cont.

- A closed box with a lid is the optimal shape of a building for seismic resistance.
- Smaller ‘boxes’ with intersecting walls are stronger than wide interior spaces with long spans.

Materials

- Wood is lightweight and therefore the seismic forces are lesser than would be generated by a heavy masonry or concrete building.
- Wood buildings can be very strong, as is evidenced by the photograph on right after the 9.0 Richter scale Alaska earthquake in 1964

Materials

- Plywood shear walls are economical and strong, and the lighter weight of wood makes it a common choicer for lower-rise buildings.
- Construction in wood is an attractive option in a high seismic area.

Materials

- Steel is very strong and malleable, meaning that it will bend, not break.
- Low-rise steel buildings which fail tend to deflect and bend, but not fail catastrophically.
- X-bracing is a common technique for providing lateral resistance in steel buildings.

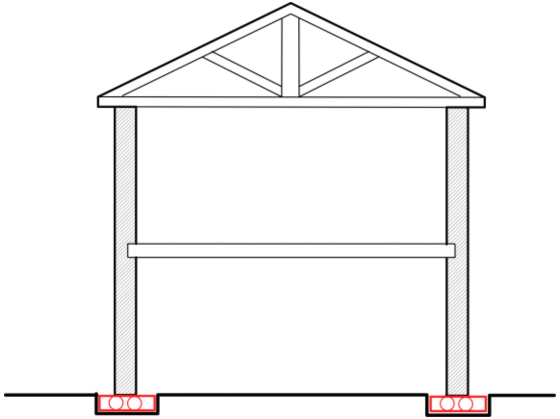
Materials

- Concrete is very heavy, but the steel reinforcement can make extremely strong shear walls.
- Note that the concrete shear walls are oriented in both directions.

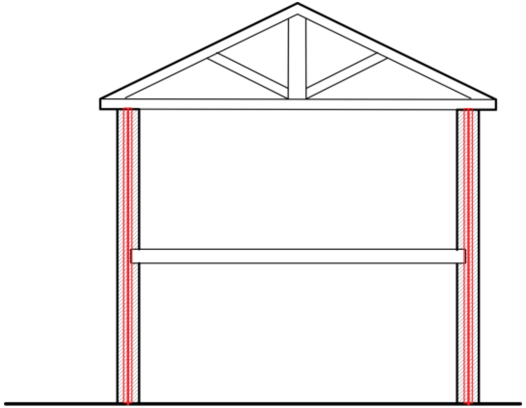
Materials

- Unreinforced masonry (URM) is comparatively weak in shear.
- Even for low-rise structures, URM buildings can be vulnerable during seismic events.

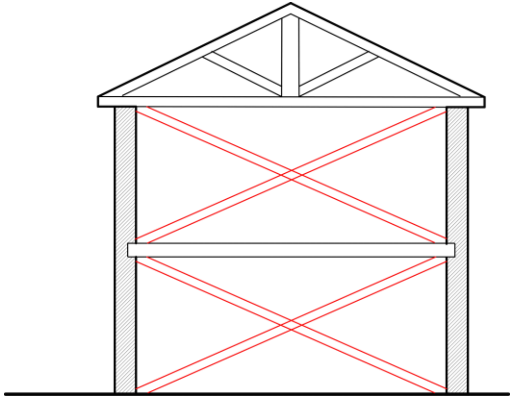
URM Buildings—Typical Seismic Upgrade Strategies



- Base Isolation



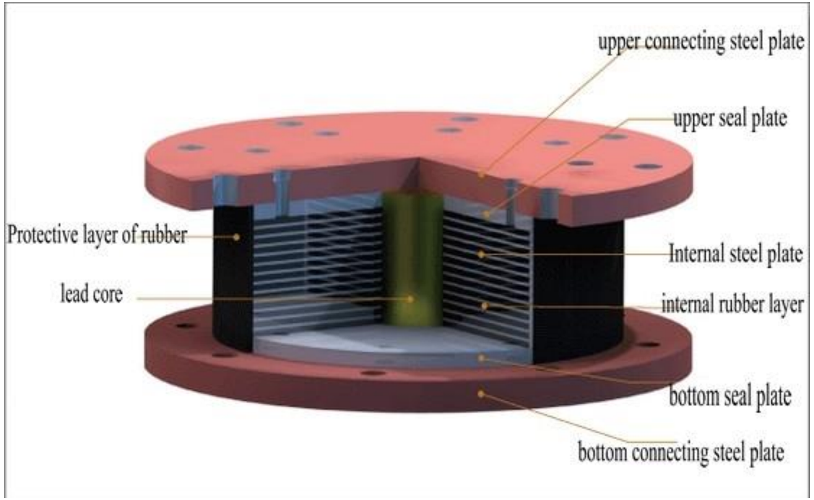
Coring



Shear Walls/X Braces

These upgrades typically are expensive and intrusive to building operations.

Base Isolation



- Effective, but expensive.

Coring

- Walls are cored and then reinforcement grouted in the hole.
- Cores are typically about 4’ on center, requiring many cores and great expense.
- Sometimes water coring is required which destroys interior finishes.

COLLECTIONS PRESERVATION

Shear Walls/X Braces

- Shear walls or X braces can be added to provide additional stiffness to the structure.
- Concrete shear walls are often added adjacent to unreinforced masonry walls.
- When shear walls are needed in open spaces, X braces are preferred.

URM Storefronts

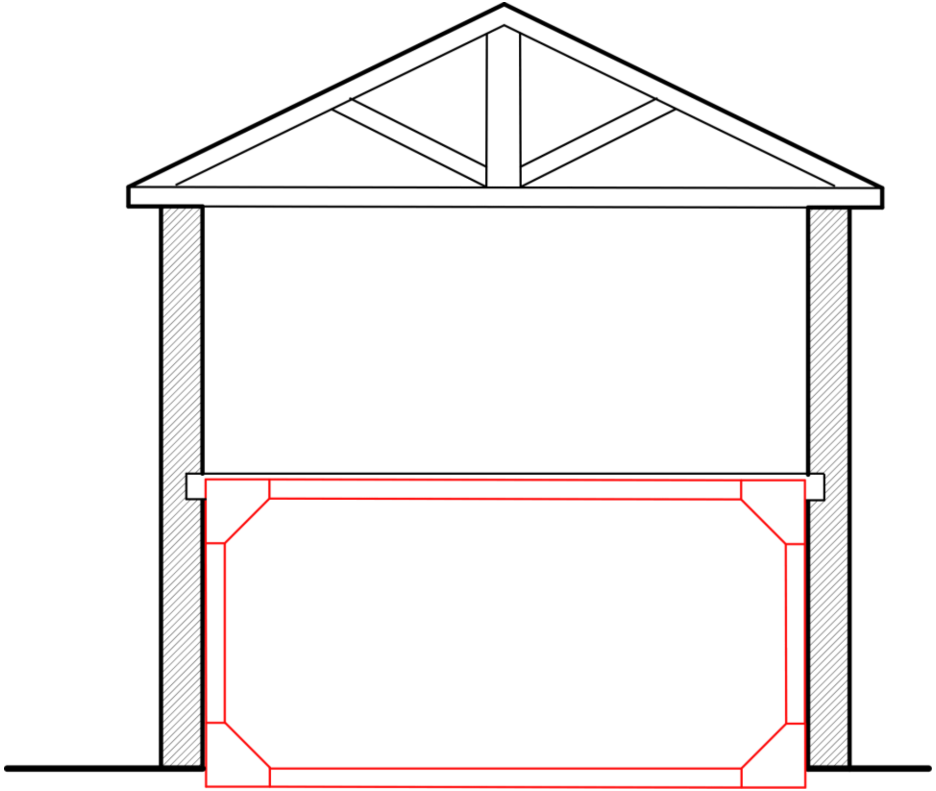
- Typical late 19th/early 20th century URM buildings have large storefront windows completely filling end walls on the ground level.
- Glass cannot act like a shear wall as it is too thin and brittle.

URM Storefronts

- While a solid brick wall makes a shear wall with some capacity, a storefront window which extends from side wall to side wall has little to no resistance to sideways forces.

URM Storefronts

- A solid shear wall or X braces would block the entrance and storefront.
- A steel frame with rigid connections at the corners can take the place of a solid shear wall.



URM Buildings

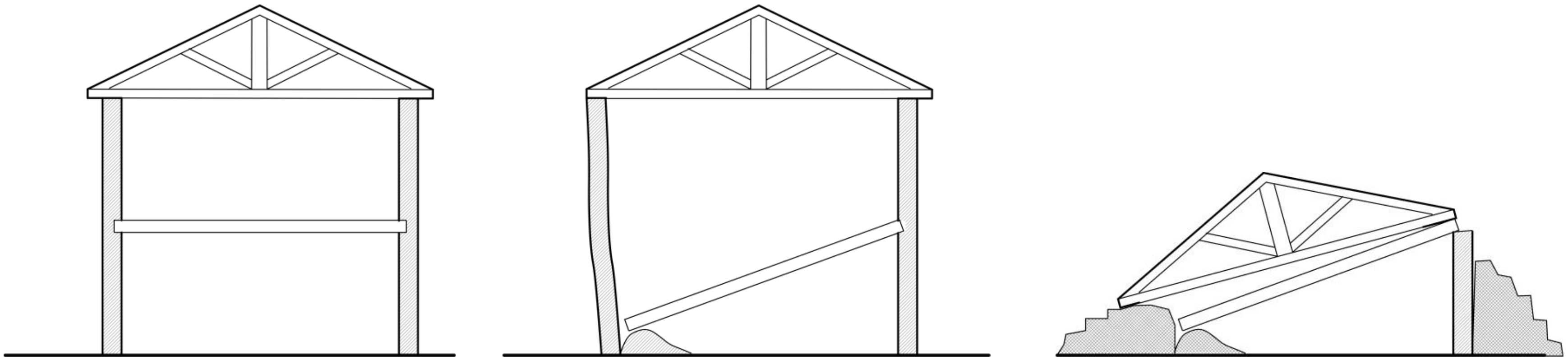
- Worst case scenario is when floor joists slide off of the supporting walls and collapse into the floors below.

Figure 1

Most photographed commercial URM building in town, the Continental Baking Company, Long Beach, California 1933 – complete collapse

(Historical Society of Long Beach, PO Box 1869, Long Beach, CA 90801 (562) 424-2220)

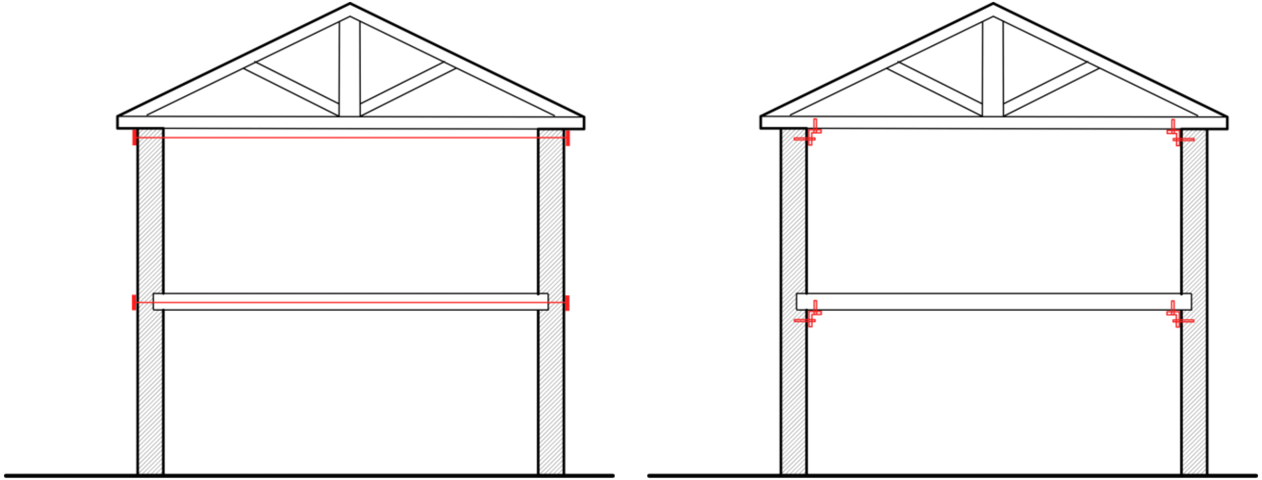
URM Buildings



- Pre-WWII construction typically does not fasten the wood joists or roof to the walls
- Typically bearing width is 4”. If the walls move more than 4” the wood joists can slide out of the masonry pocket and fall.
- Loss of life is likely in such a scenario.
- Once joists have dropped and walls are unbraced, continued shaking will quickly lead to total collapse.

Tie Rods

- Tie rods or positive connections can keep joists from sliding out of pockets in masonry walls.
- Tie rods do not make the structure ‘stronger.’ They only increase the likelihood that joists do not pull out of pockets and lead to catastrophic collapse.



- Cost may be more modest for this type of upgrade.

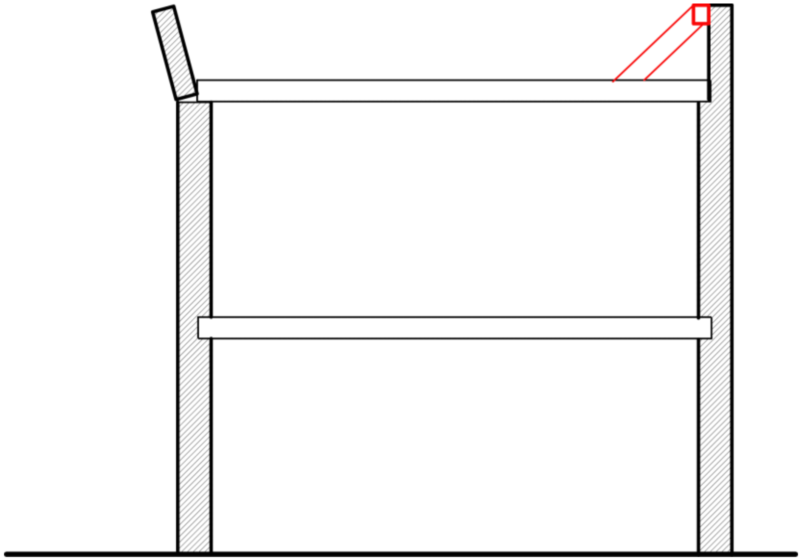
Tie Rods

- Tie rods ‘tie’ the walls together.
- Tie rods extend from wall to wall (usually running through the floor structure so they are not seen).
- During a seismic event the tie rods keep the joists from sliding out of their joist pockets.

COLLECTIONS PRESERVATION

URM parapets and gables

- Masonry walls can ‘fall out’ of the building, especially in gables and parapets that are higher above the ground.
- Lateral forces are greater the higher above the ground (think of the game, ‘Crack the Whip’).
- Parapets often can be braced without disturbing interiors.



URM parapets and gables

- While the roof likely had sufficient resistance to restrain the brick gable (at least for the 5.6 Magna Earthquake), typically there is only a friction connection at such locations.

What to do?

- 1. Determine the seismic risk of your facility.
- 2. Determine what kind of building you have. Is it wood frame, steel frame, reinforced concrete, or unreinforced masonry (either brick or adobe)?
- 3. Determine the approximate year the building was constructed (this can give you an idea of the construction type. For example, most post 1960 masonry buildings are reinforced.)
- 4. Consult with your museum board and determine the best course of action for your facility. Discuss your risk, material type, construction type, and value of the collection.
- 5. If appropriate, engage a structural engineer to review the facility.

Nota bene

- An engineer cannot guarantee that a building is ‘safe.’
- What an engineer does is design repairs that will make your building compliant with a particular code.
- That code may change over time, for with each big earthquake where sensors are present, we learn far more about accelerations, frequencies, and subsurface structures.
- Be informed and make positive decisions. Don’t just wait.

Questions?

Dr. Elwin C. Robison

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This project was made possible in part by the National Endowment for the Humanities.

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BREAK (5 Minutes)

Seismic Prepardness

COLLECTIONS PRESERVATION

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Jennifer Hadley

Masters in Historic Textiles

Objects Conservator at The Church Hisotry Department for 17 years

Part of a team of 7 Caring for Museum/Archives Collections, 24 Historic Sites/Homes across the United States and England and 26 Regional Preservation Centers around the world

How Earthquakes Move Objects

Sliding

Rocking

Overturning

Vertical Accelerations can cause objects to weigh 1.2 times their normal weight.

Motion Transference: The motion of the earthquake will transfer to the object.

COLLECTIONS PRESERVATION

Principles of Support

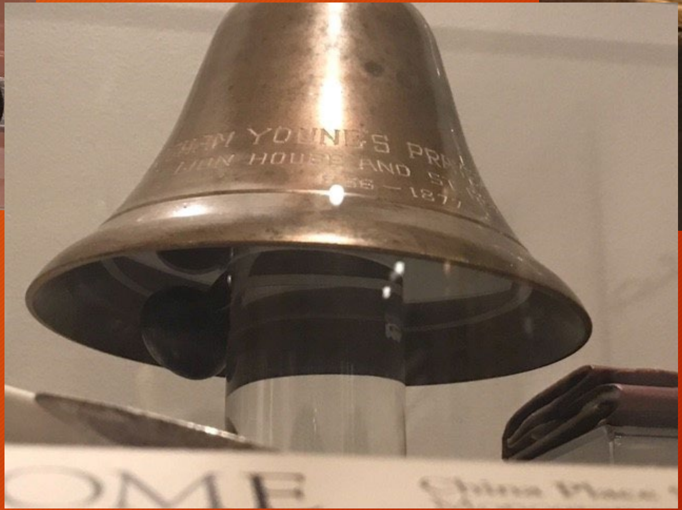
1. Support Every Part that Needs Support
   - Consider weak areas, previous breaks, pressure points, etc.
2. Don't Put Any Undue Pressure on Any Part
   - Remember previous considerations
   - Consider Motion Transference and vertical accelerations
3. Keep It Reversible
   - Permanently altering an object can cause more problems in the future.

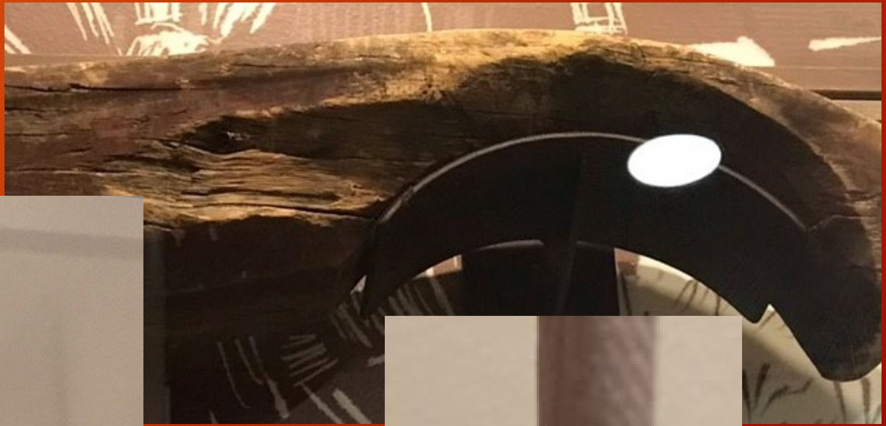
Weights and Straps

Shelf Straps

Stops/Clips

Contours





Adhesives- Worth the risk?


Damage to table and artifact

Museum Wax and Lascoux Dots

Anchors and Base Isolation

BREAK (5 Minutes)

COLLECTIONS PRESERVATION

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