Seismic Vulnerability And Building Performance For Structures And MEP Equipment

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for IEEE San Francisco IEEE / IAS San Francisco

Friday, March 26, Marriott Pleasanton

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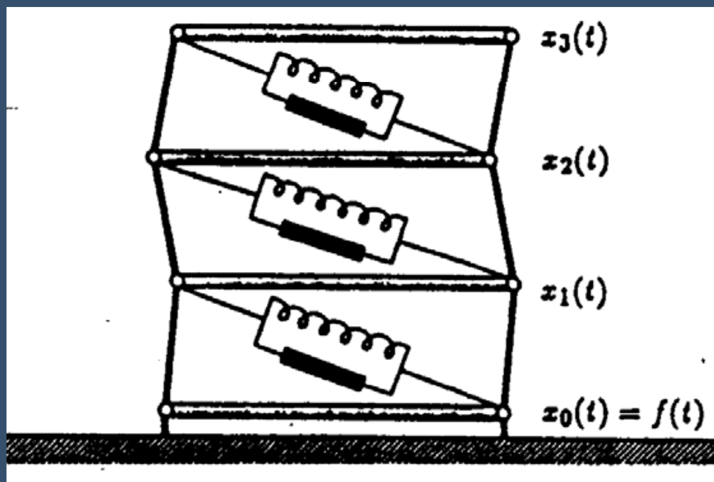
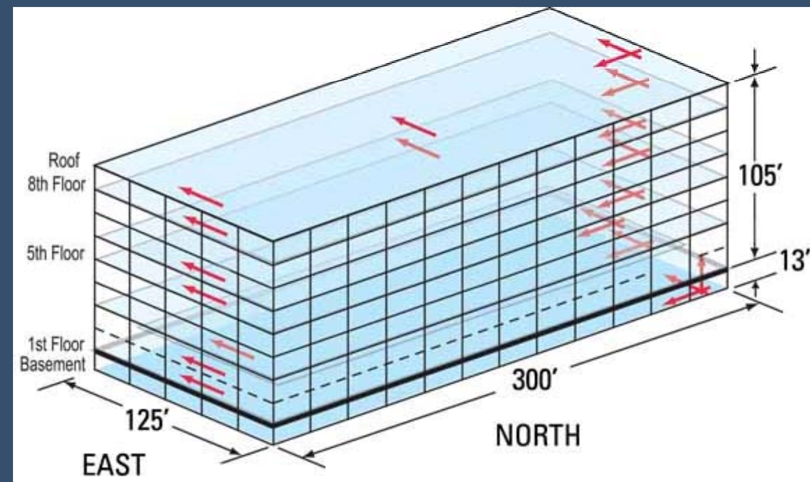
Learning Objectives





- Gain a more thorough understanding of how buildings perform during earthquakes
- Evaluate new technologies in structural enhancement & retrofitting
- Examine methods of protecting MEP equipment and surrounding infrastructure

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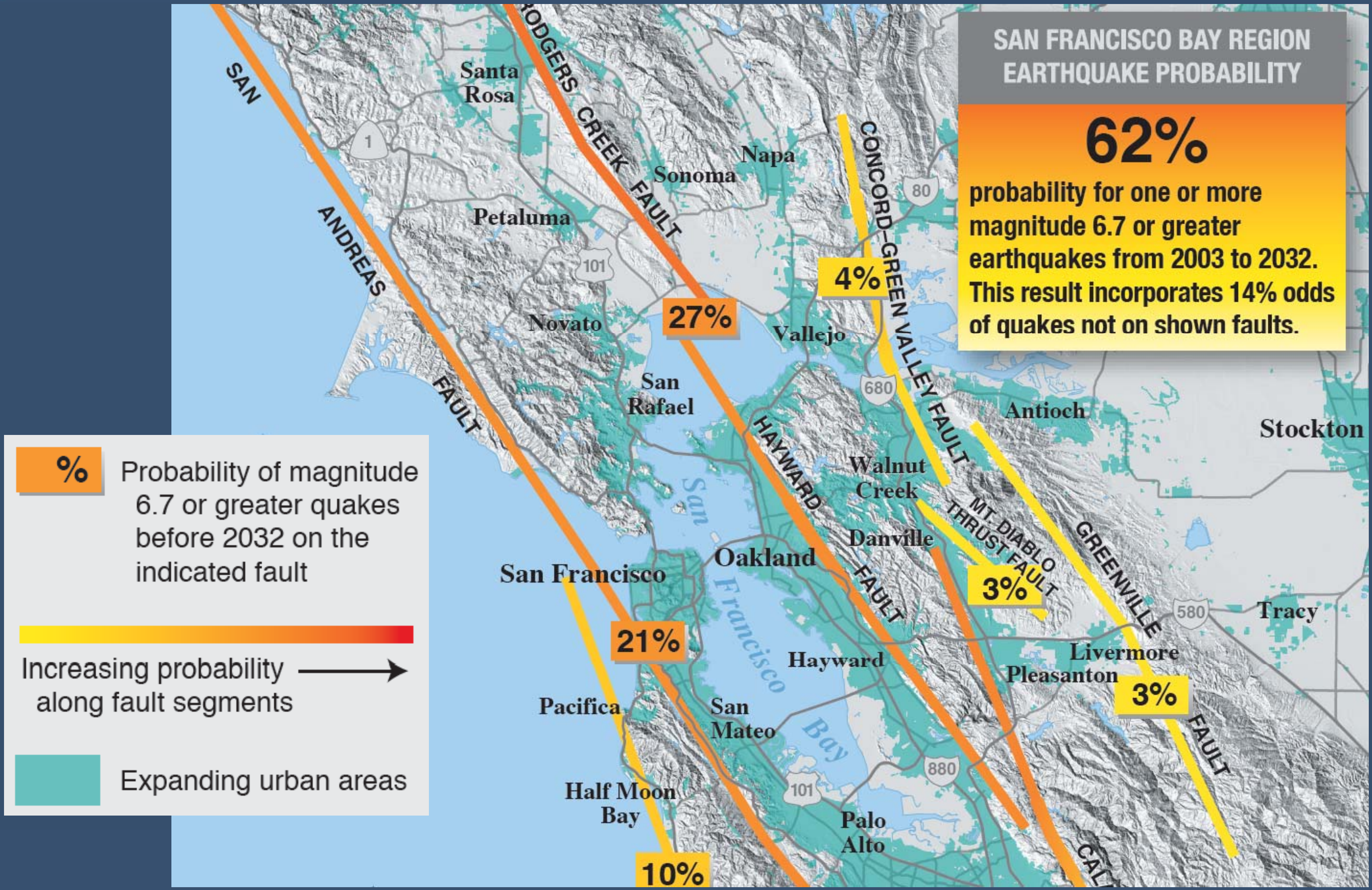
Evaluating Seismic Risk



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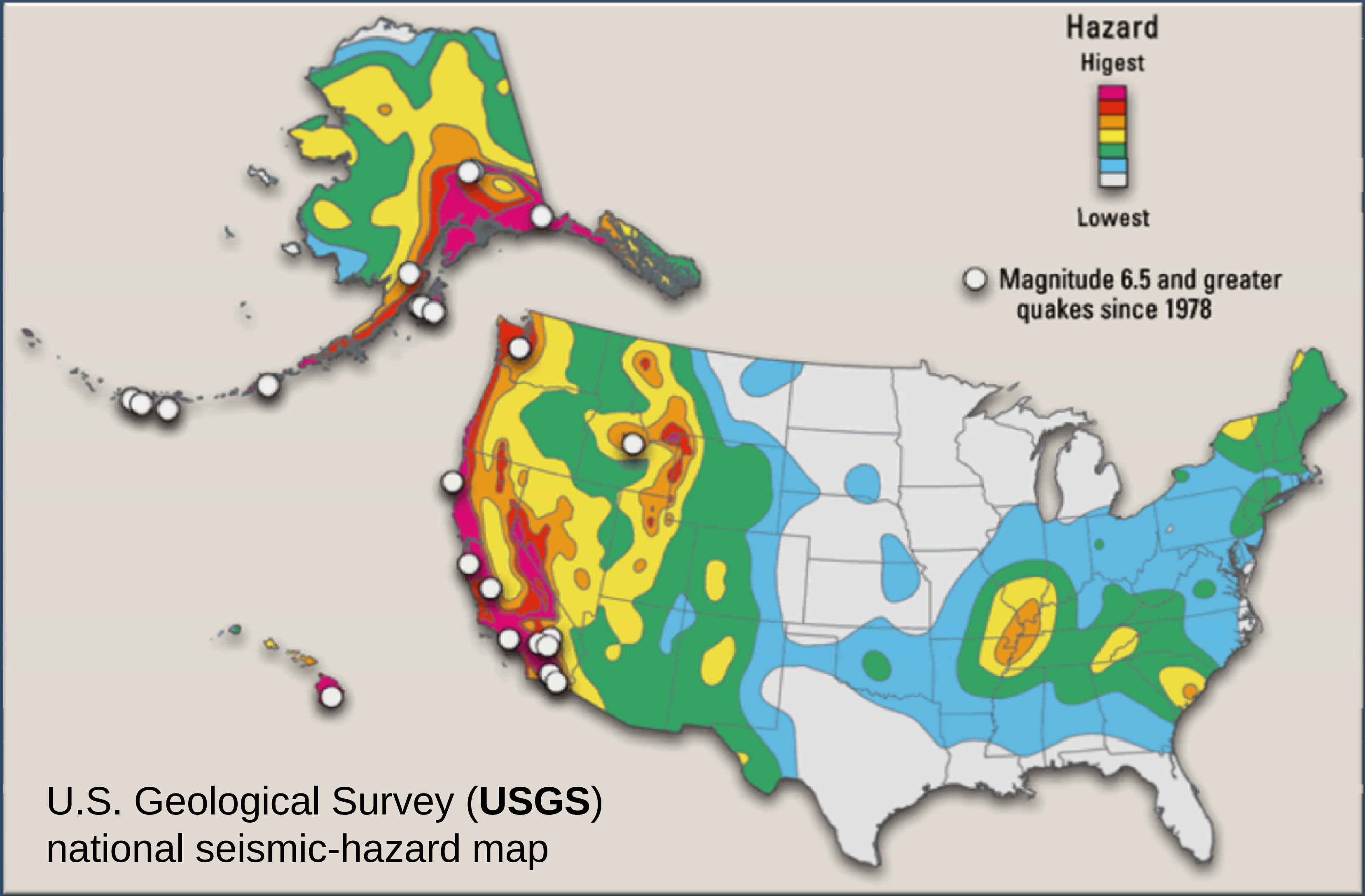
Evaluating Seismic Risk

MODIFIED MERCALLI SCALE		RICHTER SCALE	
I.	Felt by almost no one.	2.5	Generally not felt, but recorded on seismometers.
II.	Felt by very few people.		
III.	Tremor noticed by many, but they often do not realize it is an earthquake.	3.5	Felt by many people.
IV.	Felt indoors by many. Feels like a truck has struck the building.		
V.	Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.		
VI.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs.	4.5	Some local damage may occur.
VII.	Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.		
VIII.	Specially designed structures damaged slightly, others collapse.	6.0	A destructive earthquake.
IX.	All buildings considerably damaged, many shift off foundations, Noticeable cracks in ground.		
X.	Many structures destroyed. Ground is badly cracked.	7.0	A major earthquake.
XI.	Almost all structures fall. Very wide cracks in ground.	8.0 and up	Great earthquakes.
XII.	Total destruction. Waves seen on ground surfaces, objects are tumbled and tossed.		

Evaluating Seismic Risk – National



U.S. Geological Survey (**USGS**)
national seismic-hazard map

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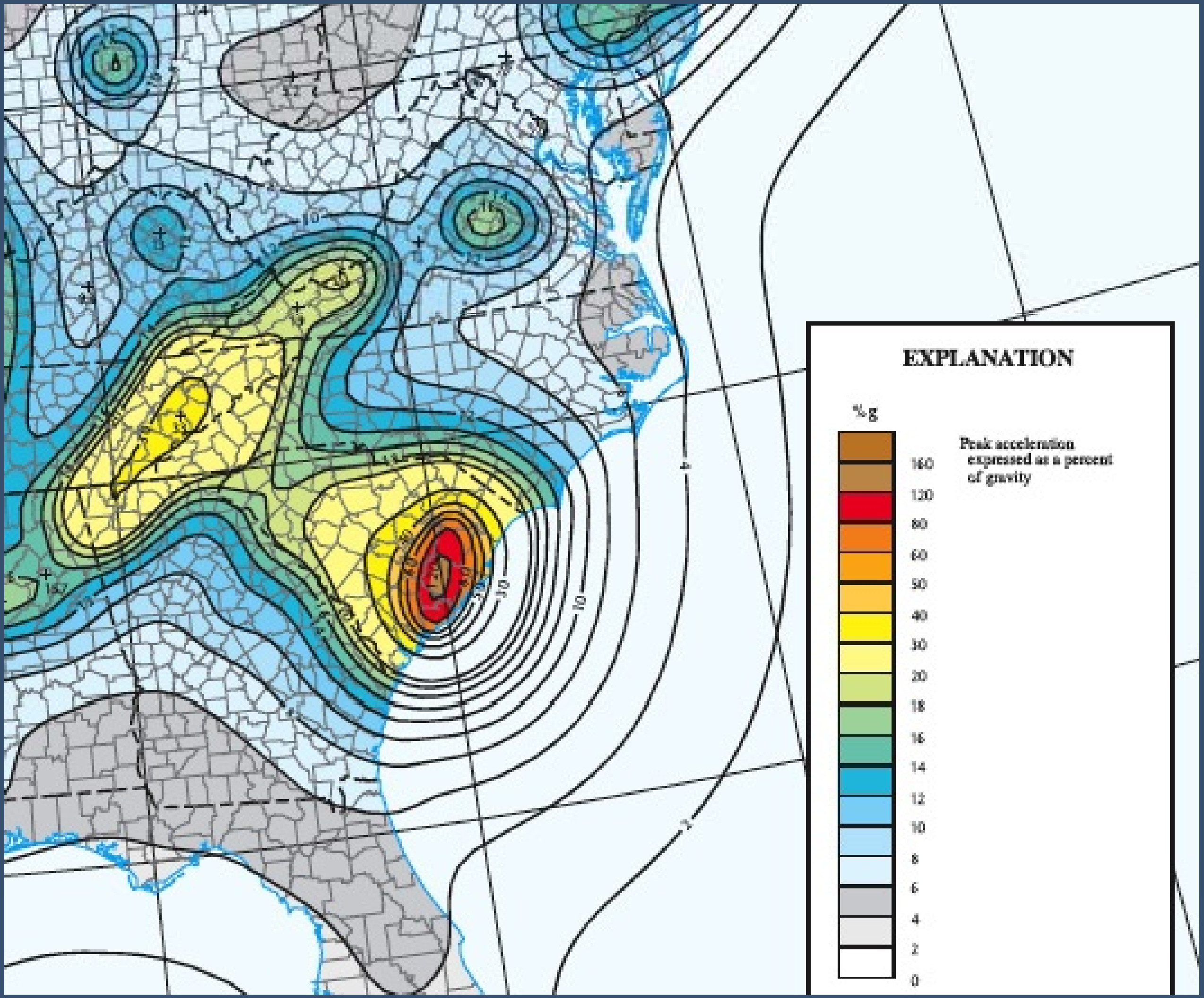
Evaluating Seismic Risk



Southeastern US

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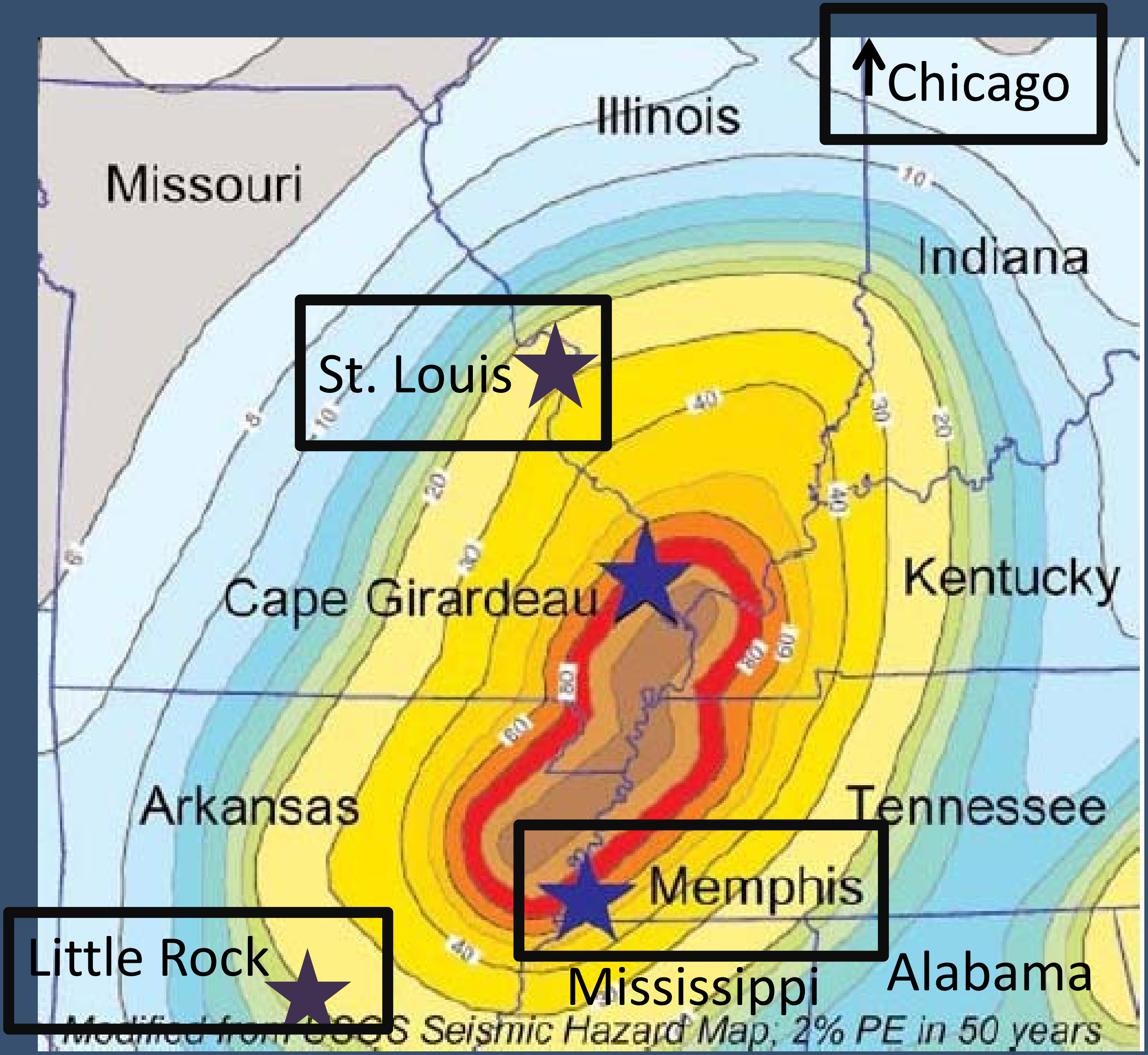
Evaluating Seismic Risk



New Madrid Zone

Evaluating Seismic Risk

New Madrid Zone

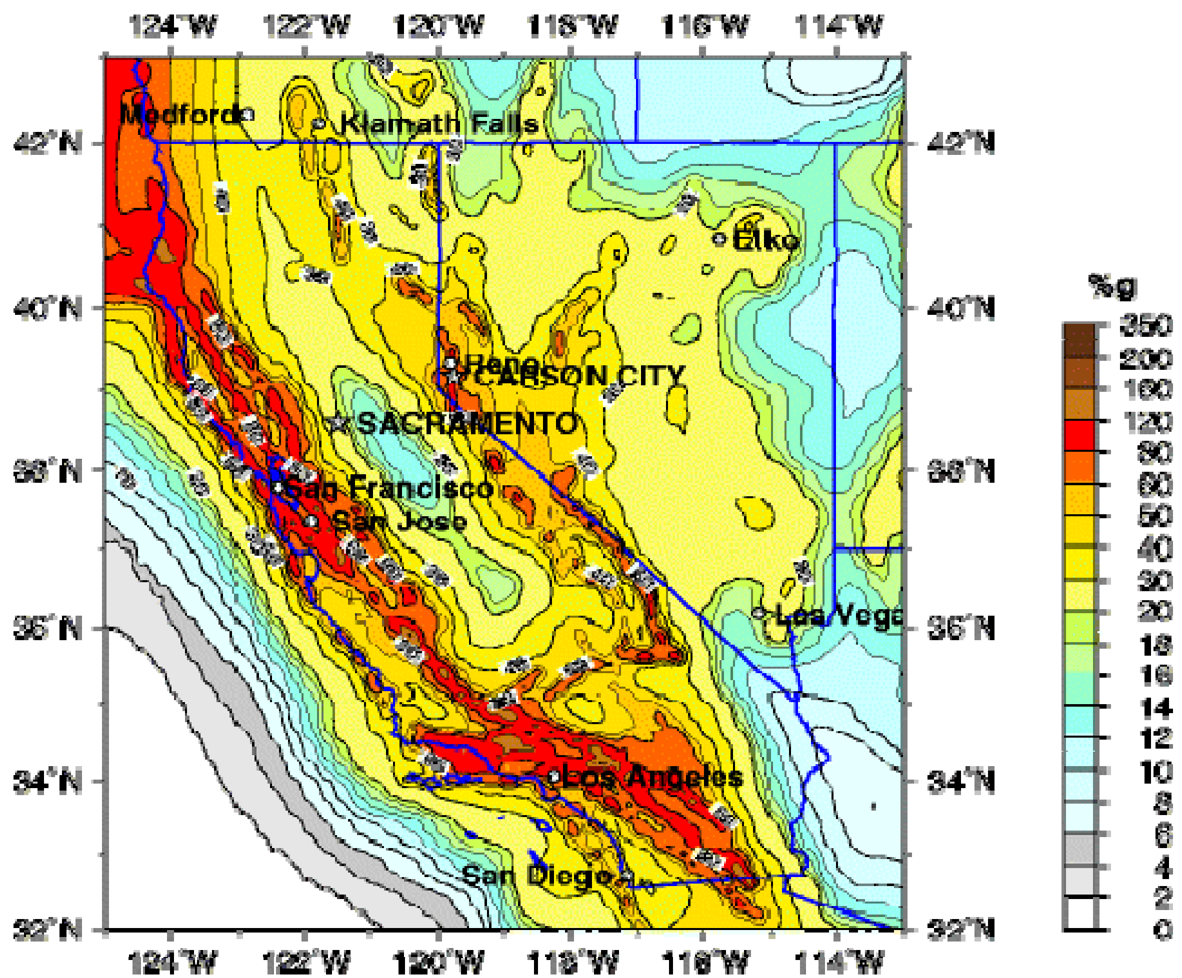
+ New Madrid quakes often cited as strongest series of quakes ever known

+ 1811 quake "felt area" is assumed to be 2 million square miles (half the US)

+ Combination of hard bedrock below and loose materials at surface makes potential for damage relatively high and widespread

+ Cities: Memphis, St. Louis, Cape Girardeau

Evaluating Seismic Risk



Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
National Seismic Hazard Mapping Project (2008)

[Western US]

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How Buildings Perform During an Earthquake

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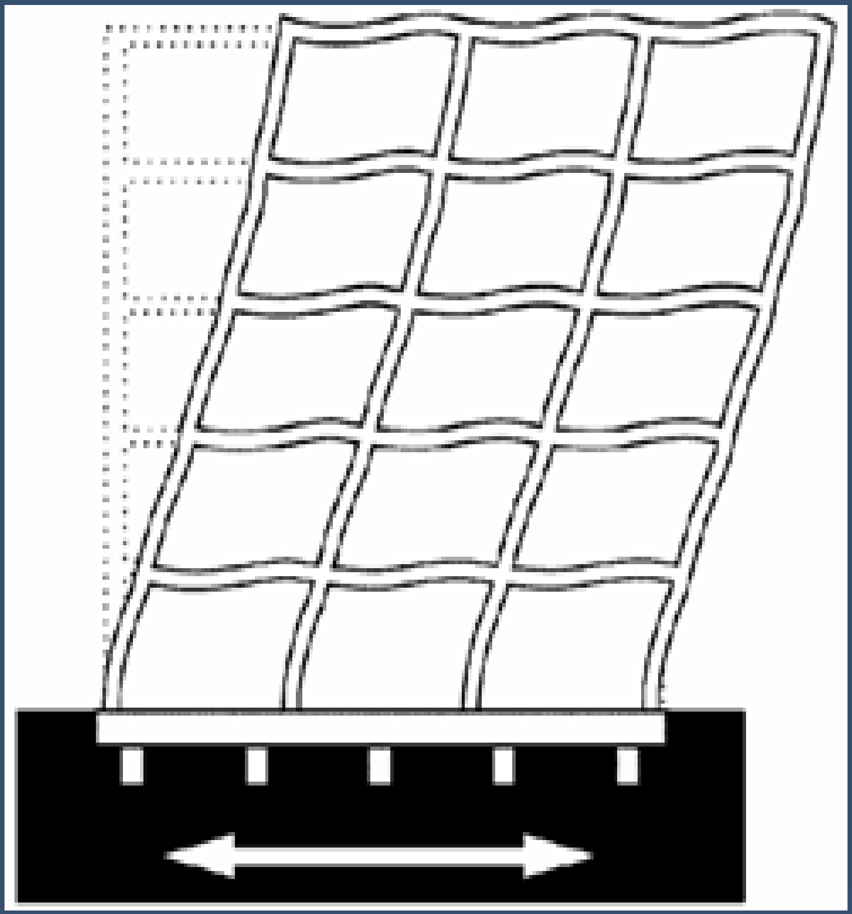
How Buildings Perform During an Earthquake



Note: Buildings do not Initially move – the ground moves and the buildings respond to the ground motion.

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How a Building's Shell Performs During an Earthquake

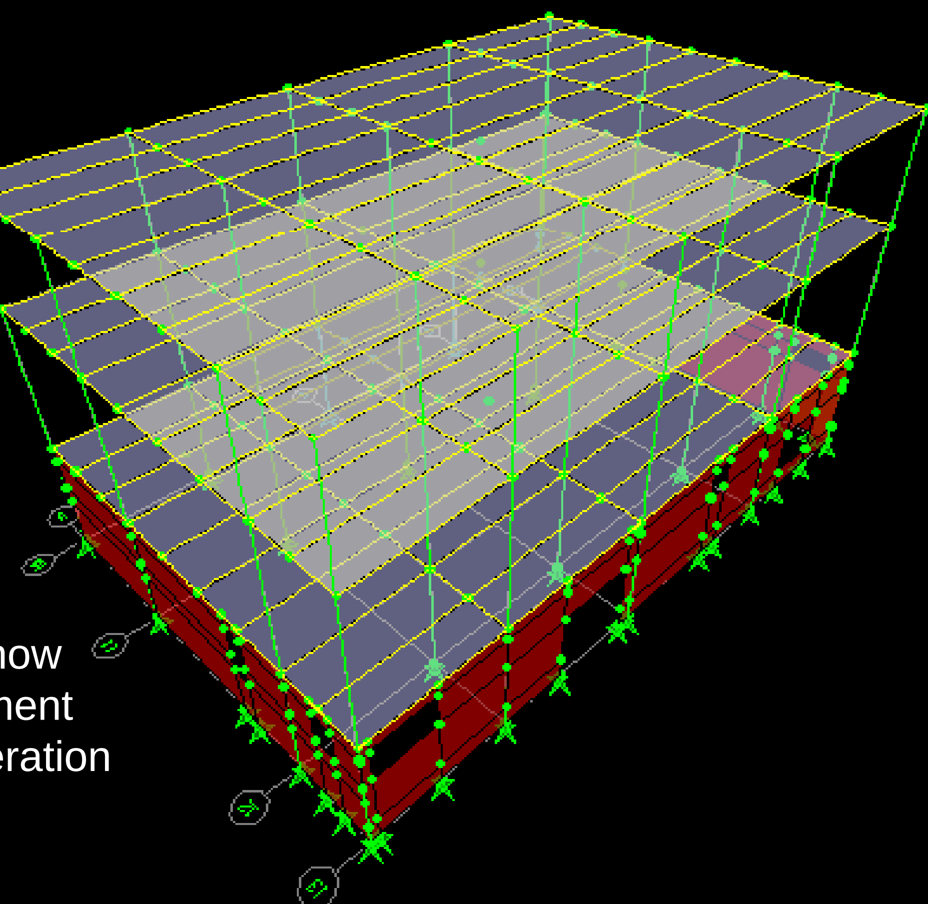

Illustration of how ground movement imparts acceleration and building displacement

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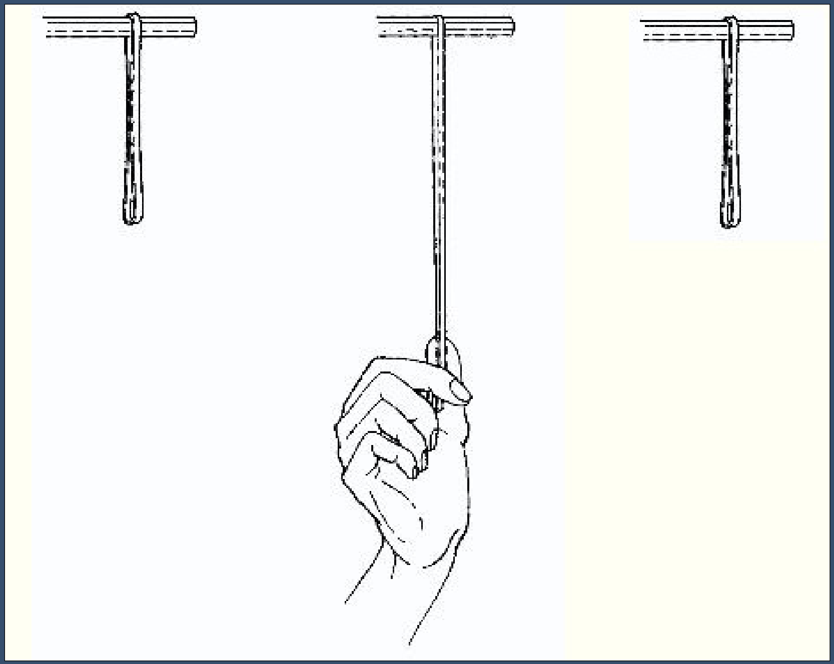
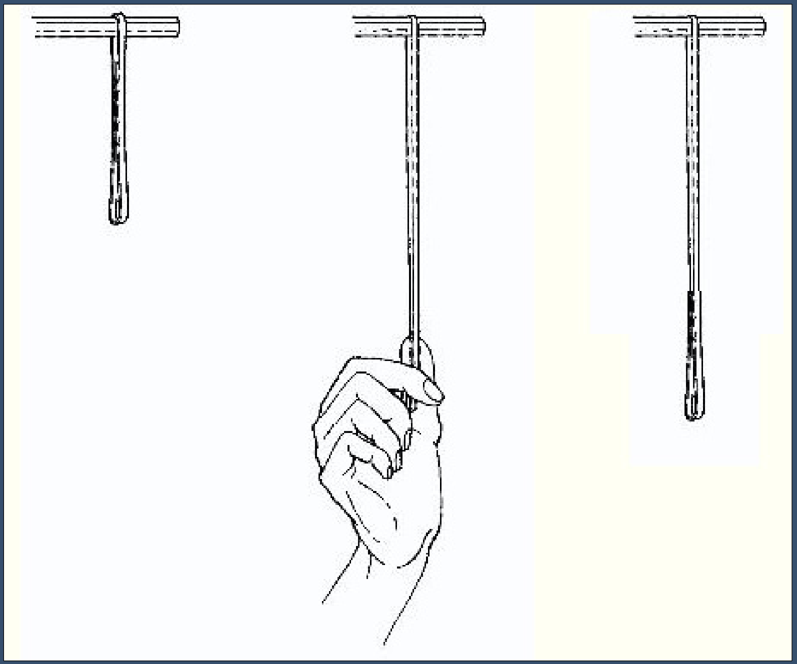
How Buildings Perform During an Earthquake



Elastic



Inelastic

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How Buildings Perform During an Earthquake (Inelastic Range)

Seattle, WA suffered over 1B damage after the 2001 M6.8 quake

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Brief Look at Code Changes

Rating systems in North America are maturing and experiencing a paradigm shift in the way they approach sustainable design:

- + AWAY from prescriptive methodologies
- + TOWARDS one that emphasizes quantifiable performance

NEW Performance- based codes provide clearer guidance than the OLD prescriptive codes taking into consideration the actual growing complexity of the architectural designs

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The “Old” Prescriptive Code

- Acknowledged a design-base earthquake would occur

- Lower R – value = less able to dissipate energy

- Everyone had to trust how the R factor was assigned and design for elastic displacement while acknowledging that a real earthquake would probably be **3 times the severity** as the code prescribed = inelastic behavior anticipated and counted upon to dissipate “energy”

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Code Changes

Catalysts For Change

- 1989 Loma Prieta & 1994 Northridge earthquakes
- exhibited damage to buildings and contents that, although achieving "life safety," exhibited unacceptable levels of non-structural and content damage resulting in lost production and down time.
- Emerging building modeling and technologies
- New materials
- Inflexible standards inhibited innovative solutions
- Engineers sought a better way to depict true building behavior

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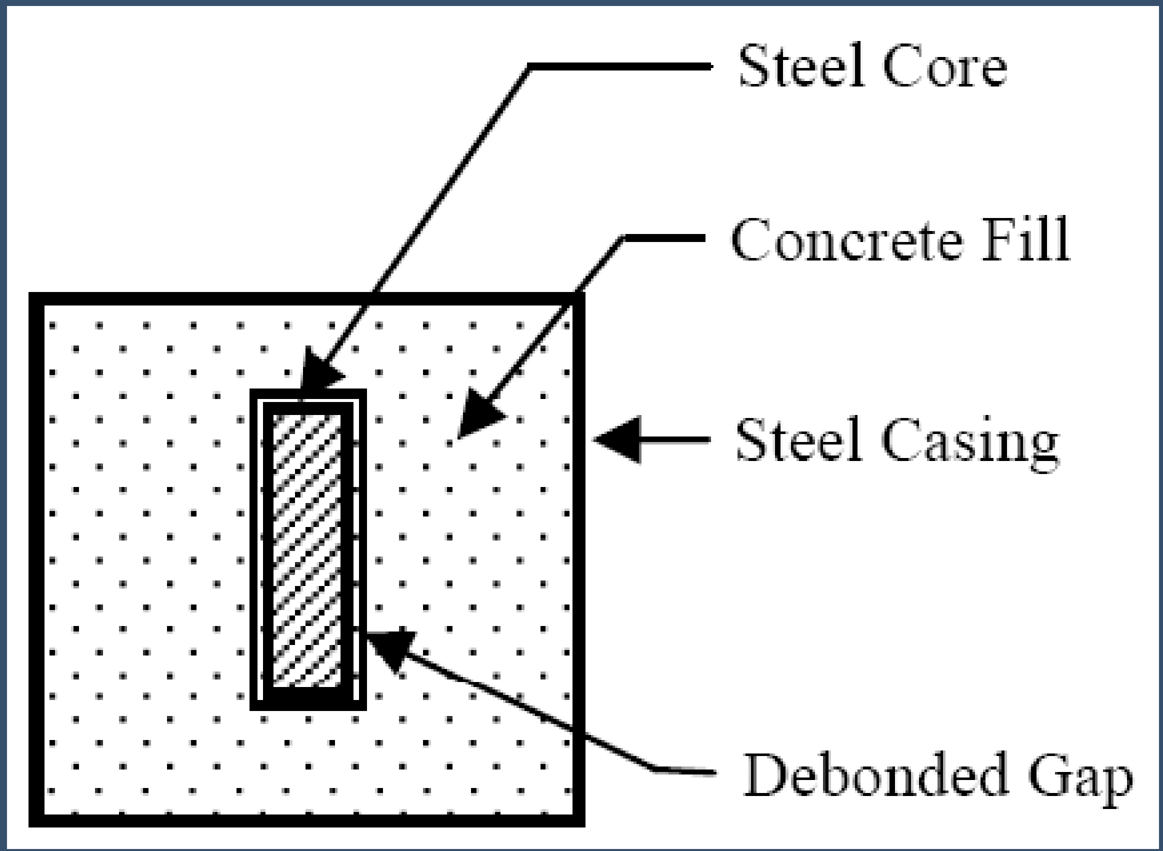
Retrofitting Technologies

There are effectively 6 Lateral Force Resisting Systems generally used in building construction:

1. **Concrete Shearwalls**
2. **Special Concentric Braced Frames**
3. **Moment Frames**
4. **Buckling Restrained Braced Frames**
5. **Fluid Viscous Dampers**
6. **Base Isolation**

Retrofitting Technology: BRFB's



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Retrofitting Technology: BRFB's

UC Berkeley Stanley Hall Replacement Project (2003)

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Retrofitting Technology: Fluid Viscous Dampers

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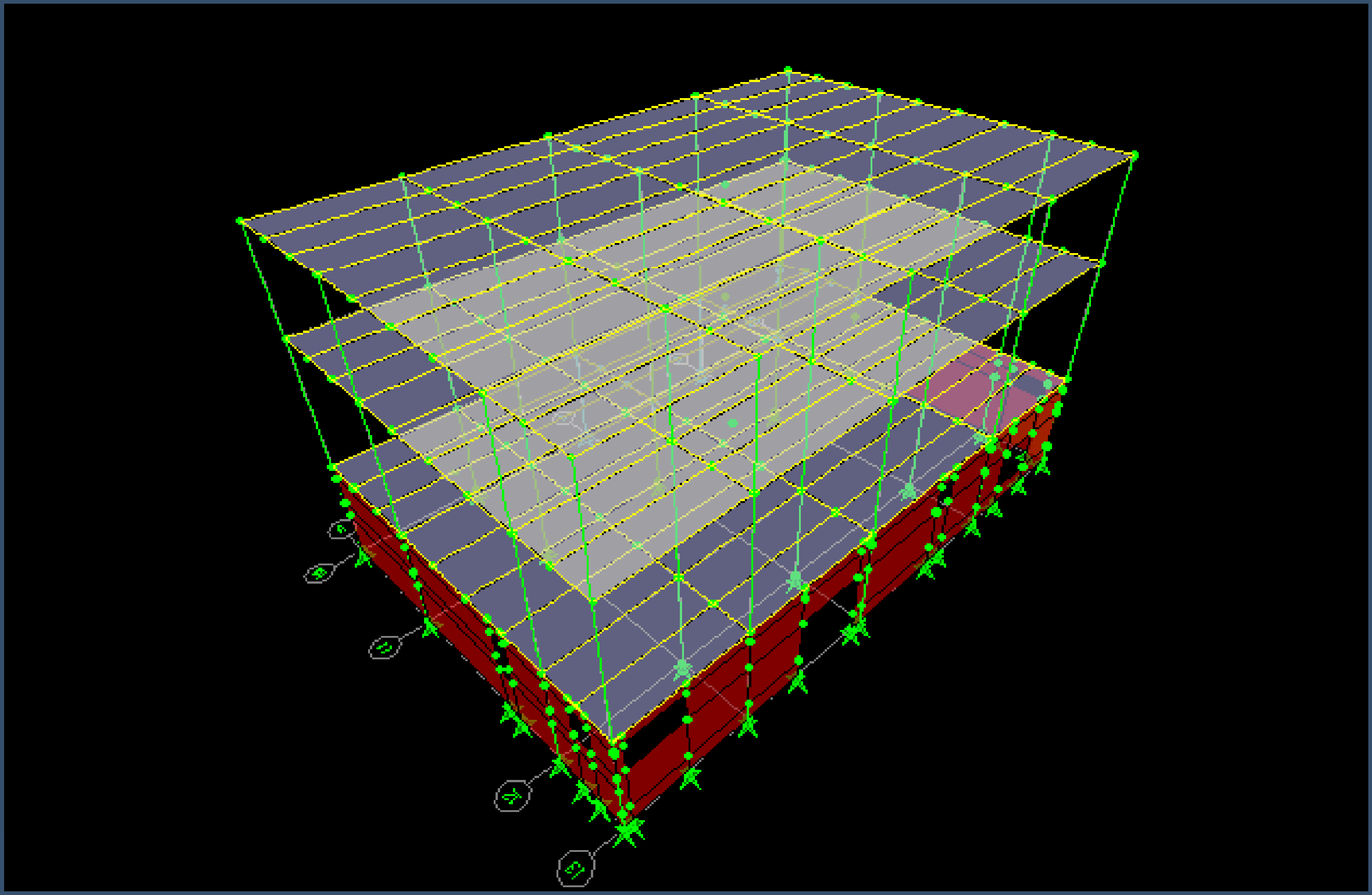
Model Without Fluid Viscous Dampers



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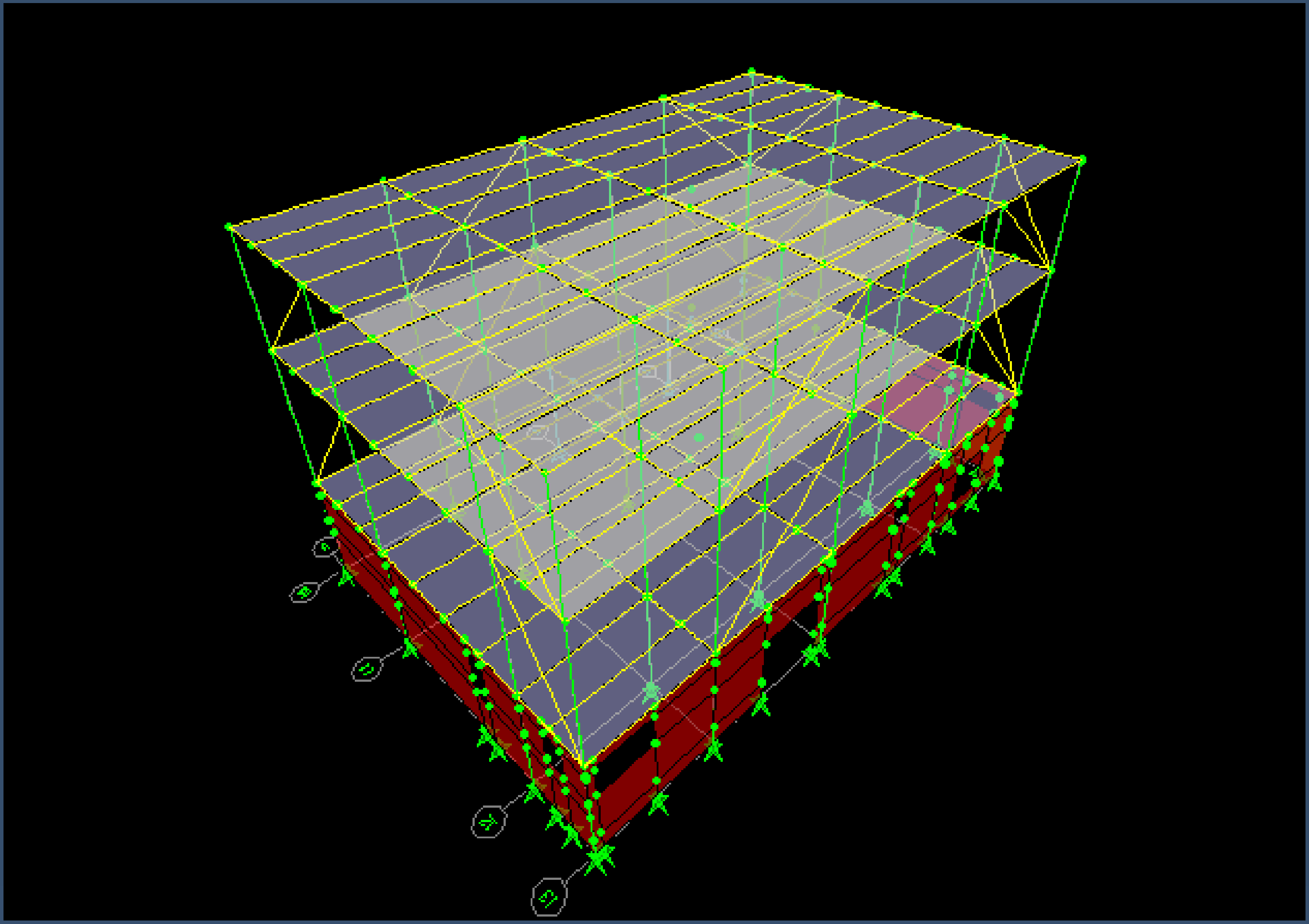
Model With Fluid Viscous Dampers



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Retrofitting Technology: Base Isolation

Oldest known Base Isolated structure/ building

Mausoleum of Cyrus in Pasargadae
(a city in ancient Persia – now Iran)
Dates back to VI century BC

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Retrofitting Technology: Base Isolation

model on right is base isolated

Source: Cal State University at Northridge

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Retrofitting Technology: Base Isolation

- Building moves independently from ground motion
- Most advanced + successful system to limit building damage during a seismic event
- Optimizes the structure's response to seismic events
- Allows for continuous operation

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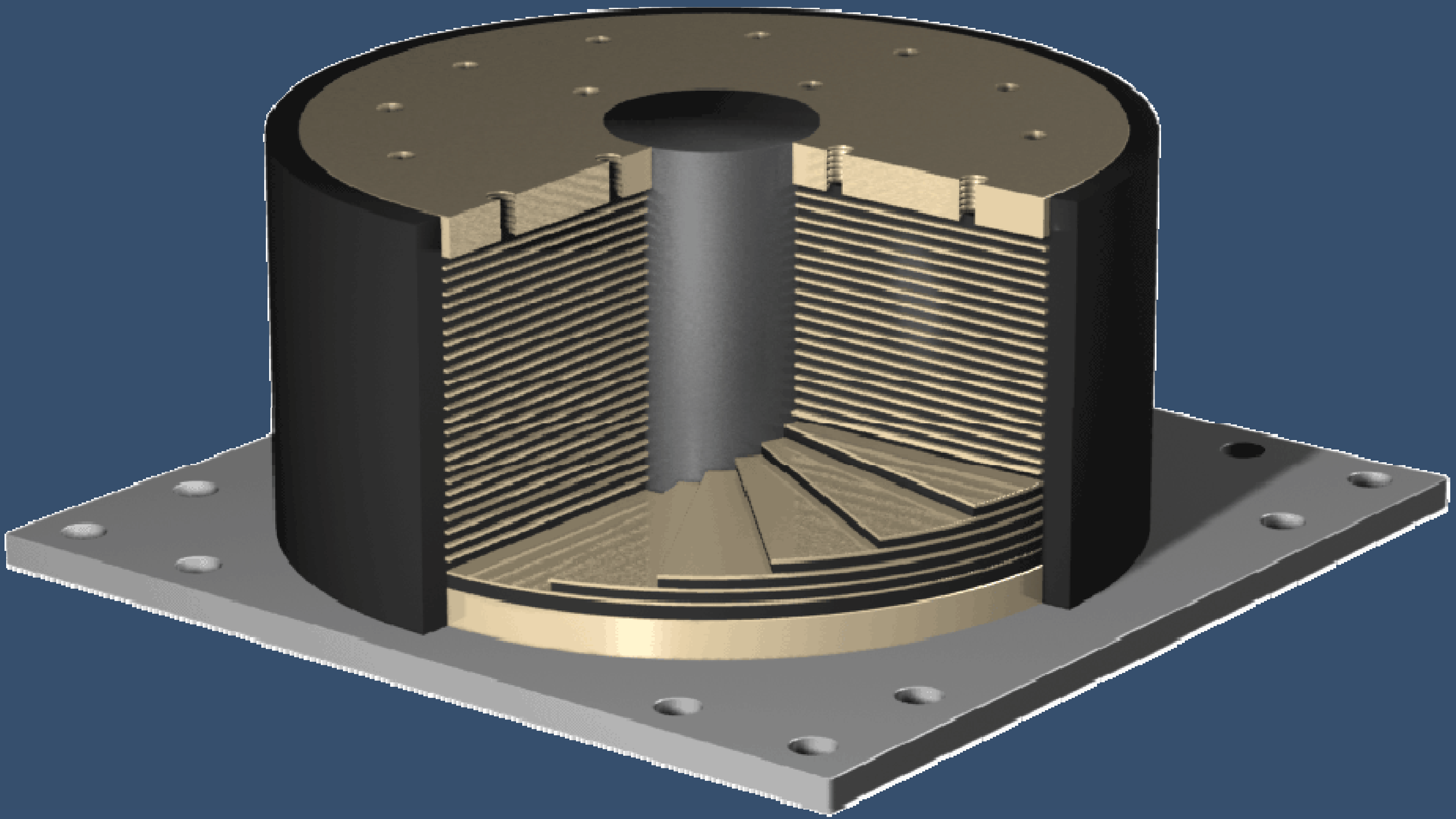
Retrofitting Technology: Base Isolator



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Retrofitting Technology: Base Isolation

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Retrofitting Technology: Base Isolation

Base Isolation also protects non-structural elements + equipment by reducing the entire structure's acceleration during an earthquake, as opposed to reinforcement alone.

365 Main Data Center (2002) San Francisco, CA

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Retrofitting Technology: Base Isolation

isolators

The Tan Tzu Medical center in Taiwan is currently under construction and at 1.7 million square feet is the largest isolated structure in the world. Base Isolation was chosen so that the hospital would be operational immediately after an earthquake.

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Retrofitting Technology: Base Isolation (Friction Pendulum)

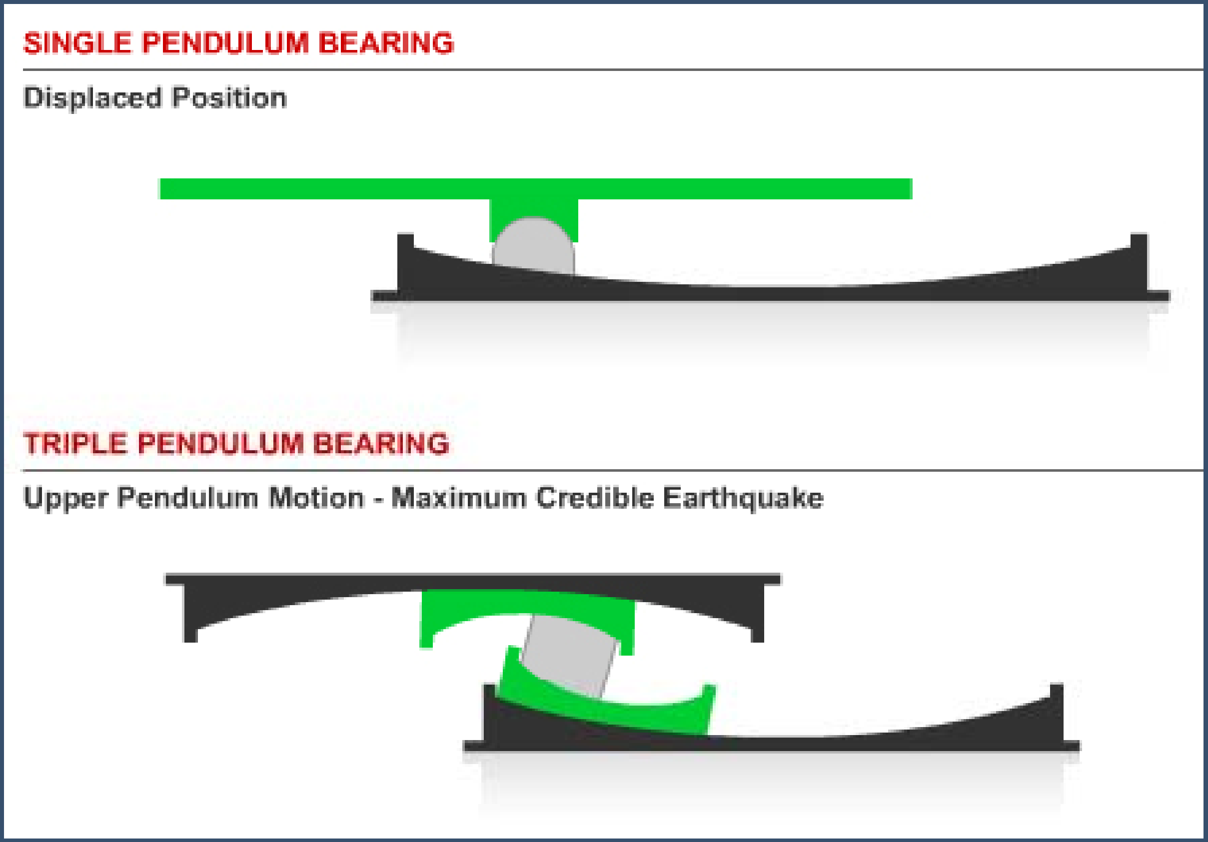
Triple Pendulum ™ Bearing

Incorporates three pendulums in one bearing,
each with properties selected to optimize the structure's response for different earthquake strengths and frequencies.

Single Pendulum Bearing

The original Friction Pendulum™ bearing. Consists of a single slider moving on a concave surface.

Retrofitting Technology: Base Isolation (Friction Pendulum)



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Retrofitting Technology: Base Isolation (Friction Pendulum)

Mills-Peninsula Health Services Hospital in San Mateo, CA

The ± 450,000 square foot Sutter Health medical facility uses Triple Pendulum™ seismic isolation to withstand a magnitude 8 earthquake.

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Mission Critical Operations

PERFORMANCE OBJECTIVE LEVELS

- **LIFE SAFETY**
  - **production stoppage**
  - **product loss**
- **REDUCED DAMAGE**
  - **lost capital**
  - **weakened ability to create new product**
- **IMMEDIATE OCCUPANCY**
  - **lost stock**
  - **lose market position**

← Retail/ Commercial

← General Production Facilities

← Mission Critical/ Essential Services

Mission Critical Operations

- Utilities
- Critical Public Infrastructure
- Hospitals
- Laboratories
- Production Facilities
- Life Science Facilities
- Data Centers
- other 24 hr operations

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Mission Critical Operations

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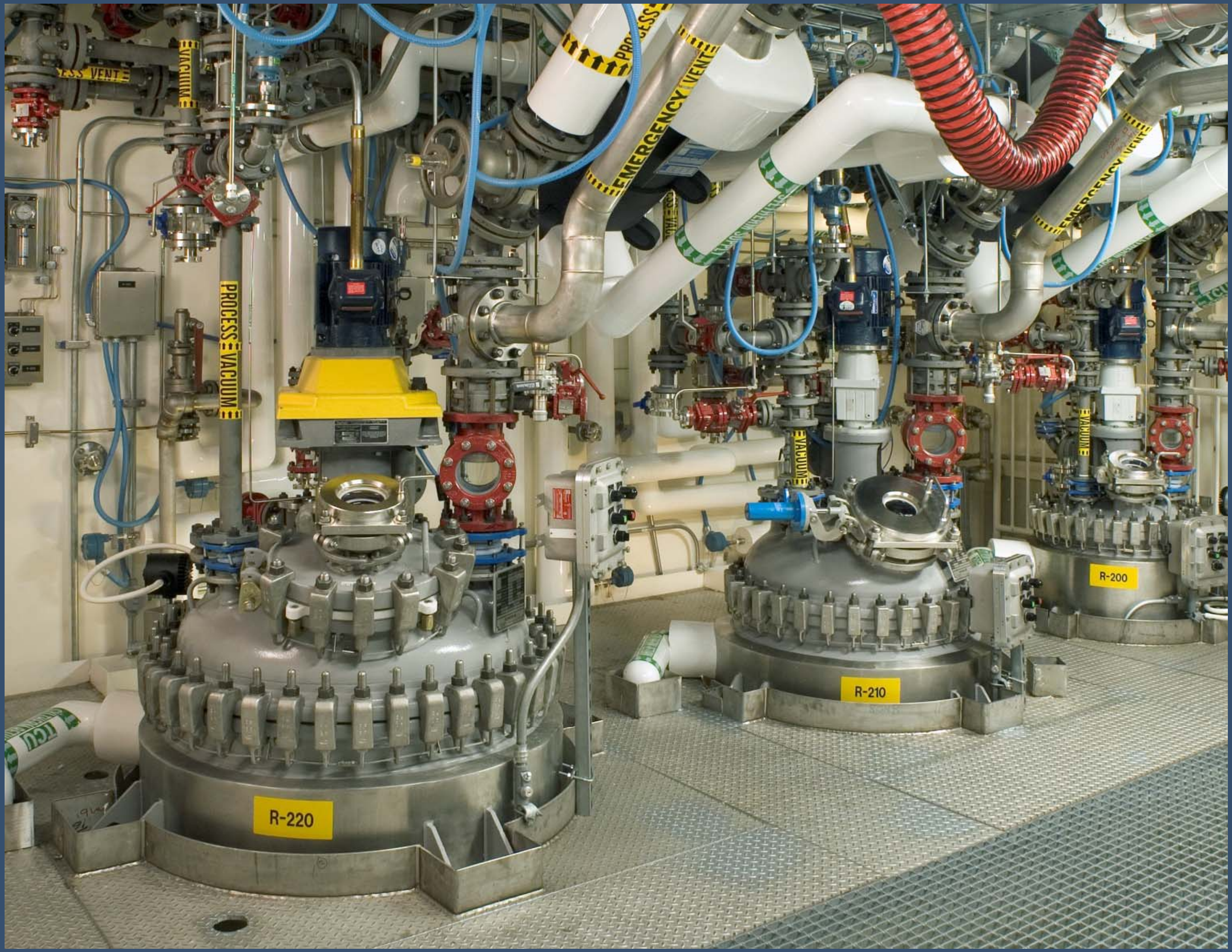
Mission Critical Operations



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Mission Critical Operations

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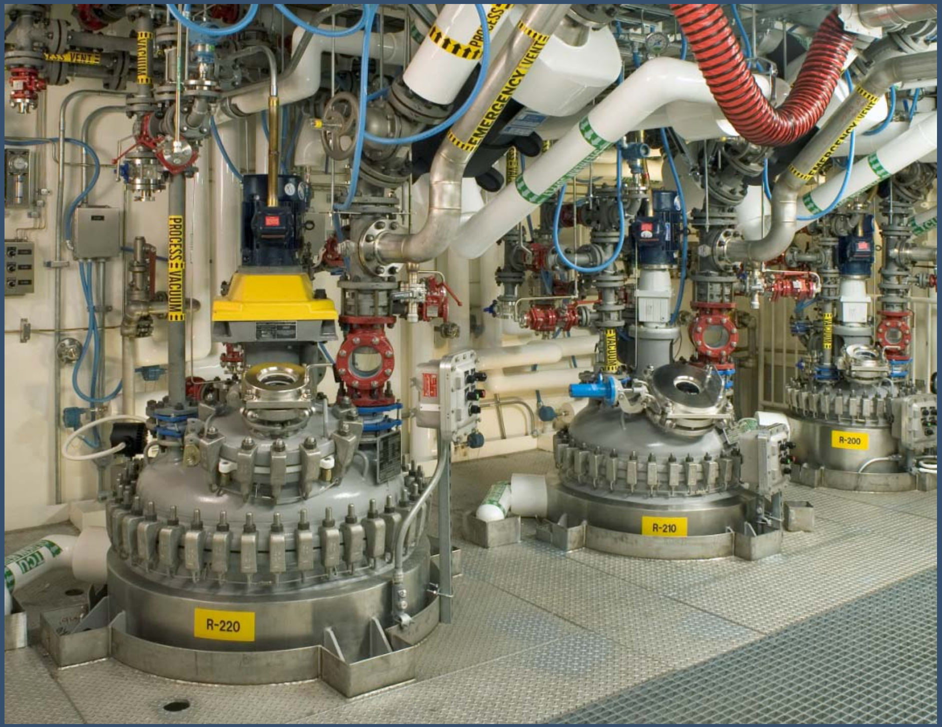
Mission Critical Operations

Case Study



+ Major Bay Area Pharmaceuticals Company
+ Need to store product in minus 35 degree freezers
+ In earthquake, faced with not being able to get product out because the building would be red-tagged, or product lost entirely

Structural Solution

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Structural Solution:

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Mission Critical Operations

Solution:

+ Encouraged heavy masses on upper level floors

+ This building will meet immediate occupancy under DBE and better than life safety under MCE

+ Paid for enhanced design by "tuning" the foundation capacity to the structure capacity

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Mission Critical Operations

Case Study # 2:

+ Existing "Pre-Northridge" Moment Frame buildings

+ Balance of Campus had been retrofitted to reduce damage due to "Pre-Northridge" Steel Moment Frame Connections.

+ Owner desired to reduce risk or known deficiencies and add 75,000 SF

Solution

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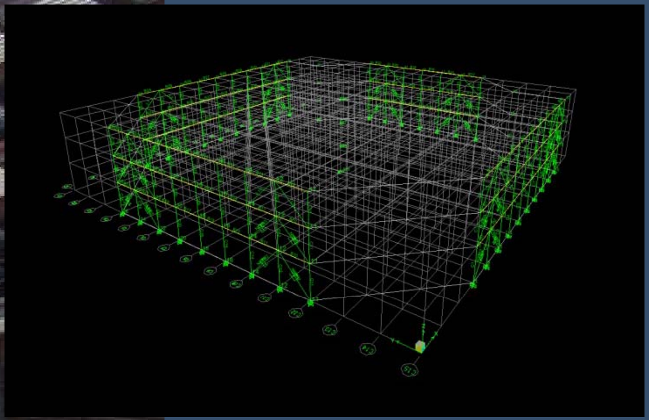
Mission Critical Operations

Solution:

+ Attach new 75,000 GSF to both towers, retrofit towers with FVD's

+ Total solution increased value of existing assets and paid for it with savings to LFRS of new 75,000 SF story addition.



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Question #1:

Electrical engineers often work with structural engineers on sizing the concrete pad for floor-mounted electrical equipment (i.e. generators, switchgear, etc.,).

My experience has been that the concrete “housekeeping” pad would be sized about 4” more on each side to accommodate anchor bolts, and roughly 4” thick. With the IBC 2006/CBC 2007 requirements, how would this change the rules?

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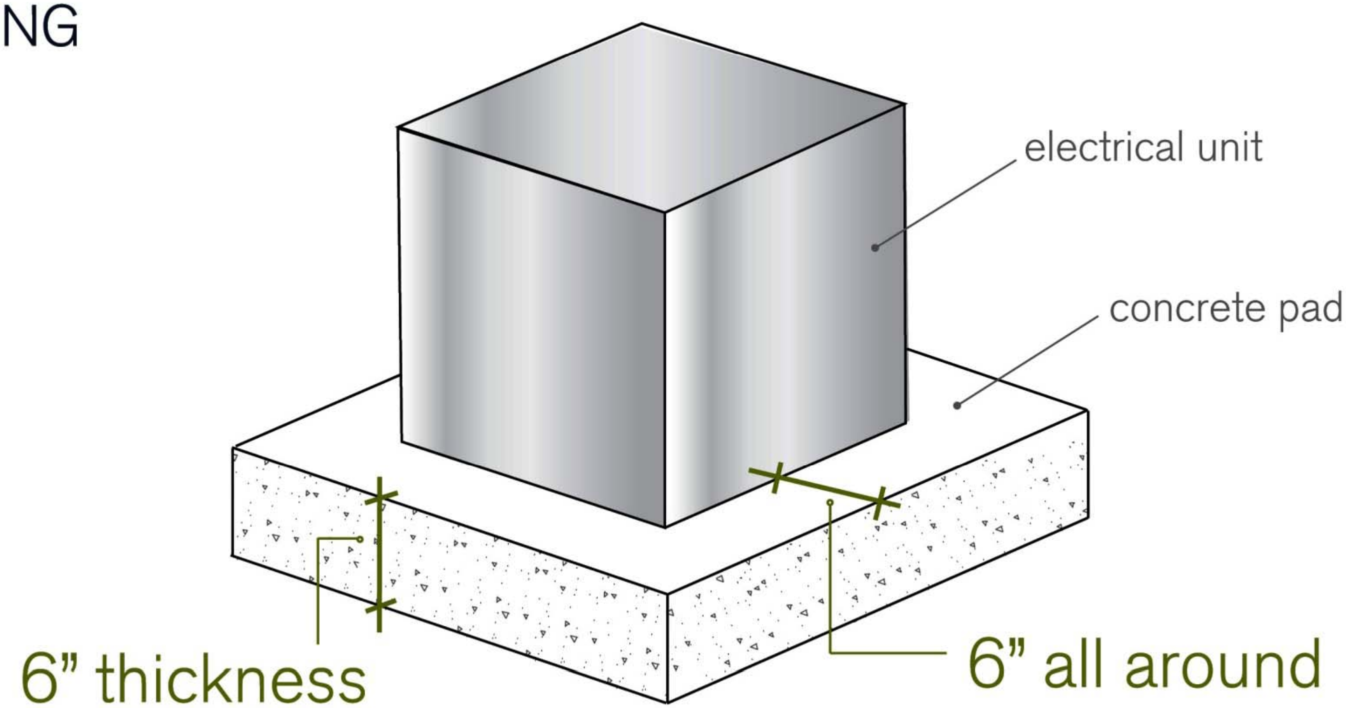
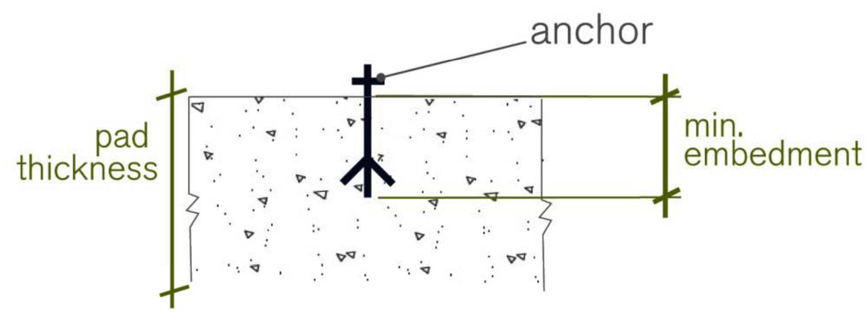
BUILDING



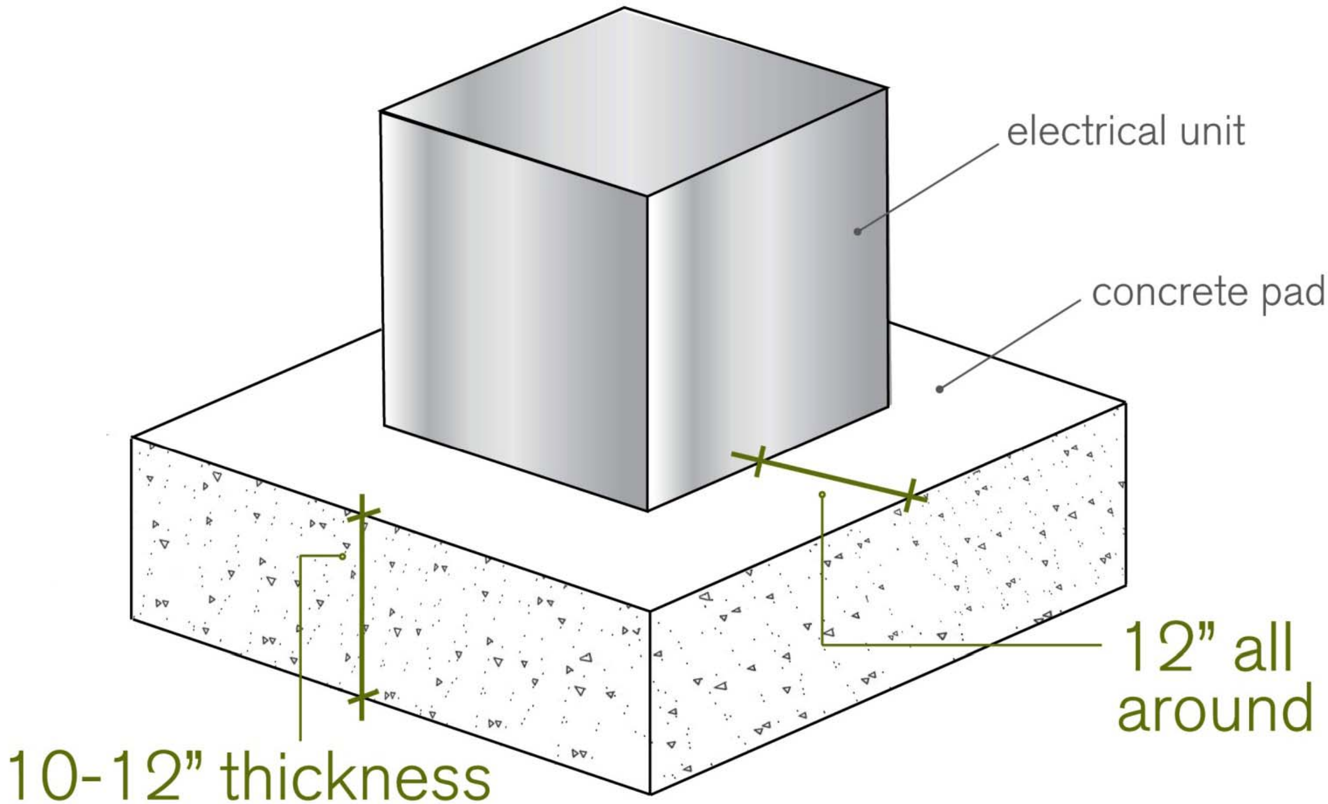
anchor type:

5/8" diameter

3 3/8" minimum embedment



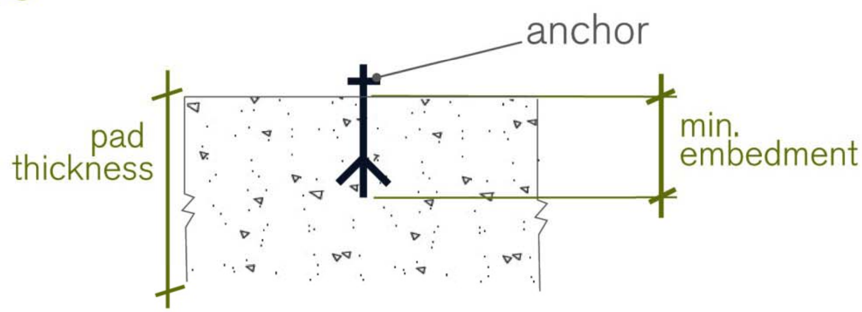
SITE



anchor type:

3/4" diameter

4 1/8" minimum embedment



Question #2:

Electrical engineers often have conduit stub-ups going into electrical distribution equipment (i.e. switchgear) for power and/or control wiring. Structural engineers often talk about not having too many conduits coming out of the concrete floor because of rebar spacing.

How can this best be corrected? Is there a rule of thumb regarding spacing requirements for conduits we need to be aware of ?

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Rules of Thumb:

- Increase amount of reinforcing to allow for partial bar severing
- Center to Center spacing of reinforcing (space reinforcing at 8” or 12”) to allow passage of 4” conduits
- Create opening in the slab on grade or structural slab to allow passage of multiple conduits

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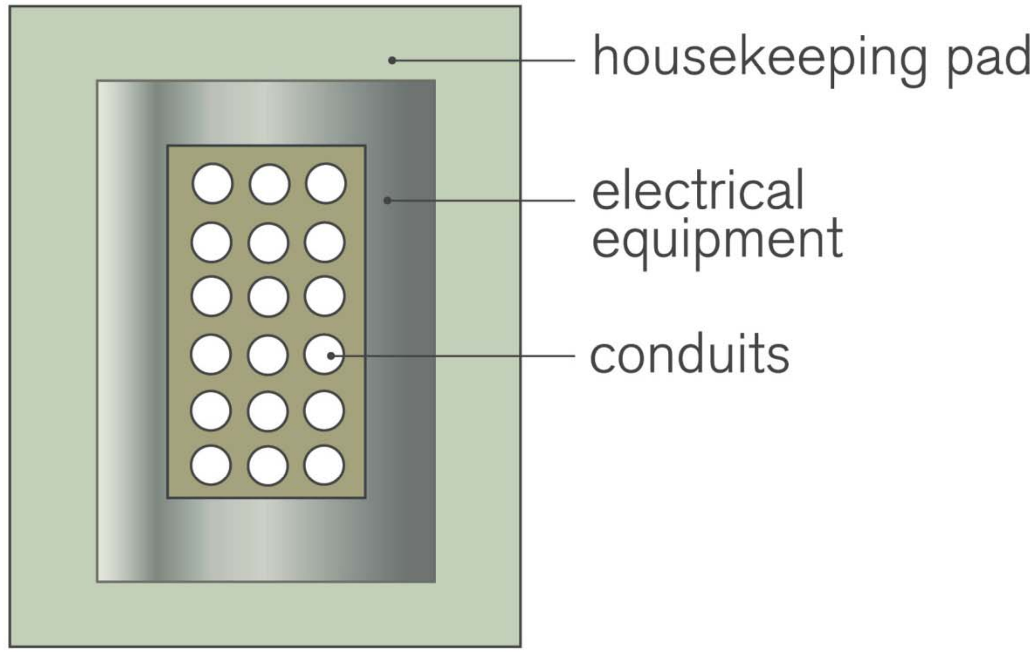
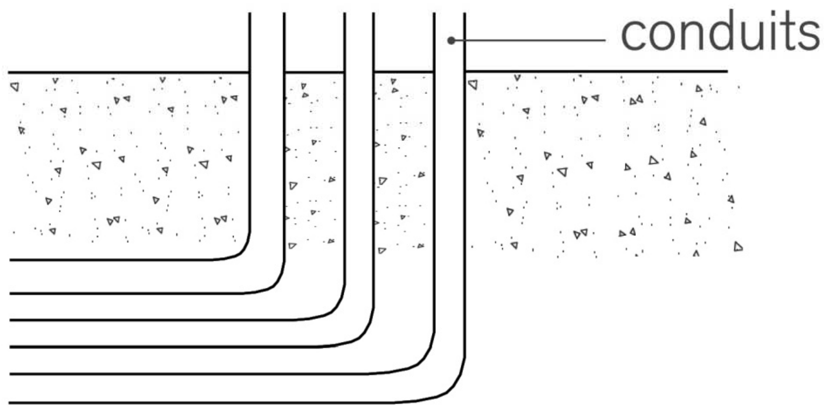
PLAN



CROSS SECTION



Question #3:

Electrical engineers are told that flexible connections are required for ceiling mounted conduits going into electrical distribution equipment from above? Is this true?

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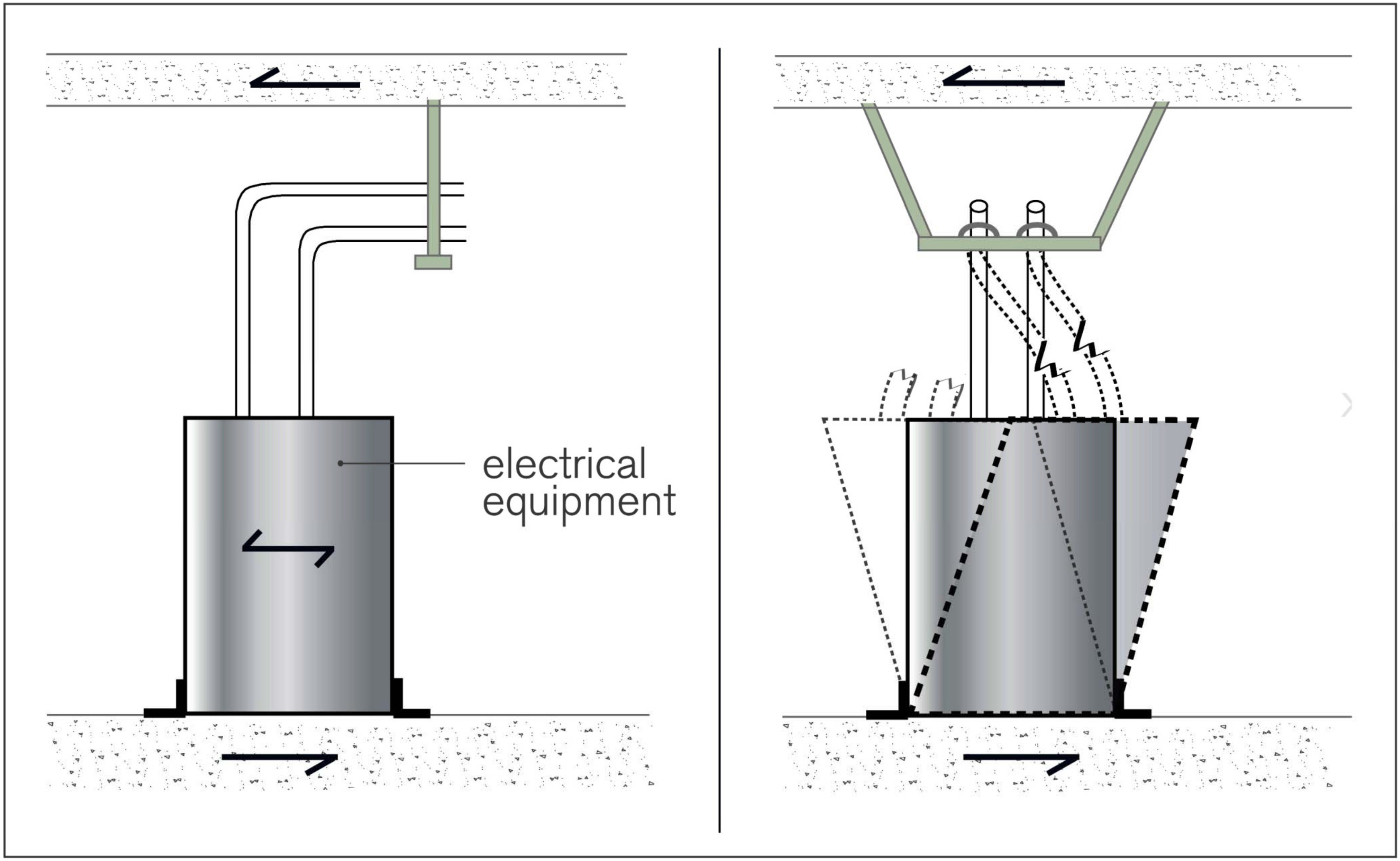
electrical
equipment

Question #3 – Part 2:

Does the type of connections needed change if the building is base isolated?

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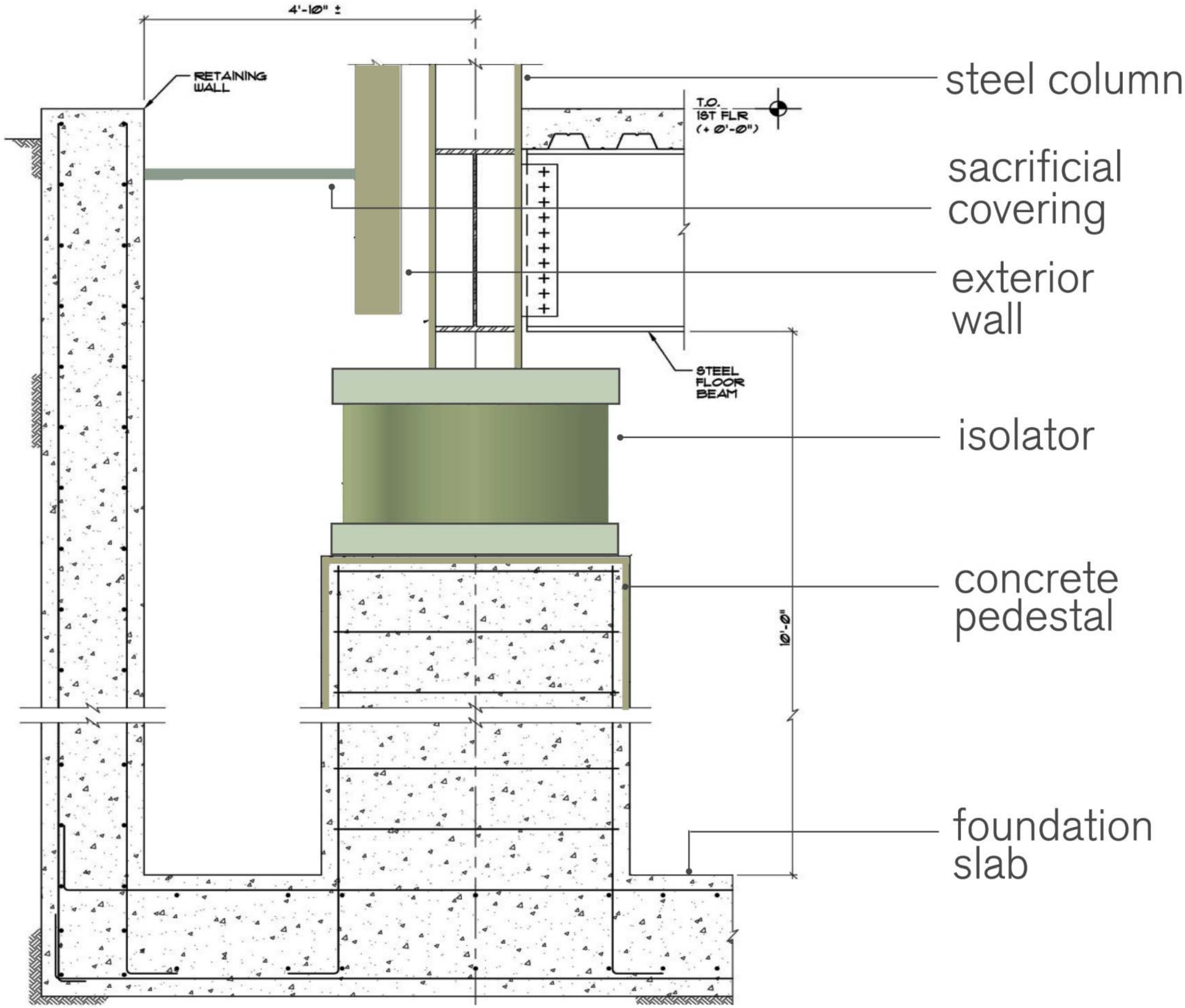
TYPICAL EXTERIOR WALL SECTION AT CONCRETE PEDESTAL/ ISOLATOR



Question #4:

What would be a good recommendation for specifying concrete, rebars, etc., during an earthquake? Spacing issues between the rebar and conduits?

Would spacers work better than concrete-encasing conduits?

Does this also apply for Ufer grounds (concrete encased electrodes)?

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Discussion:

- Generally ground does not sever conduits unless crossing over a fault

- Encasement to protect conduits from future construction activity

- Also depends on building – copper wire = couple welded to steel; will rip out. Solution = slack in grounding cable

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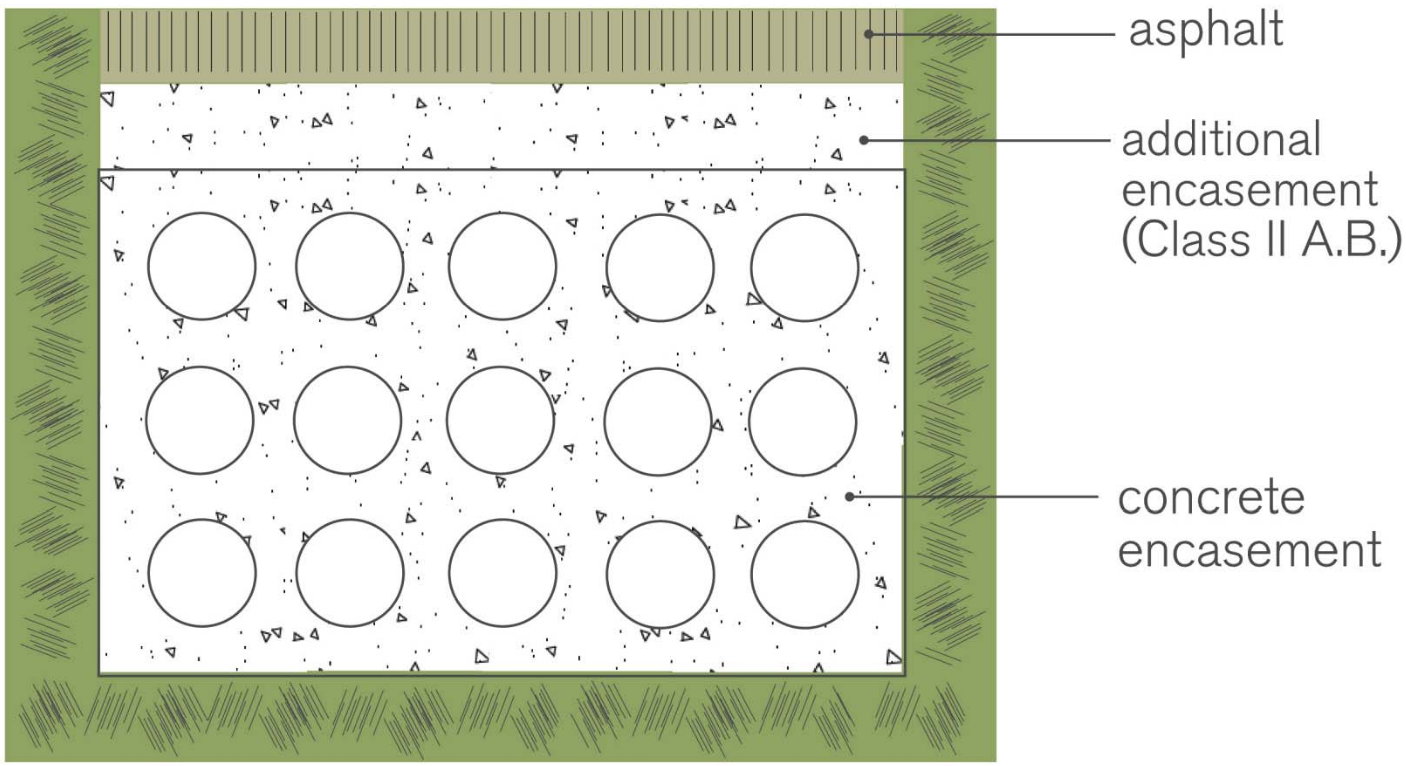
asphalt
additional
encasement
(Class II A.B.)
concrete
encasement

Question #5:

Electrical engineers deal with grounding electrode conductor connections (exothermic or mechanically welding) to I-beams. The grounding electrode conductors are usually #4/O AWG or above, but the exothermic welding connection could be severed during an earthquake. It would definitely pose an electrical safety issue if that's the case.

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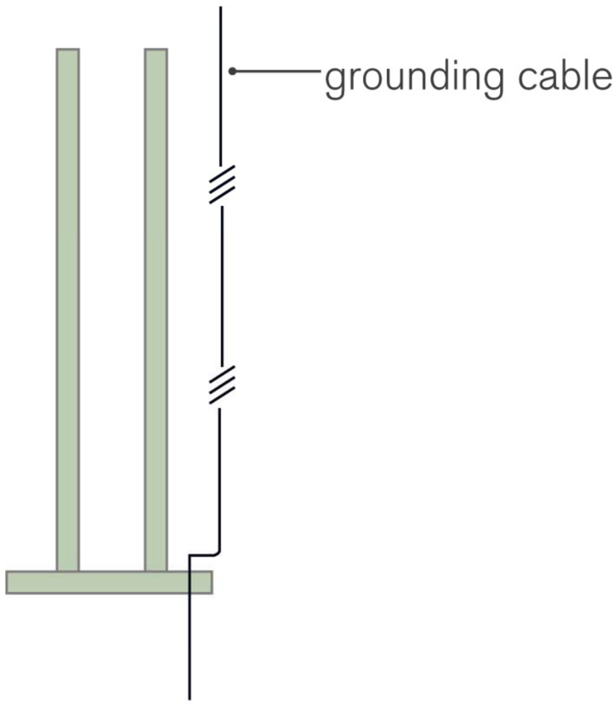

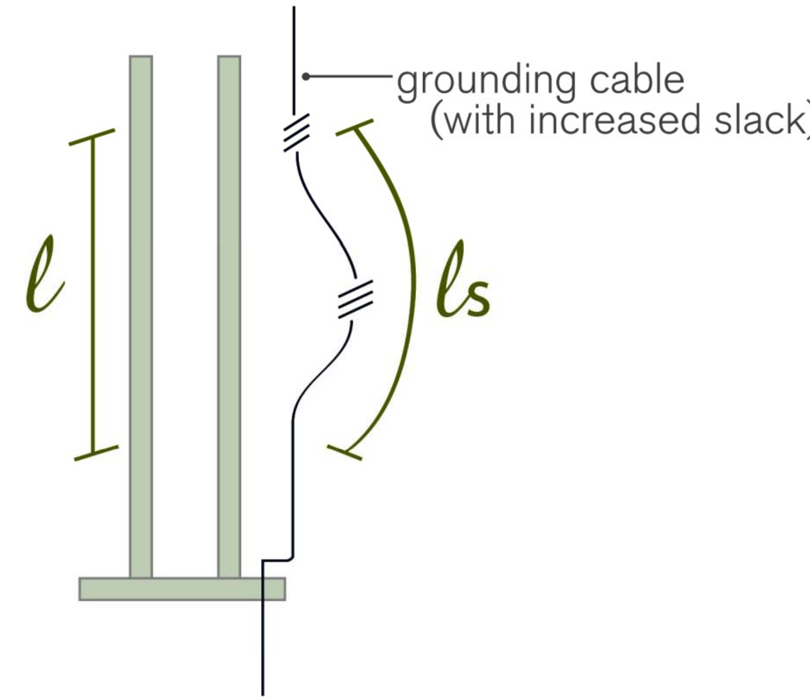

Fixed Base Building

$$\ell s - \ell = \geq 3''$$

Base Isolated Building

$$\ell s - \ell = \geq 30''$$

Other Questions?

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