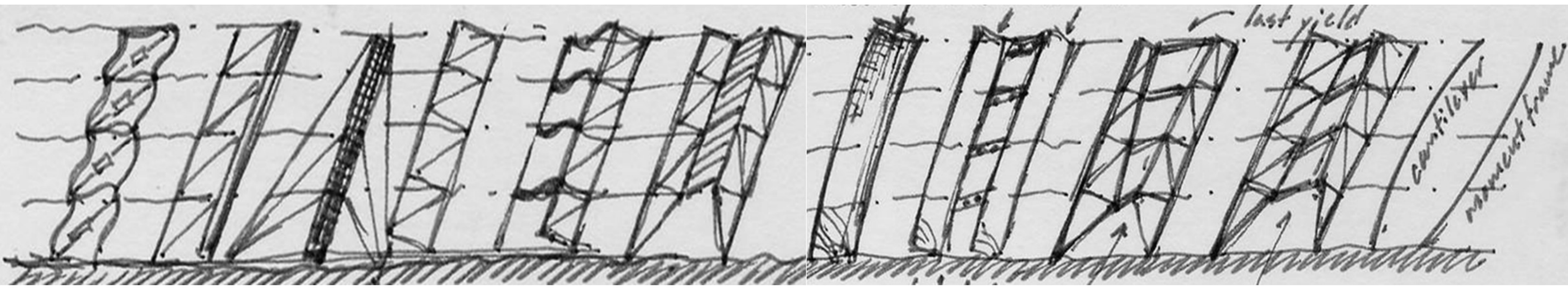
Innovation Flow from Research to Practice

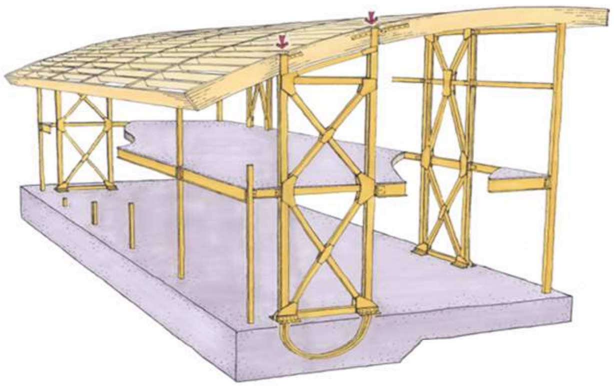


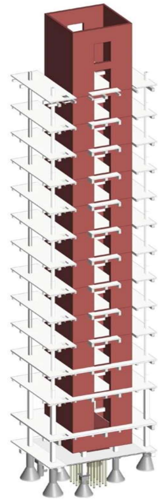
Messaging and Dissemination

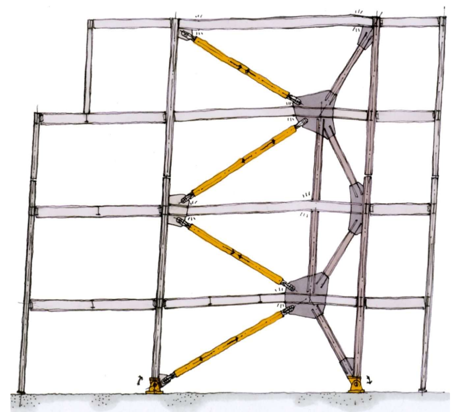
David Mar

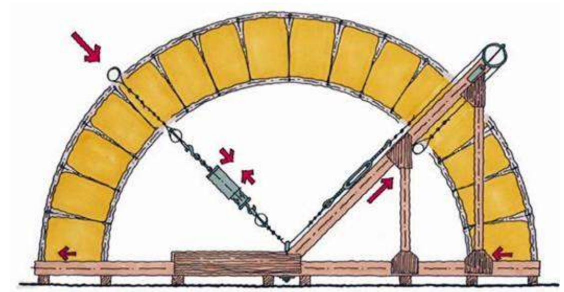
My Background:

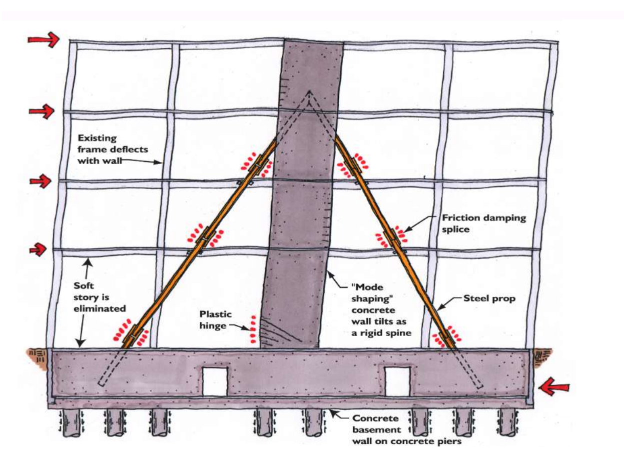
Practicing structural engineer
Early adopter of innovation
Lover of performance-based design
Inspired by research and the work coming out of UCSD

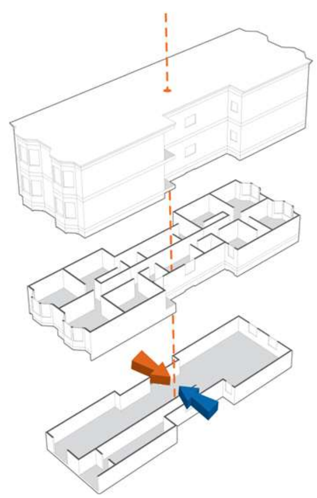


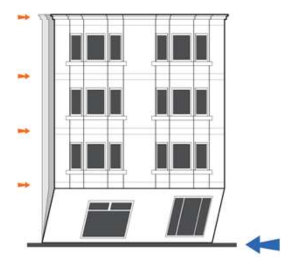


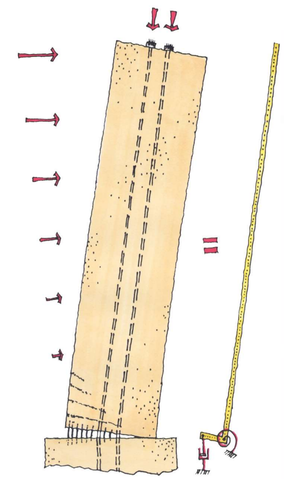


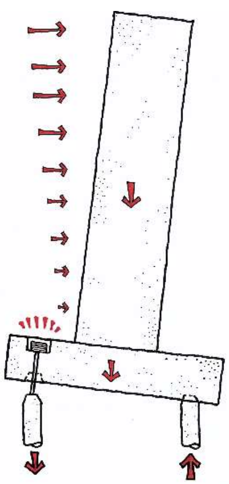



Existing
frame deflects
with wall
Friction damping
splice
Soft
story is
eliminated
Plastic
hinge
"Mode
shaping"
concrete
wall tilts as
a rigid spine
Steel prop
Concrete
basement
wall on concrete piers

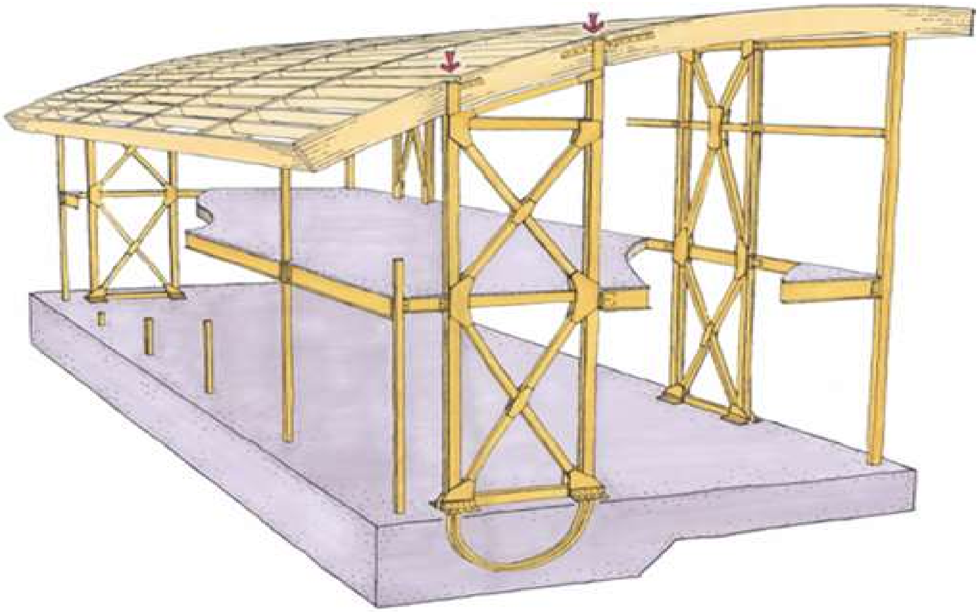


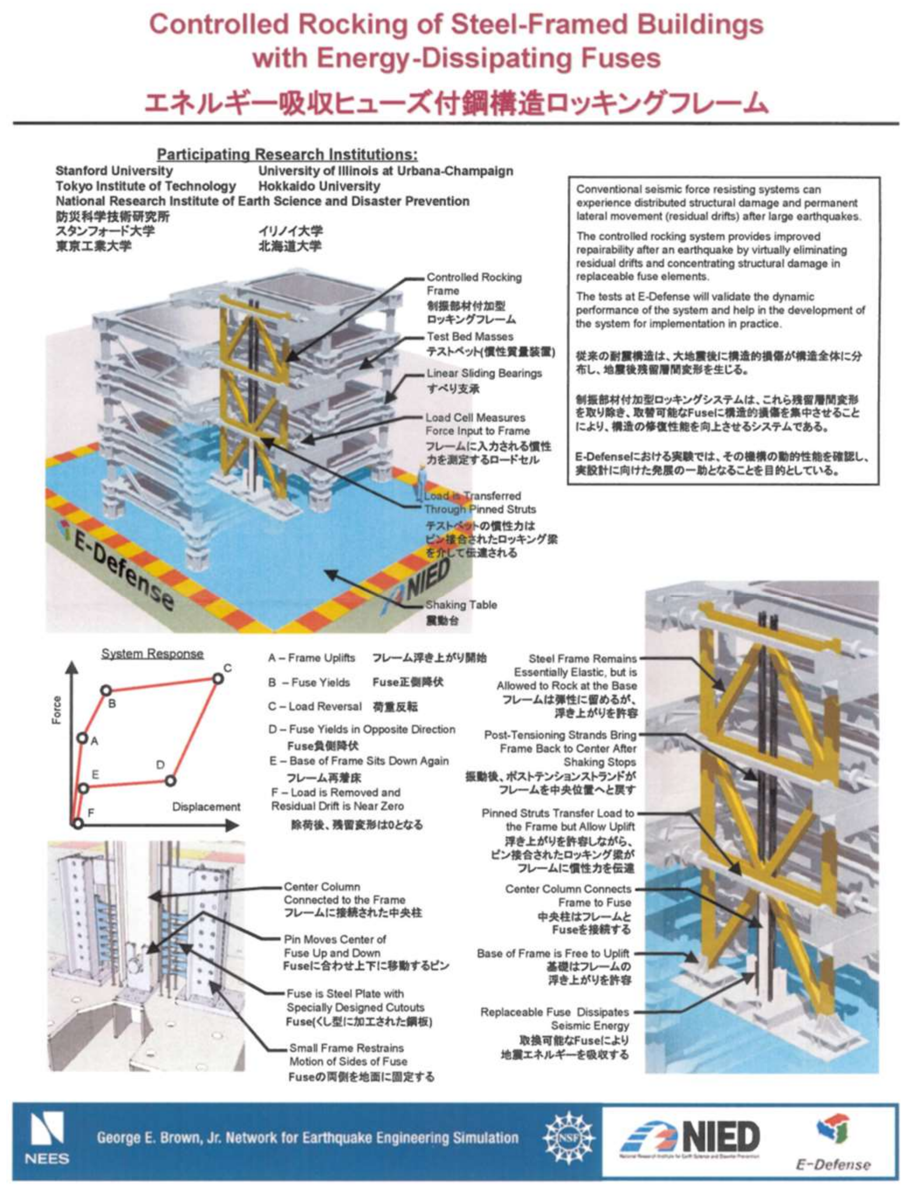




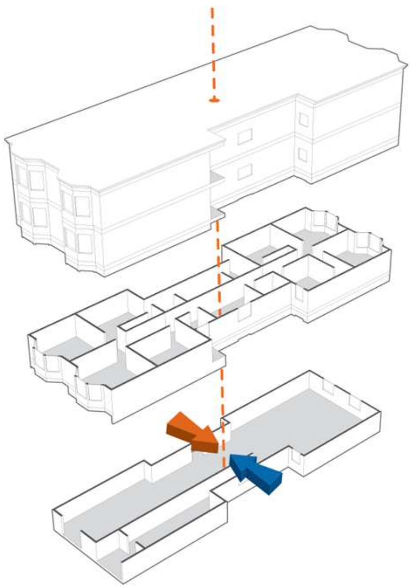


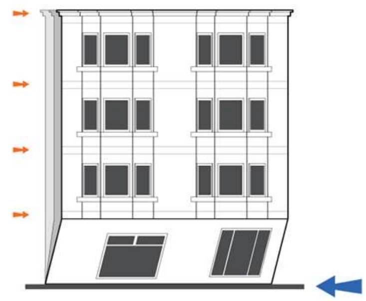
Rocking Frame Validation





FEMA P-807
Weak Story Retrofit Validation





Structure

25% of building value

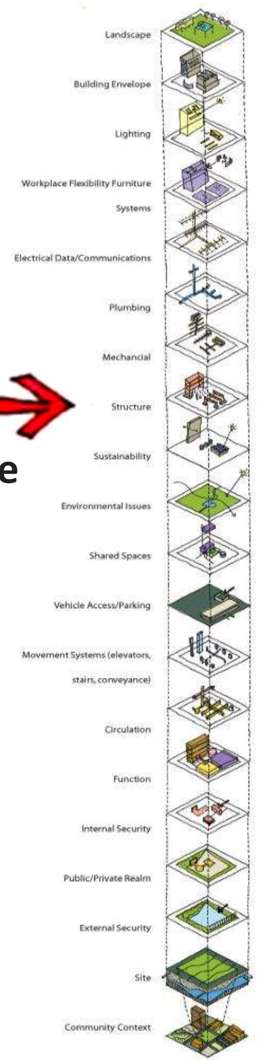
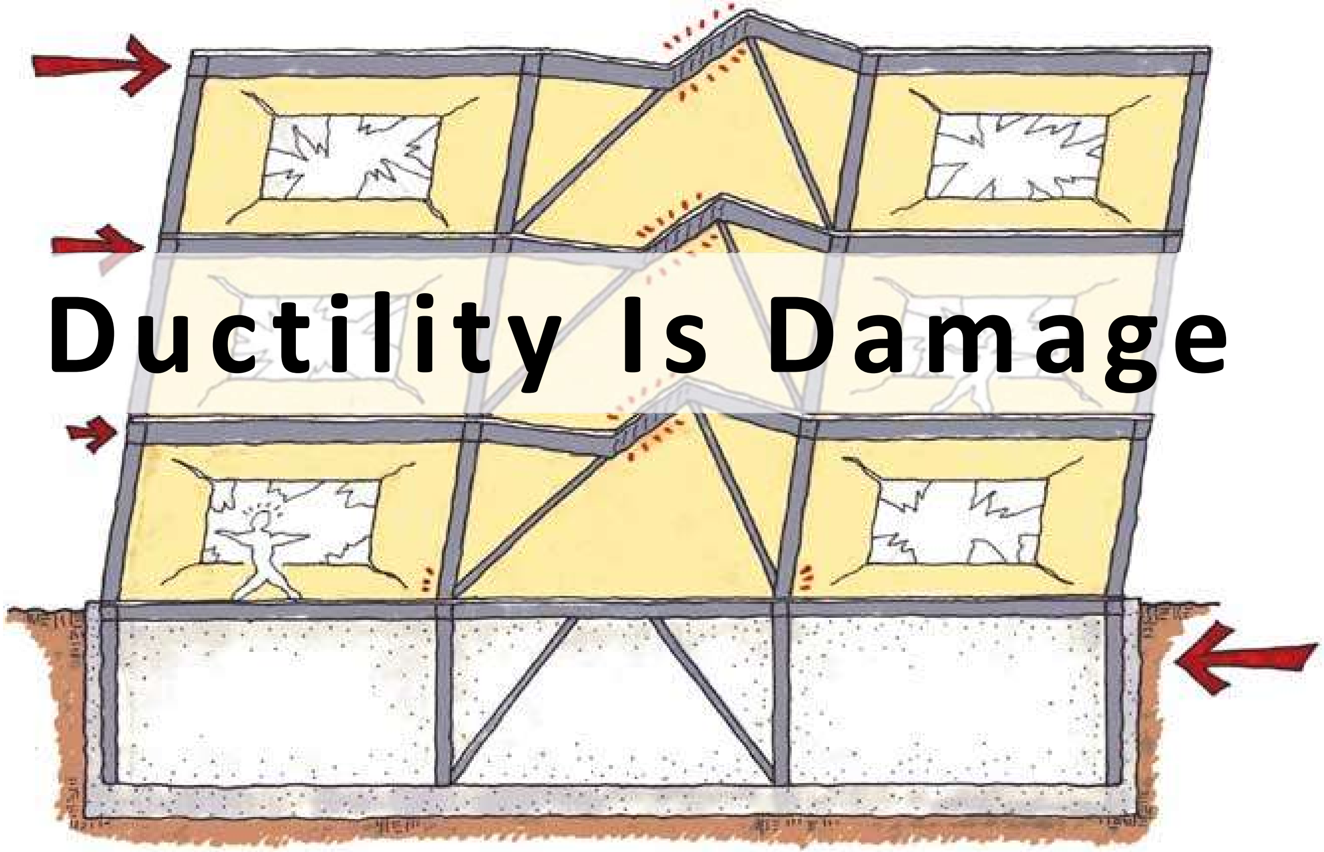


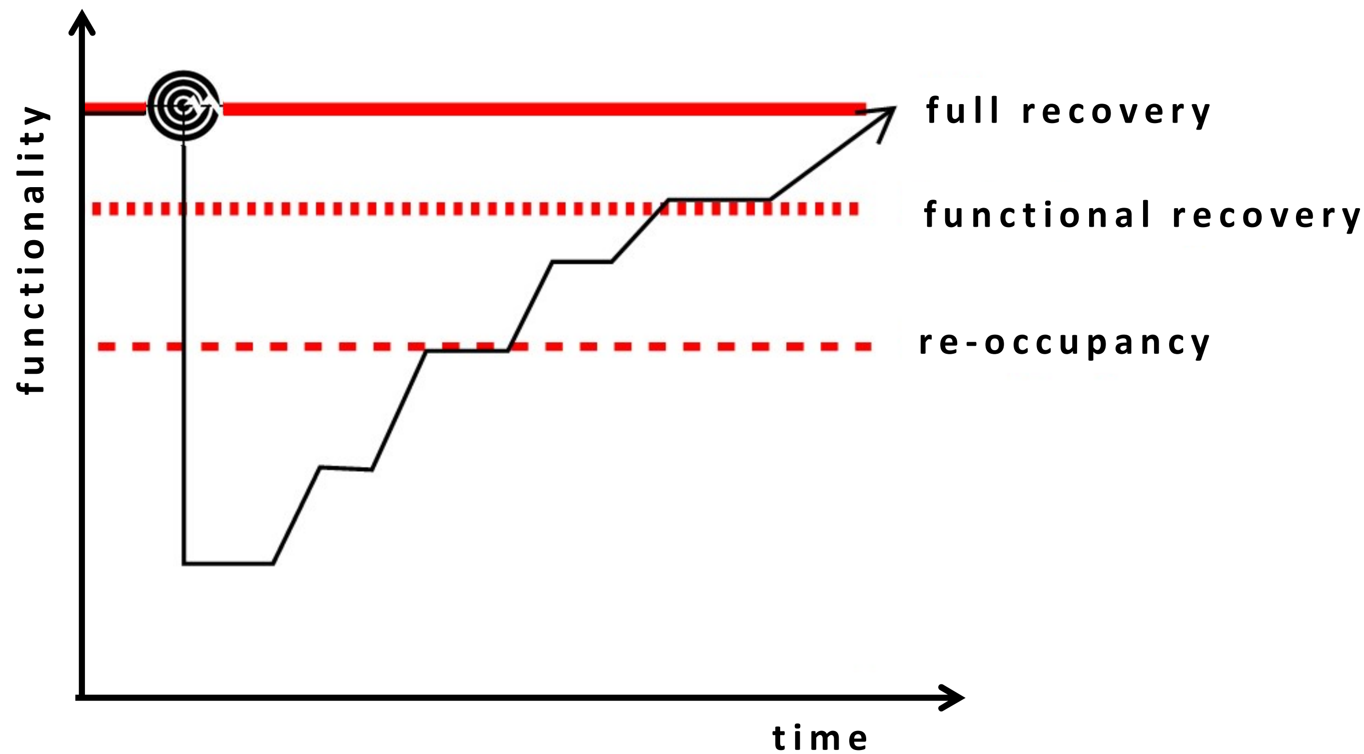
Image courtesy of BNIM

Buildings are Earthquake Proof



Ductility Is Damage

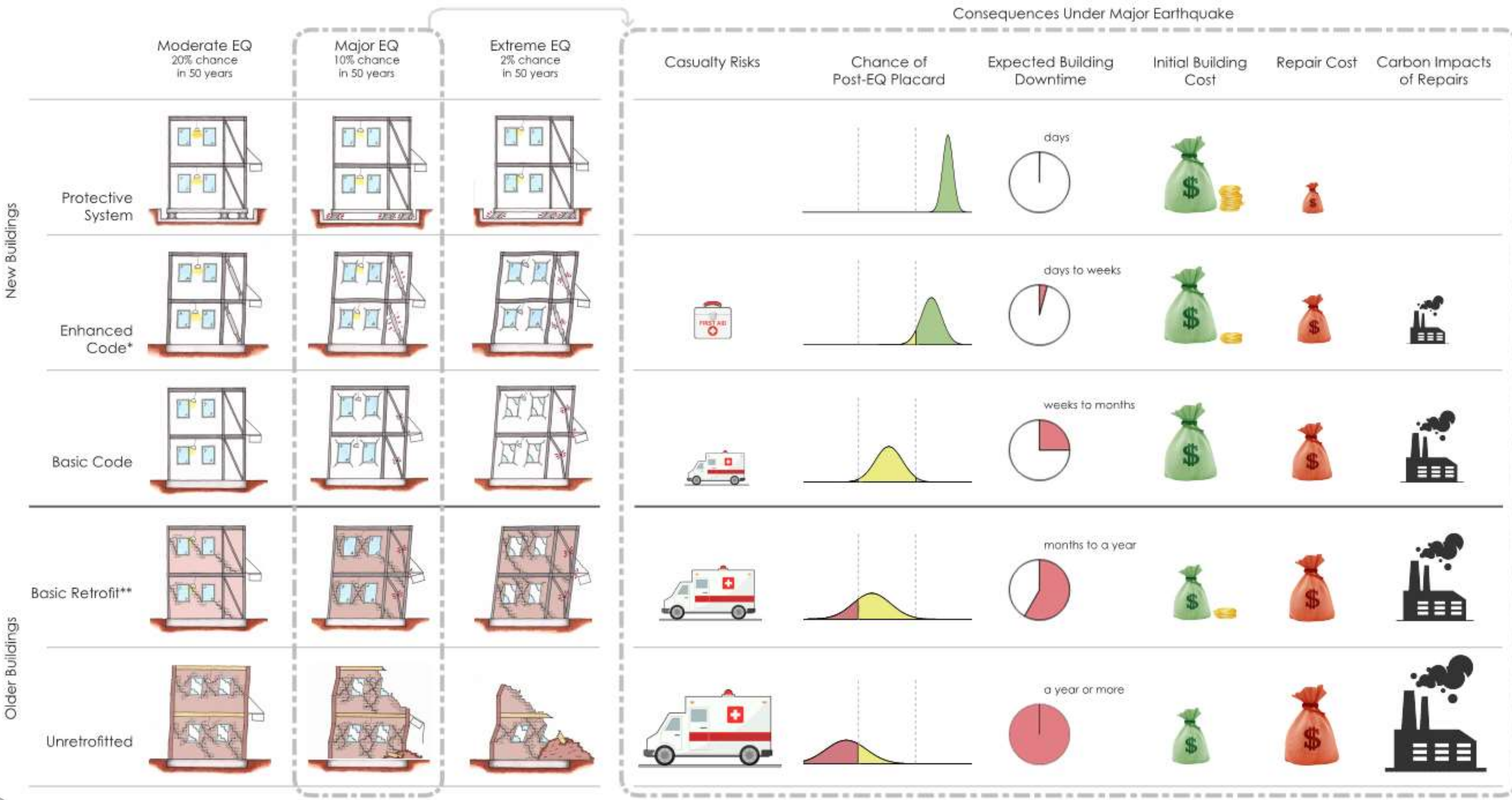
Resilience



functionality
full recovery
functional recovery
re-occupancy
time

OPTIONS FOR EARTHQUAKE RESISTANT DESIGN

Design Decisions Have Measurable Consequences



FEMA

Topic #13: Nurture engineer creativity/innovation

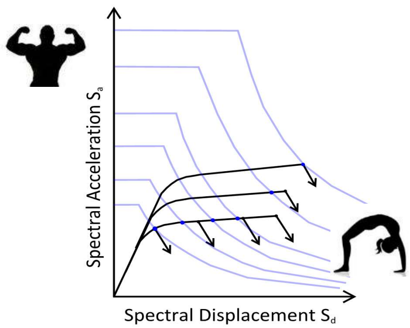
There are some who argue that despite the large number of systems currently defined in the building code, there are still too many limitations on what a responsible structural engineer can do. From this point of view, one really just has moment frames, braced frames and shear walls, each of which comes with many prescriptive requirements. How can we encourage creativity and maintain safety, but not trigger a full alternative means of compliance and peer review when something a bit different is desired?

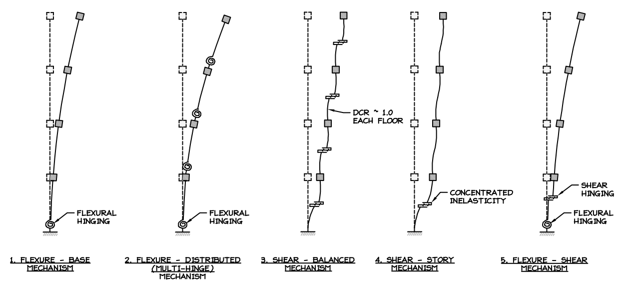
Topic #13: Nurture engineer creativity/innovation

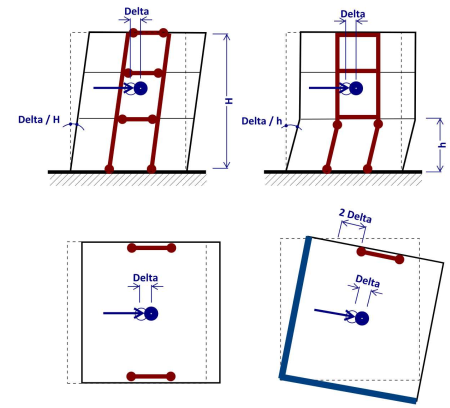
"…encourage creativity and maintain safety…"

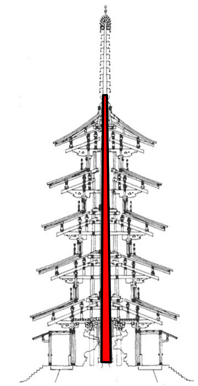
The Code

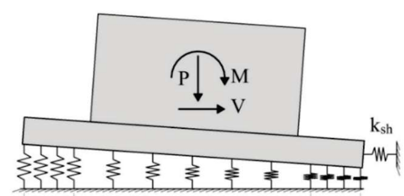
Design Method Primary Steps











Casa Adelante
San Francisco

100% Affordable Senior Housing

25% of Units for Formerly Homeless

Developers:
Chinatown Community Development Center &
Mission Economic Development Agency

Architect: Herman Colliver Locus

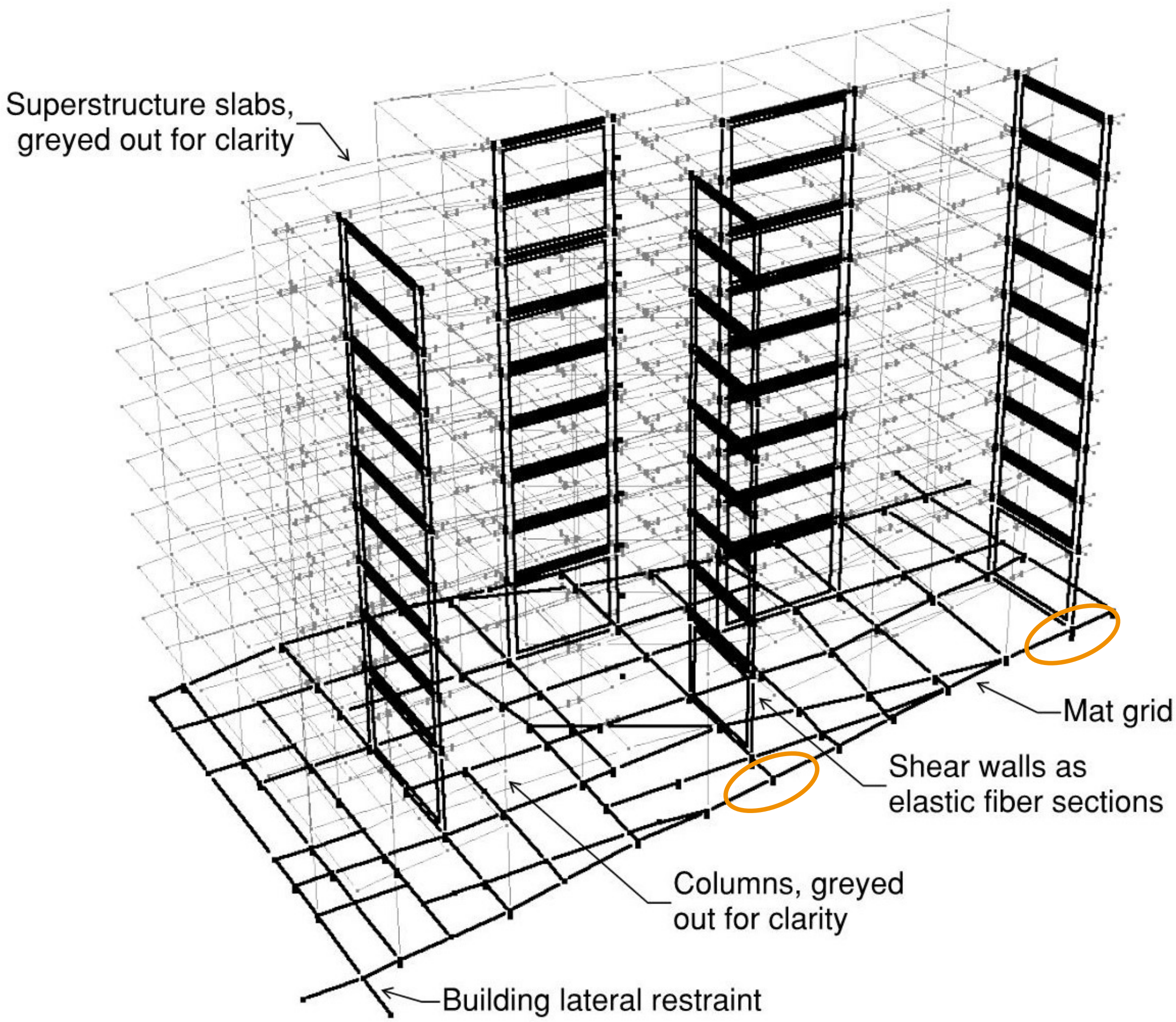
Residents Need to

Shelter-in-Place

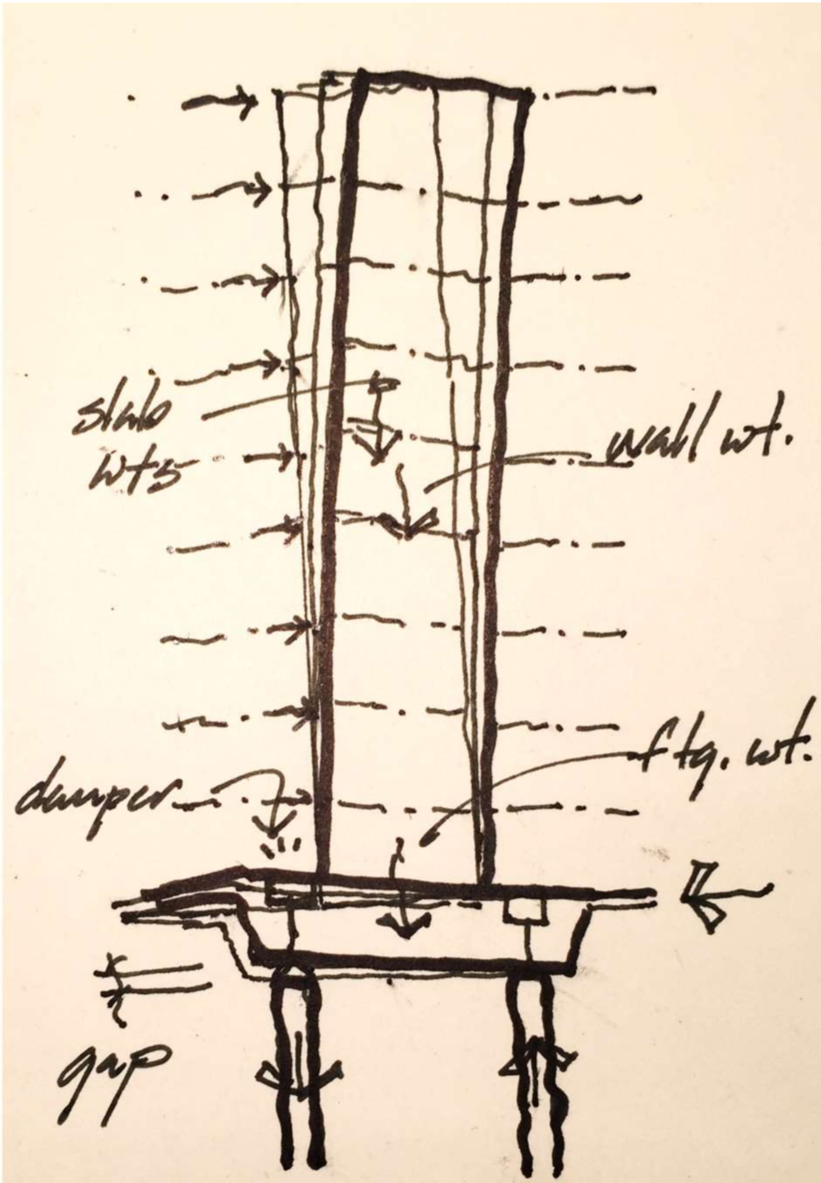
Achieve Highest Performance Possible

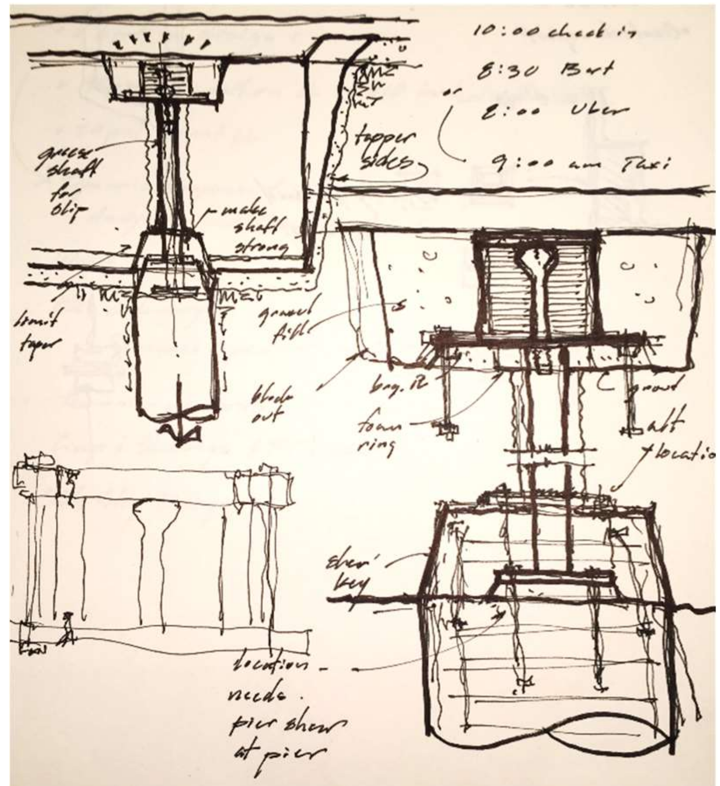
at

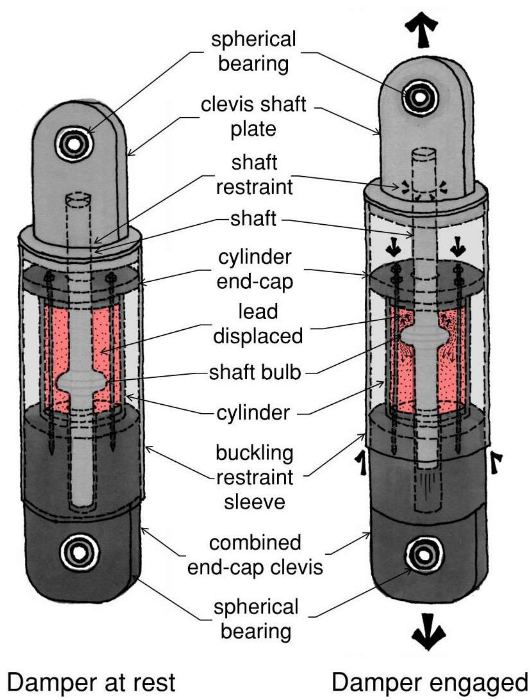
No Additional Cost

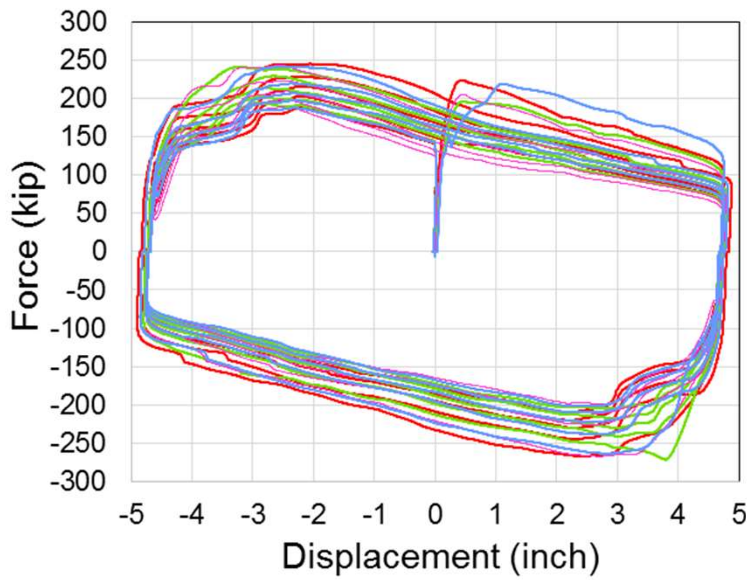


Superstructure slabs, greyed out for clarity
Mat grid
Shear walls as elastic fiber sections
Columns, greyed out for clarity
Building lateral restraint


slab wts
wall wt.
damper
ftg. wt.
gap

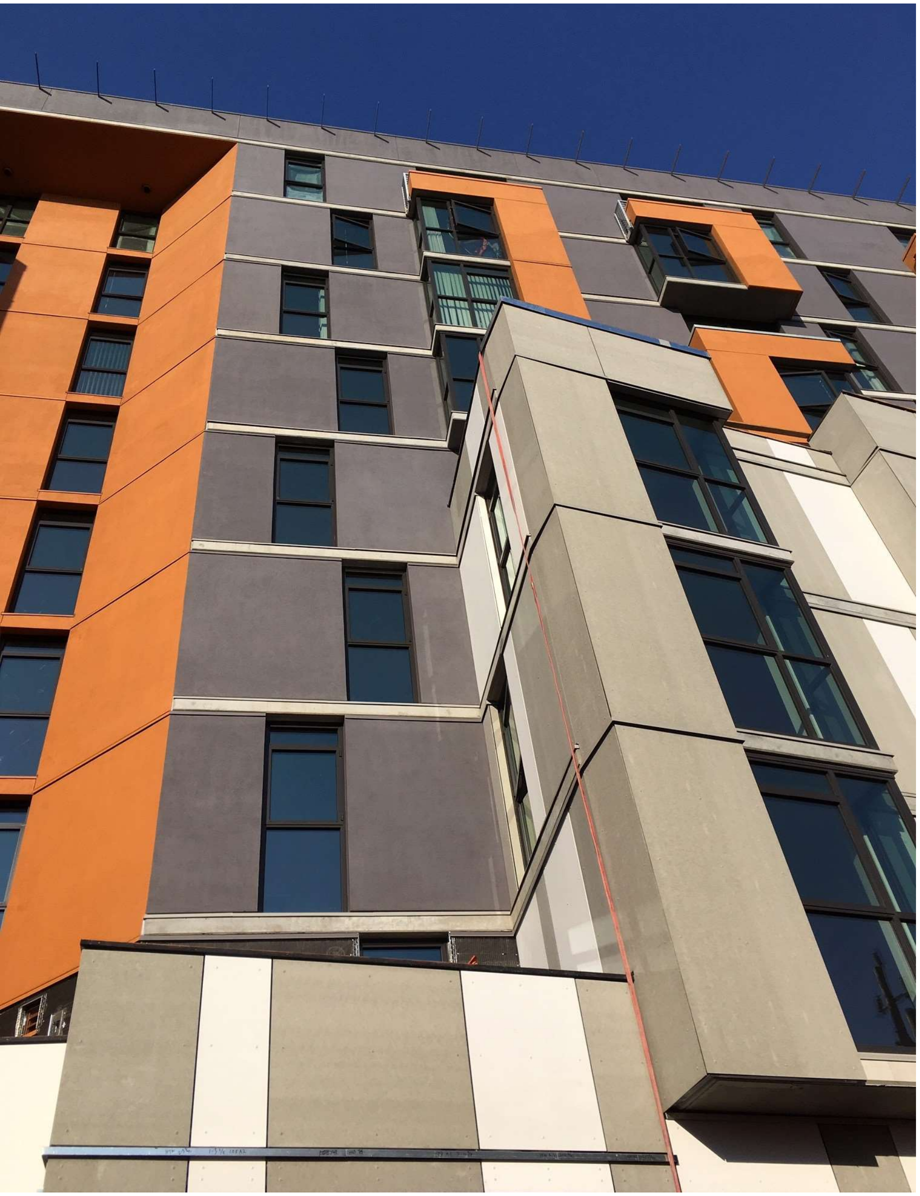

10:00 check in
8:30 Bart
or
8:00 Uber
9:00 am Taxi
taper sides
grease shaft for slip
make shaft strong
limit taper
gravel fill
block out
brg. R
foam ring
grout
alt location
shear key
location needs pier shear at pier

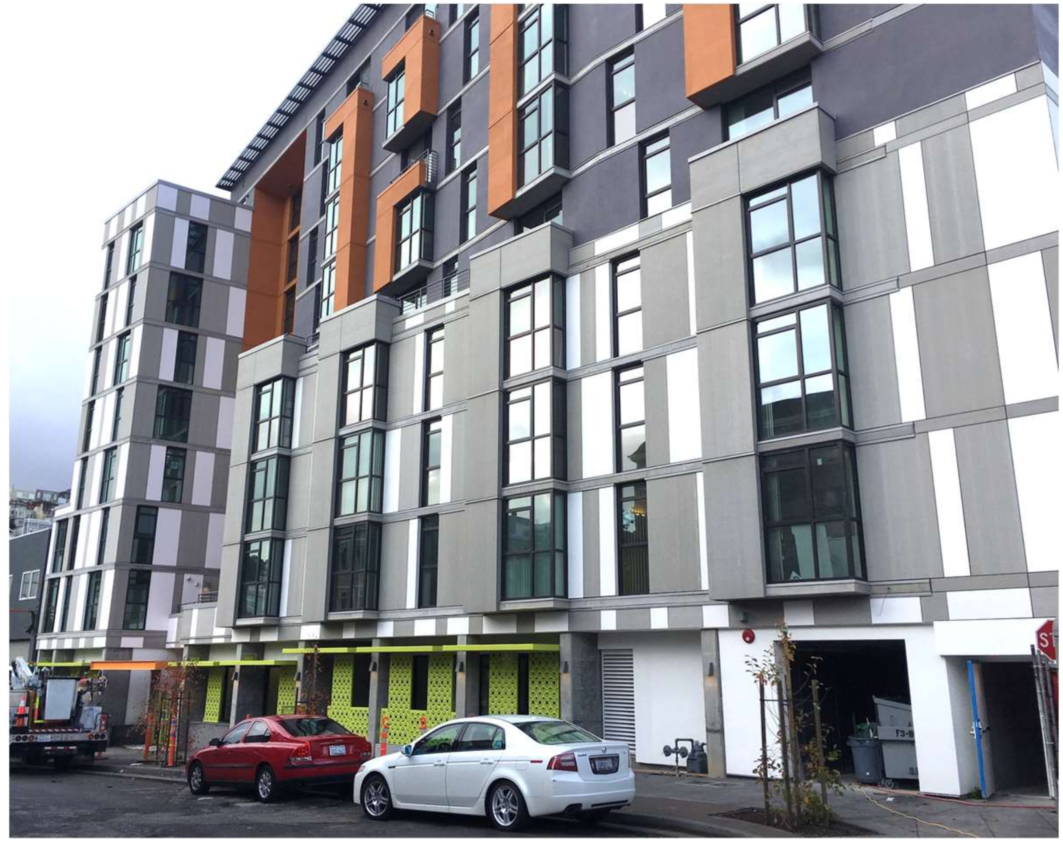

spherical bearing
clevis shaft plate
shaft restraint
shaft
cylinder end-cap
lead displaced
shaft bulb
cylinder
buckling restraint sleeve
combined end-cap clevis
spherical bearing
Damper at rest
Damper engaged


Force (kip)
Displacement (inch)
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-5
-4
-3
-2
-1
0
1
2
3
4
5


CAHILL

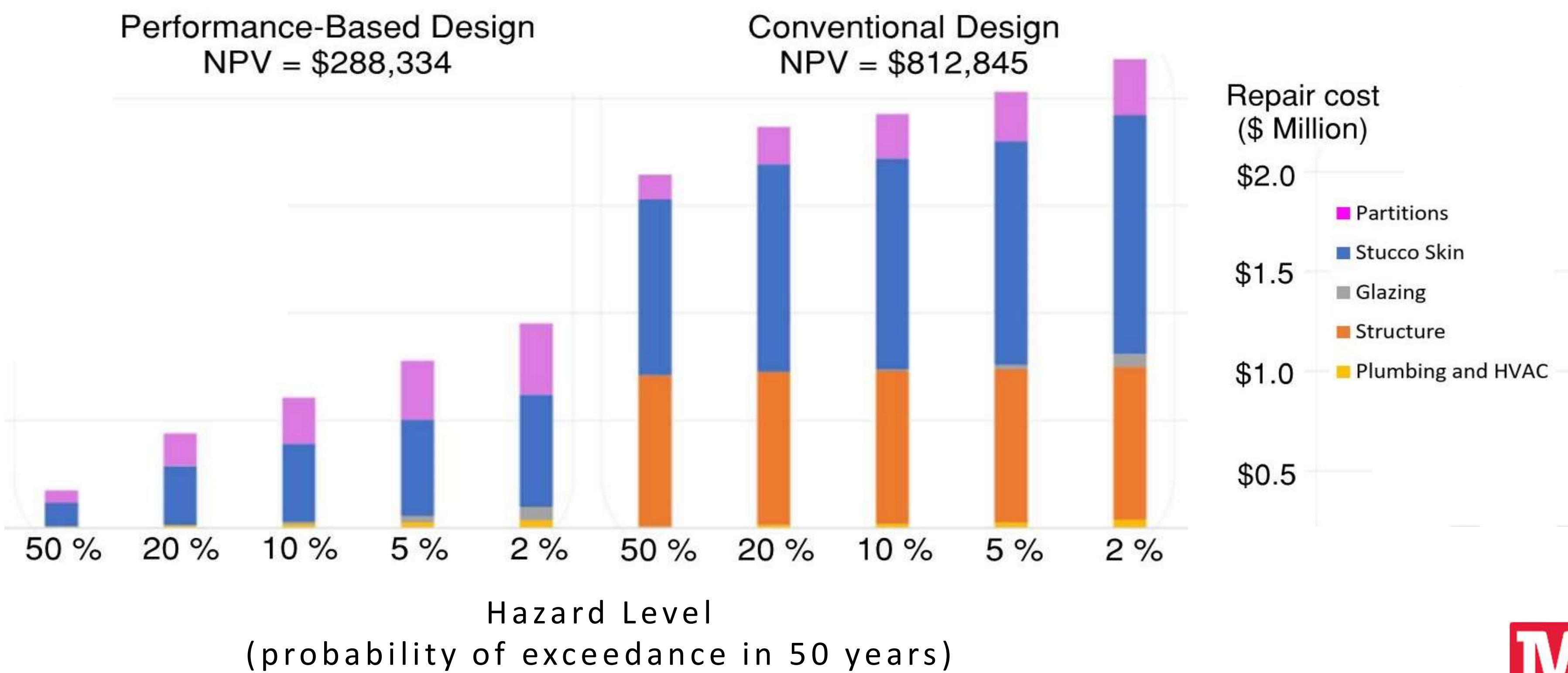

CAHILL





Economic Loss Modeling

Resilient design is more valuable by over $500,000



Similar Cost

to the conventional design

$42M Project Cost

Cost Delta

$100K for Resilience – 0.24%

Resilience Performance

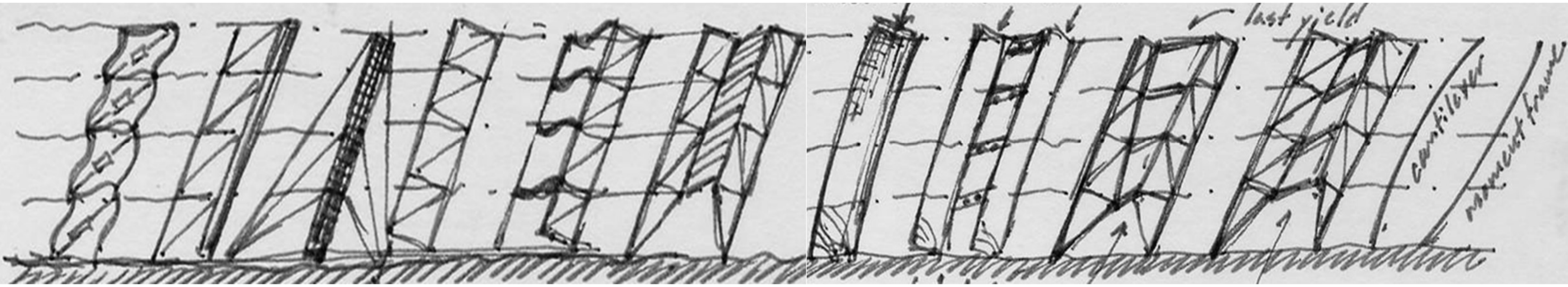
10% chance of exceedance in 50 years

REDi Re-occupancy : *0 days*

REDi Functional Recovery : *1 day*
(low – so no impeding time needed)

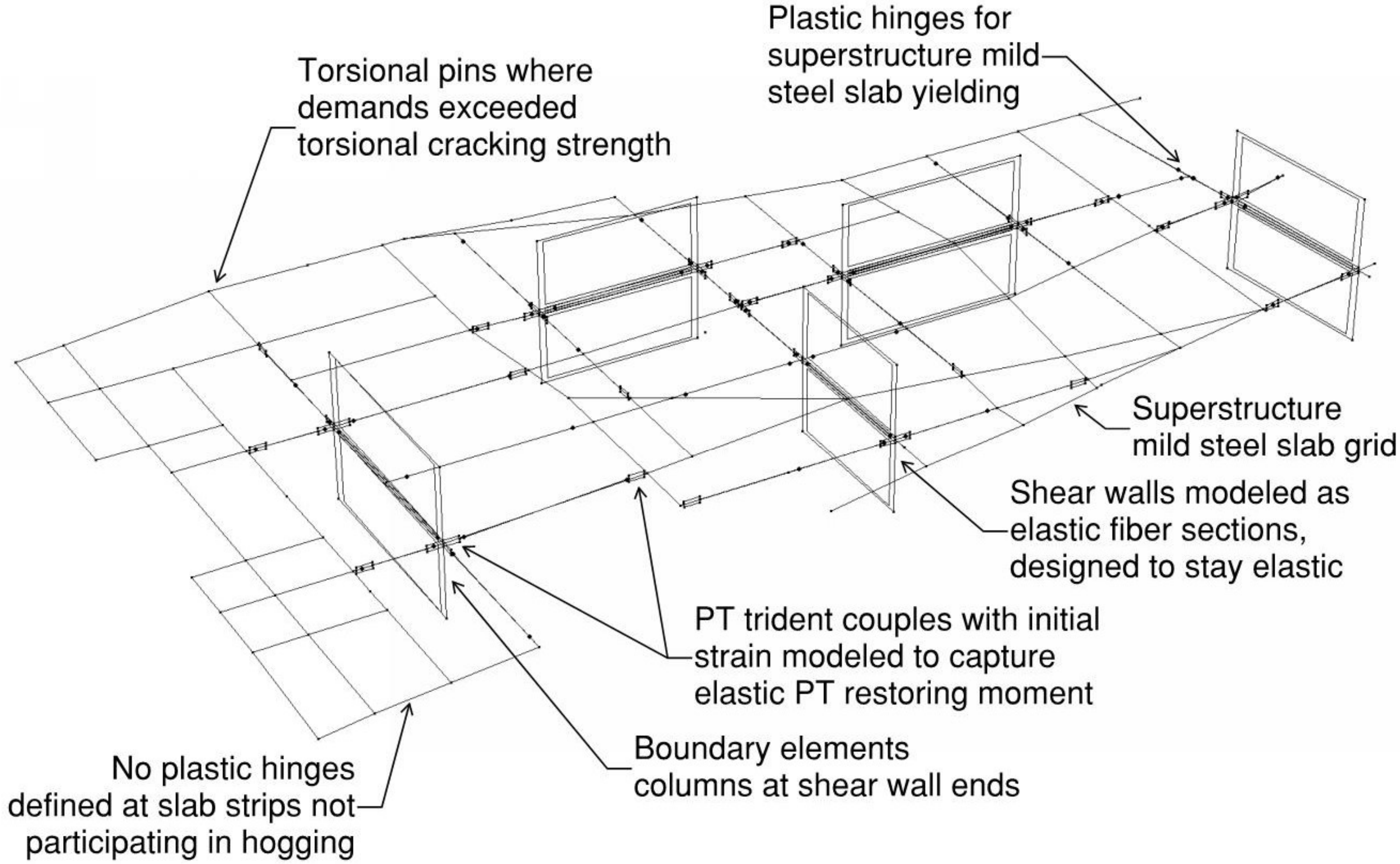
REDi Full Recovery : *4.1 weeks repair time*
(7 mo. including impeding time)

Innovation Flow from Research to Practice

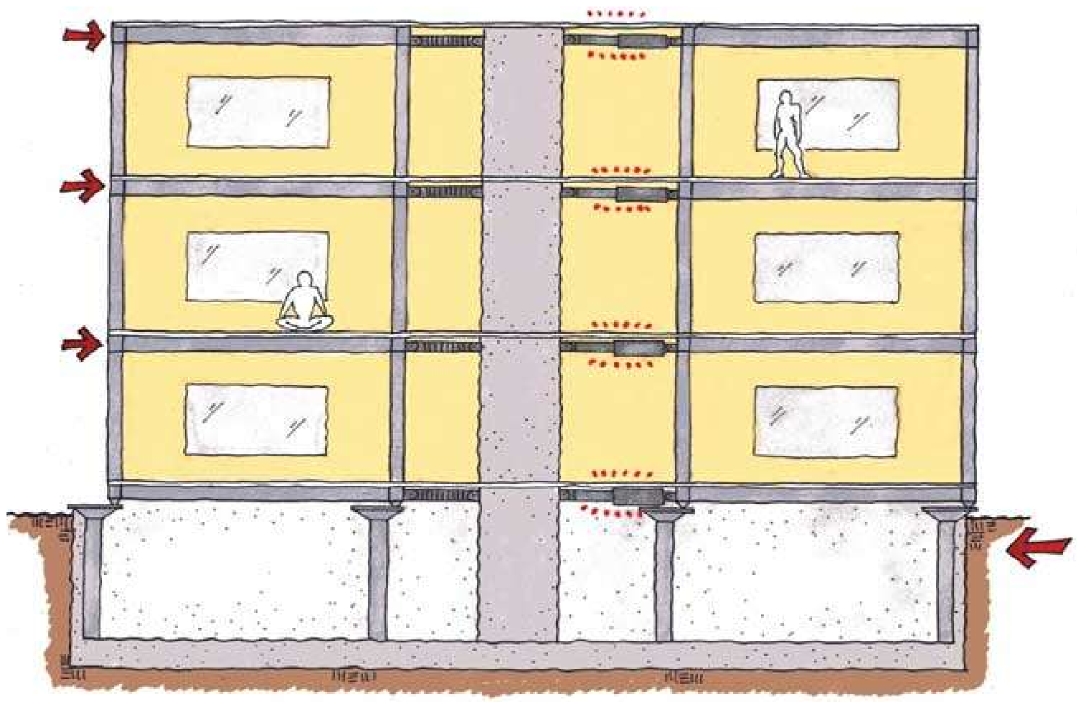


Messaging and Dissemination

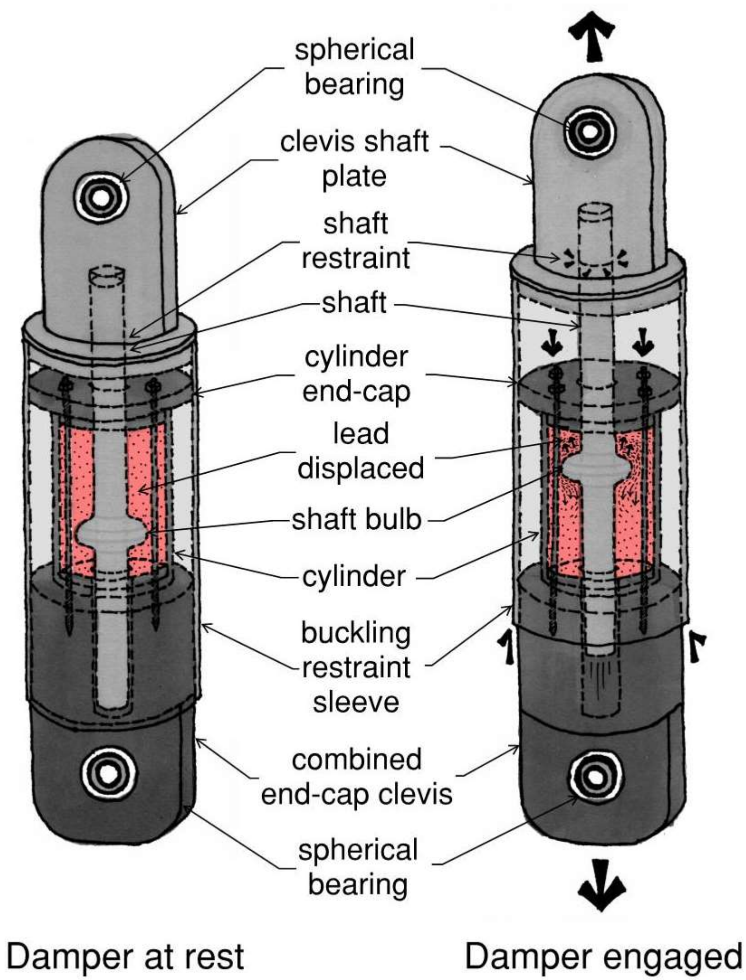
David Mar

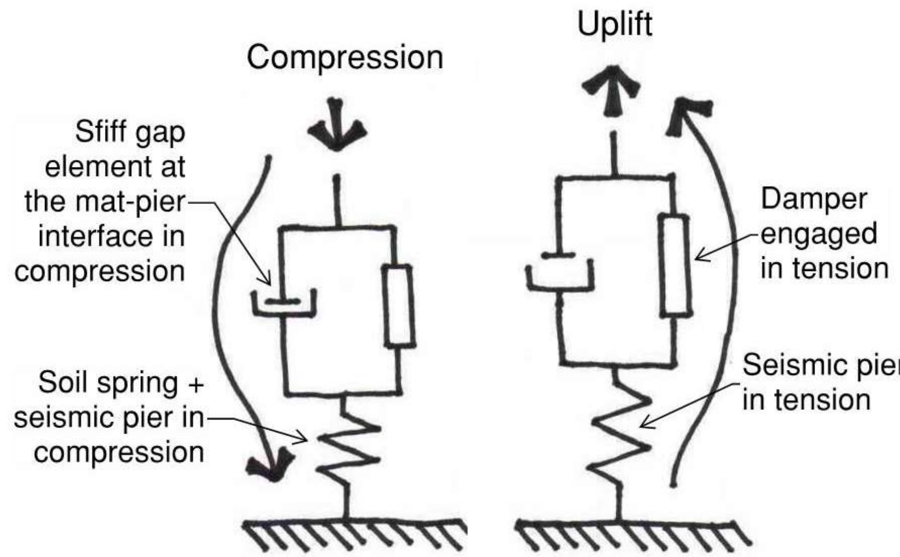


Plastic hinges for
superstructure mild
steel slab yielding
Torsional pins where
demands exceeded
torsional cracking strength
Superstructure
mild steel slab grid
Shear walls modeled as
elastic fiber sections,
designed to stay elastic
PT trident couples with initial
strain modeled to capture
elastic PT restoring moment
Boundary elements
columns at shear wall ends
No plastic hinges
defined at slab strips not
participating in hogging

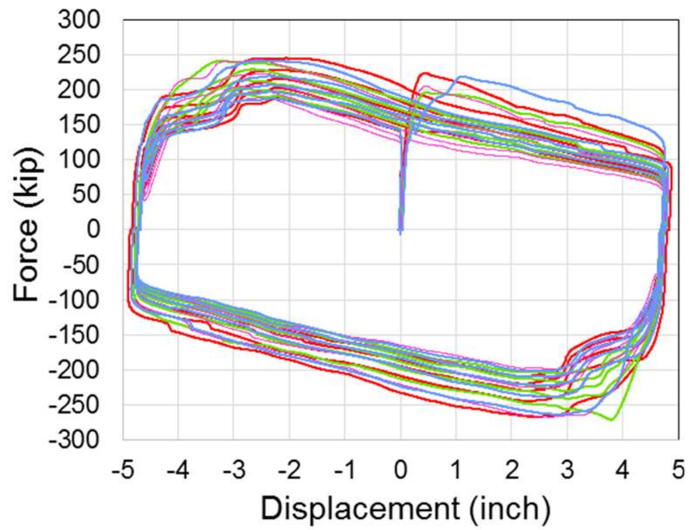


No Money for Improved Performance

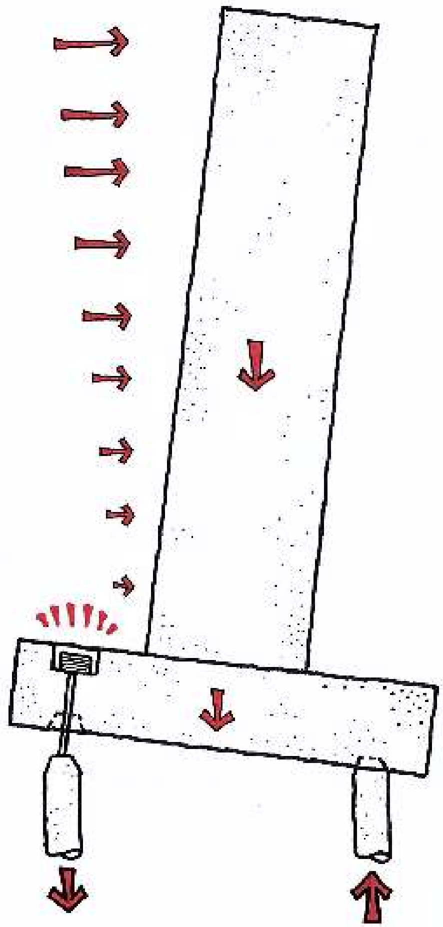

spherical bearing
clevis shaft plate
shaft restraint
shaft
cylinder end-cap
lead displaced
shaft bulb
cylinder
buckling restraint sleeve
combined end-cap clevis
spherical bearing
Damper at rest
Damper engaged


Compression
Uplift
Sfiff gap element at the mat-pier interface in compression
Soil spring + seismic pier in compression
Damper engaged in tension
Seismic pier in tension

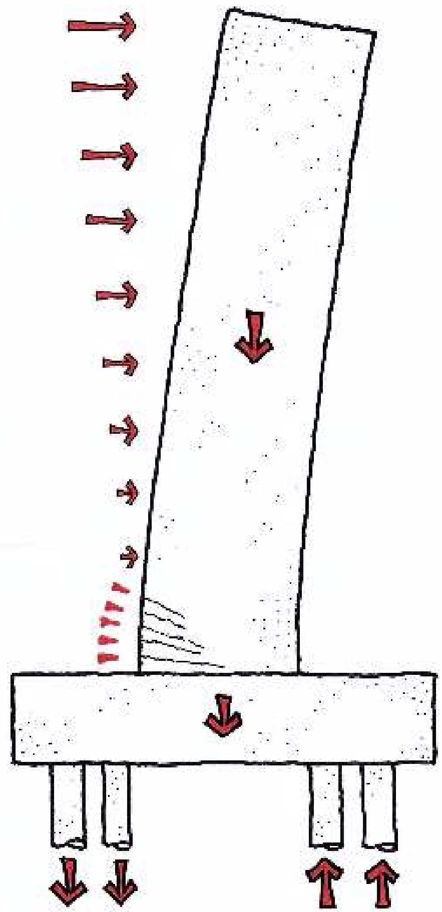
Damper Design
Testing & Fabrication



Performance Based Design

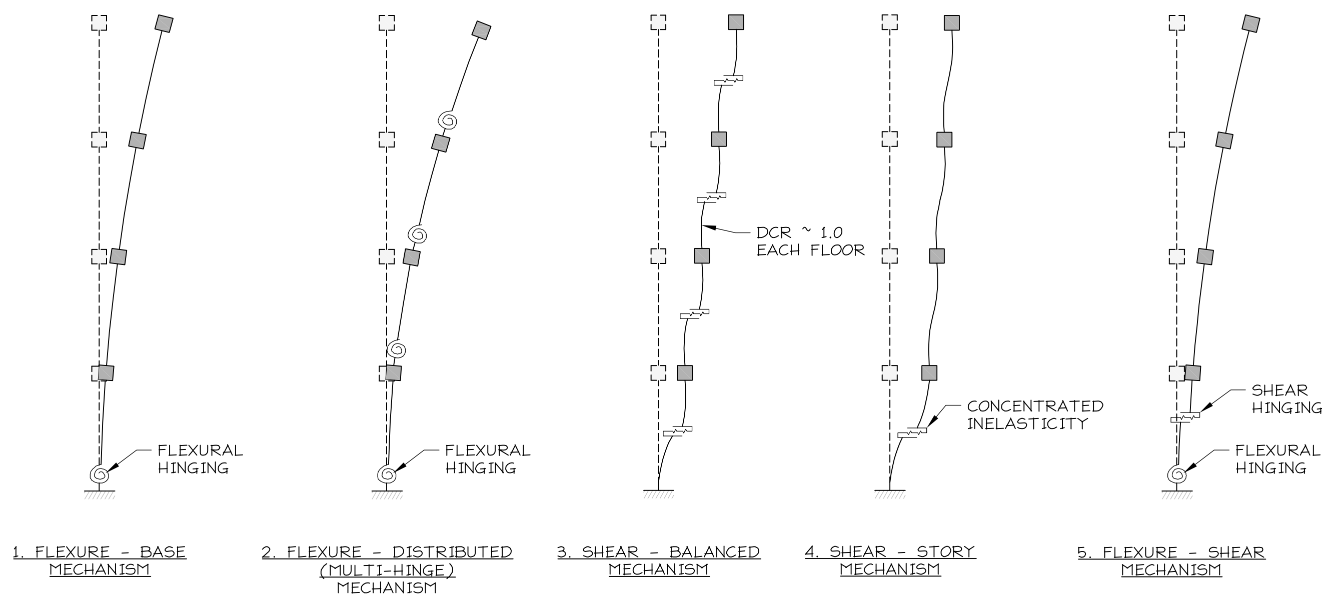


Conventional Design



Mechanisms Validated w. Capacity Design

2

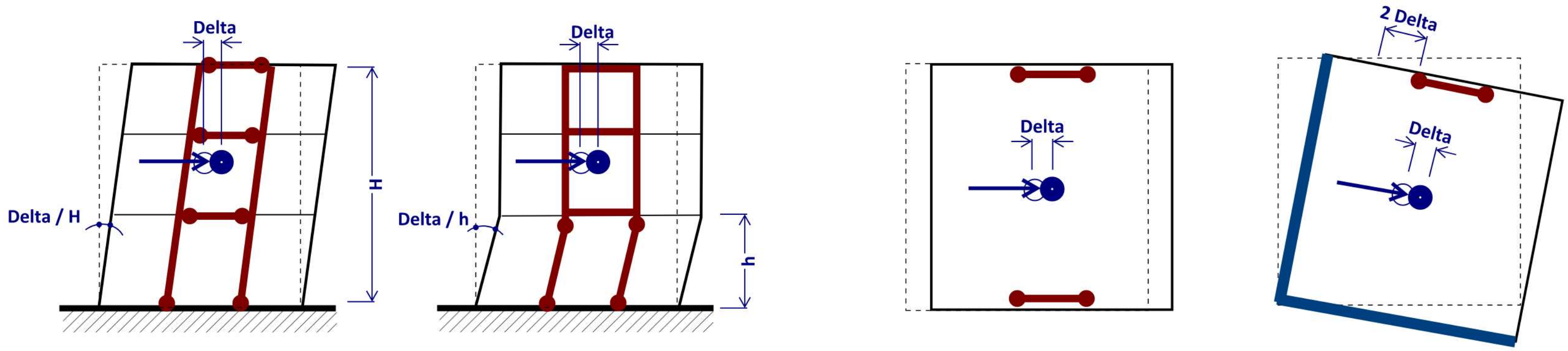


Need a formal protocol for event hierarchy
Concerns of rogue mechanisms

Code: Numerous prescriptive requirements (material and systems)

Account for Localization

Use geometric relationships to define demands

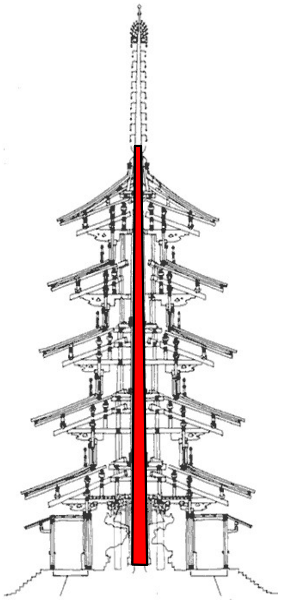


Code: Preclude Irregularities (story and plan)

4

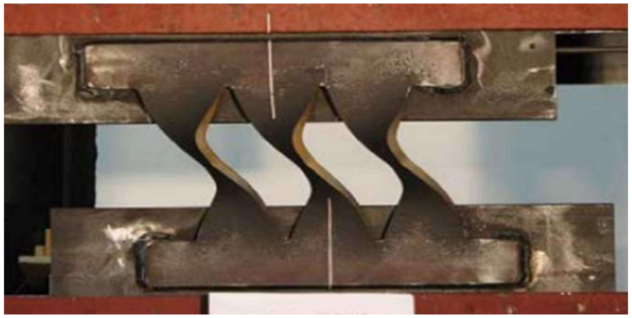
Account for Novel Distribution Systems

(spines)



Code: Strong-column weak-girder (MFs), discouraging shear mechanisms (conc. walls)

Use Defined Non-liner Components

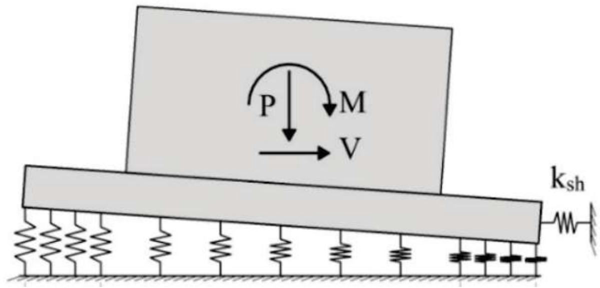


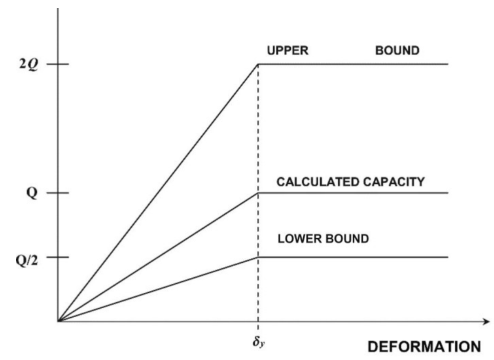
Plastic Hinge Capacities from ASCE 41
Dampers & other Fuses (yielding plates)

Code: Defines strength-displacement limits and detailing at system level

Utilize Foundation Uplift Mechanisms

Define mechanism and preclude compression failures

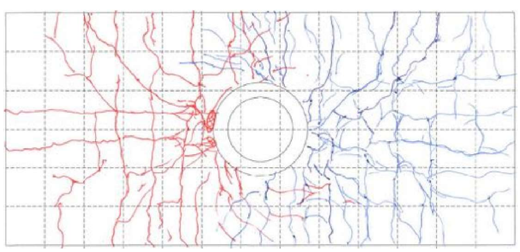


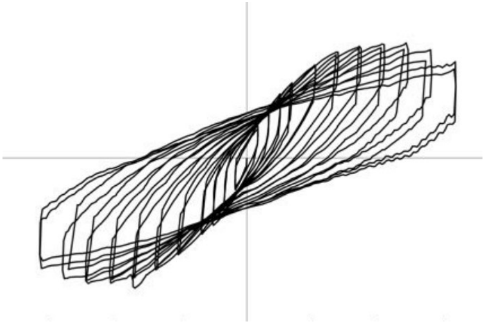


Code: Opaque in ASCE 7, high uplift "m" factor in ASCE 41

7
Enhance Gravity Deflection Compatibility Checks

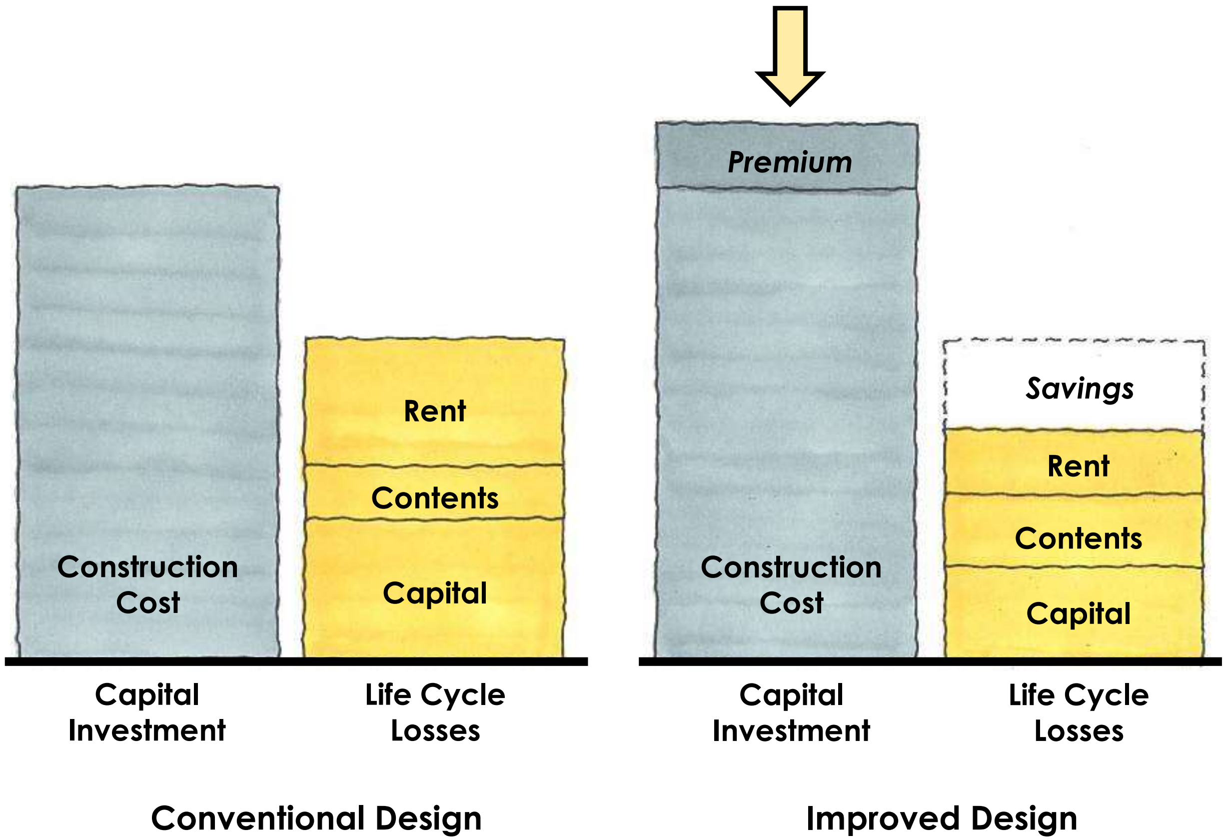
Define Gravity Drift Limits for Materials (steel, conc, wood)





Code: Defines and limits drifts on a lateral system level

Life Cycle Analysis

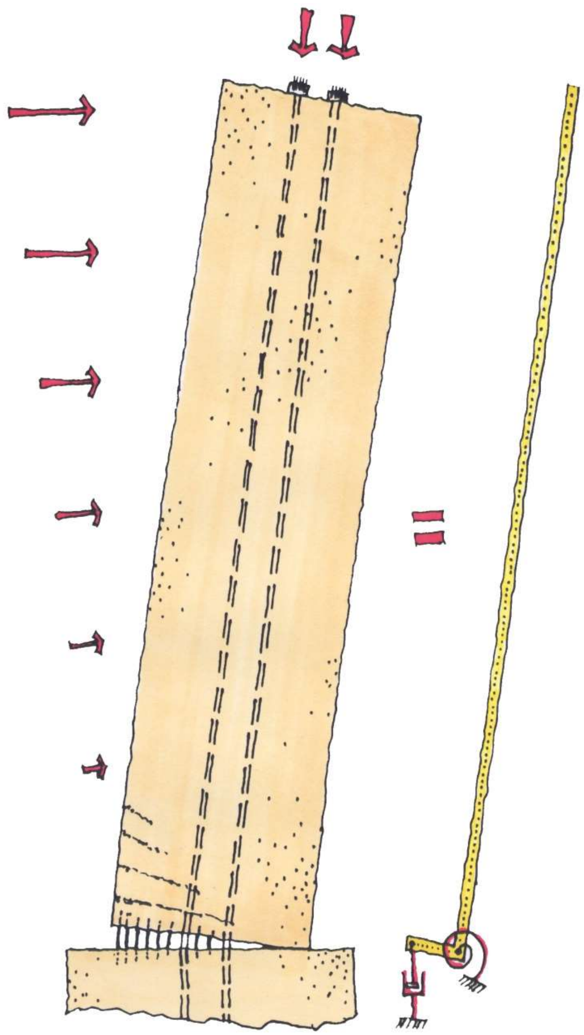


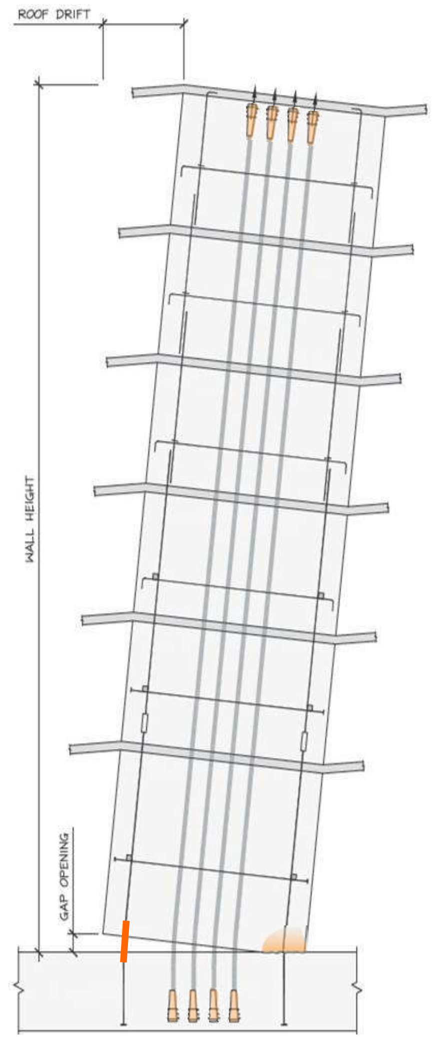
“Price is what you pay, value is what you get…”

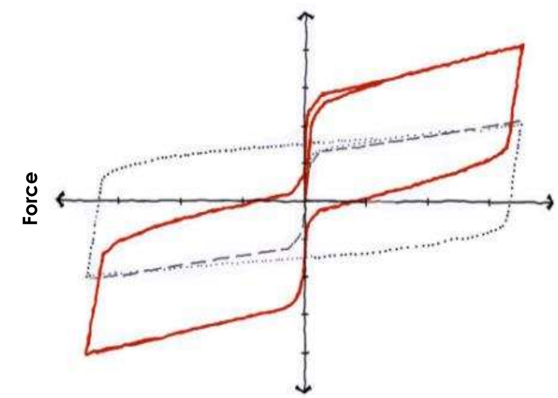
Warren Buffett

San Francisco Public Utilities HQ

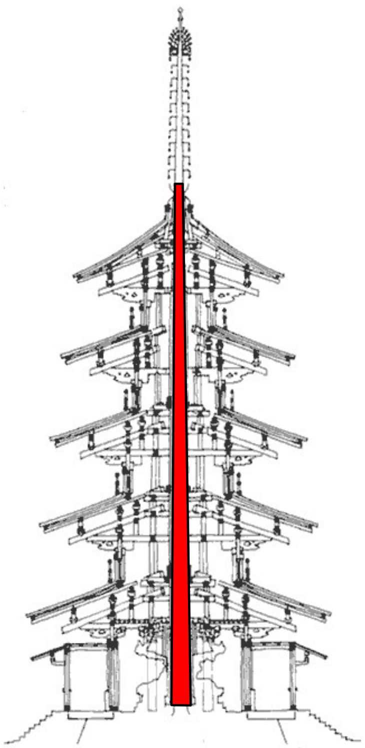
Architect: KMD/Stevens

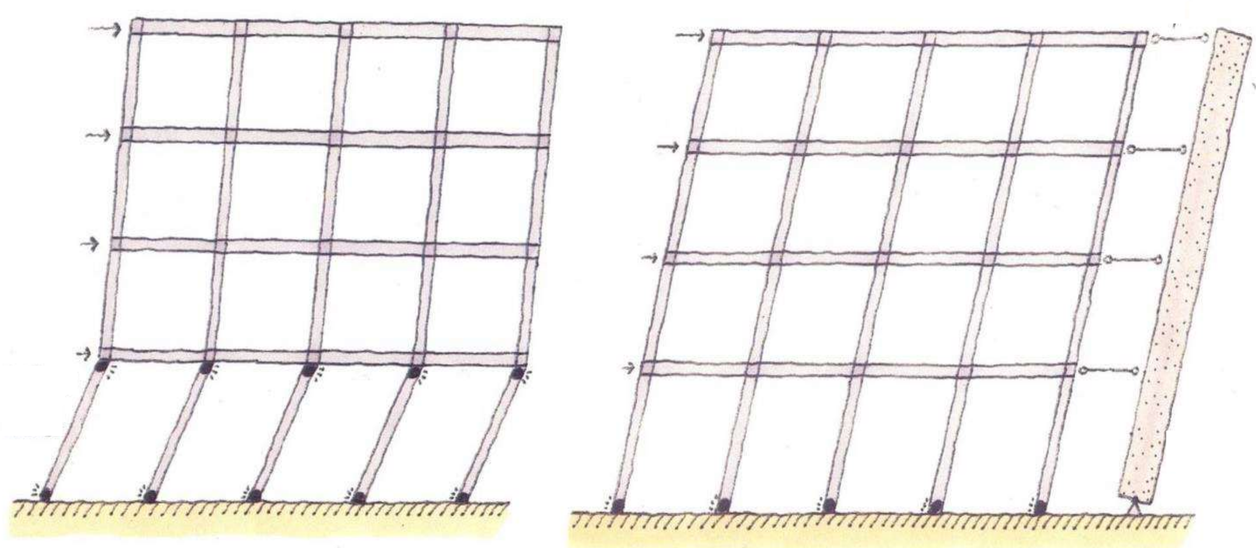


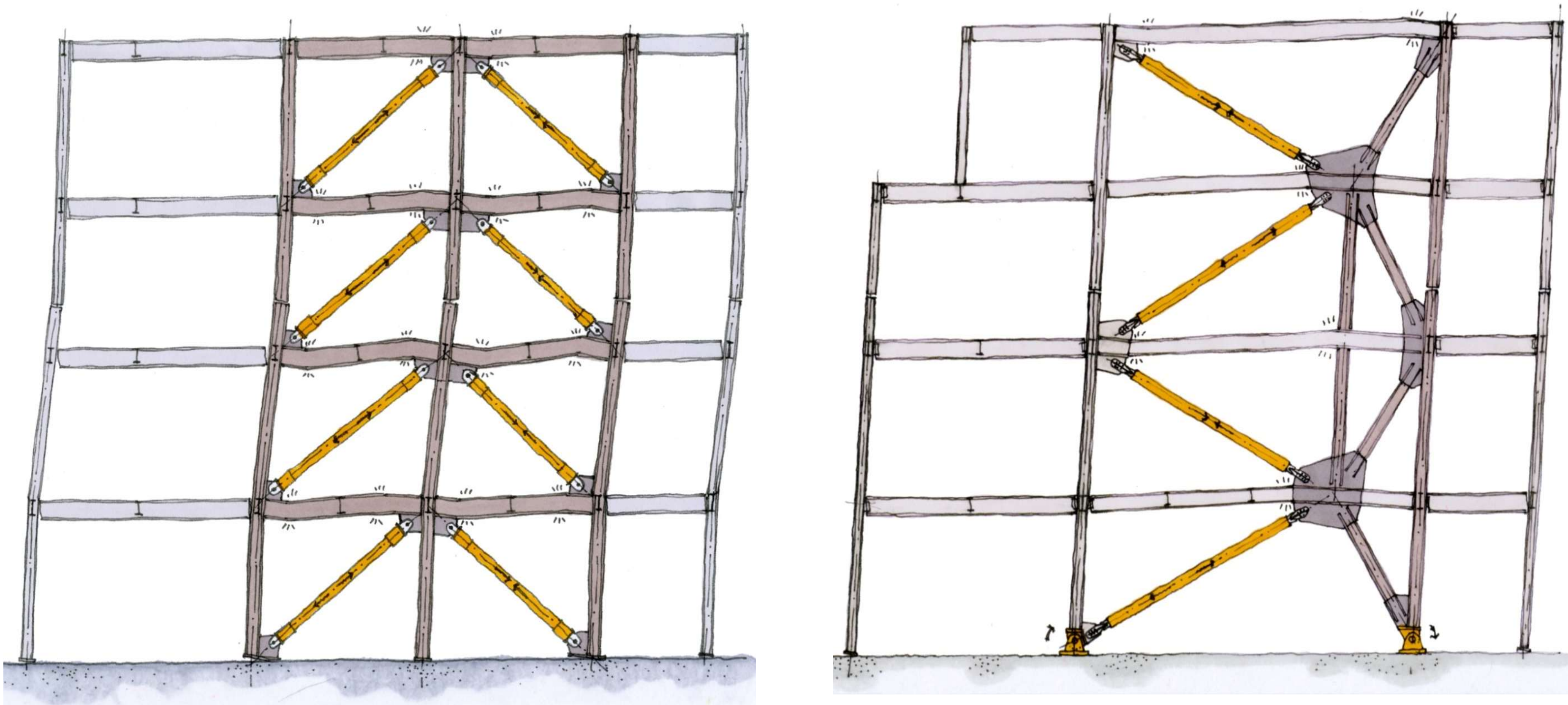

ROOF DRIFT
WALL HEIGHT
GAP OPENING

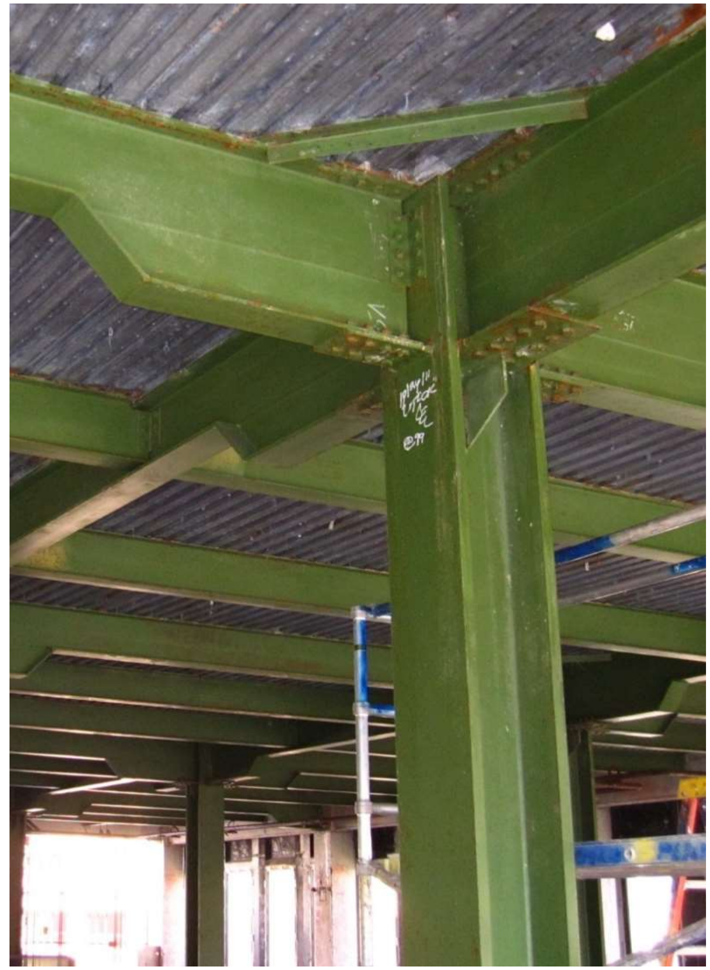

Force
Displacement

Mode-Shaping Spines

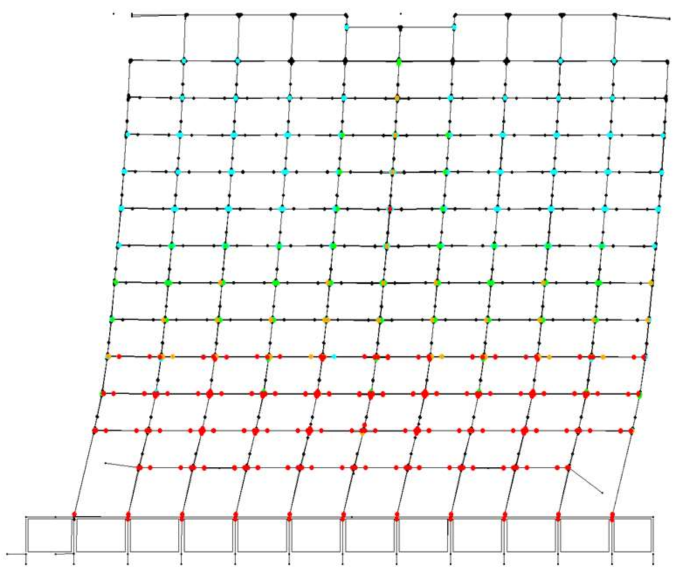




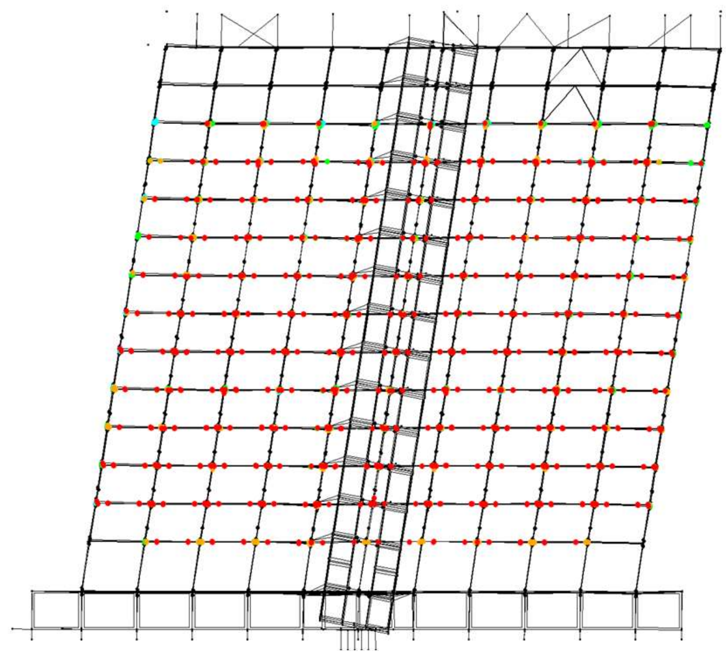




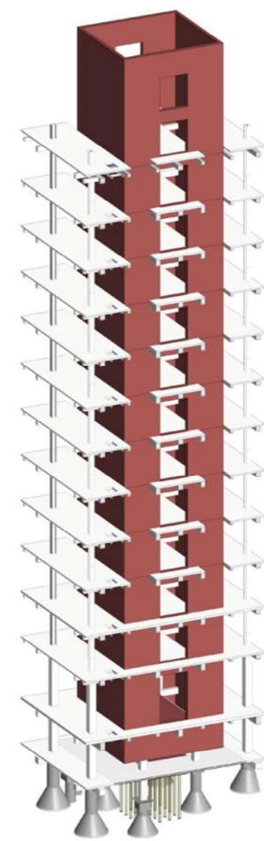
soft-story frame retrofit with a mode-shaping spine



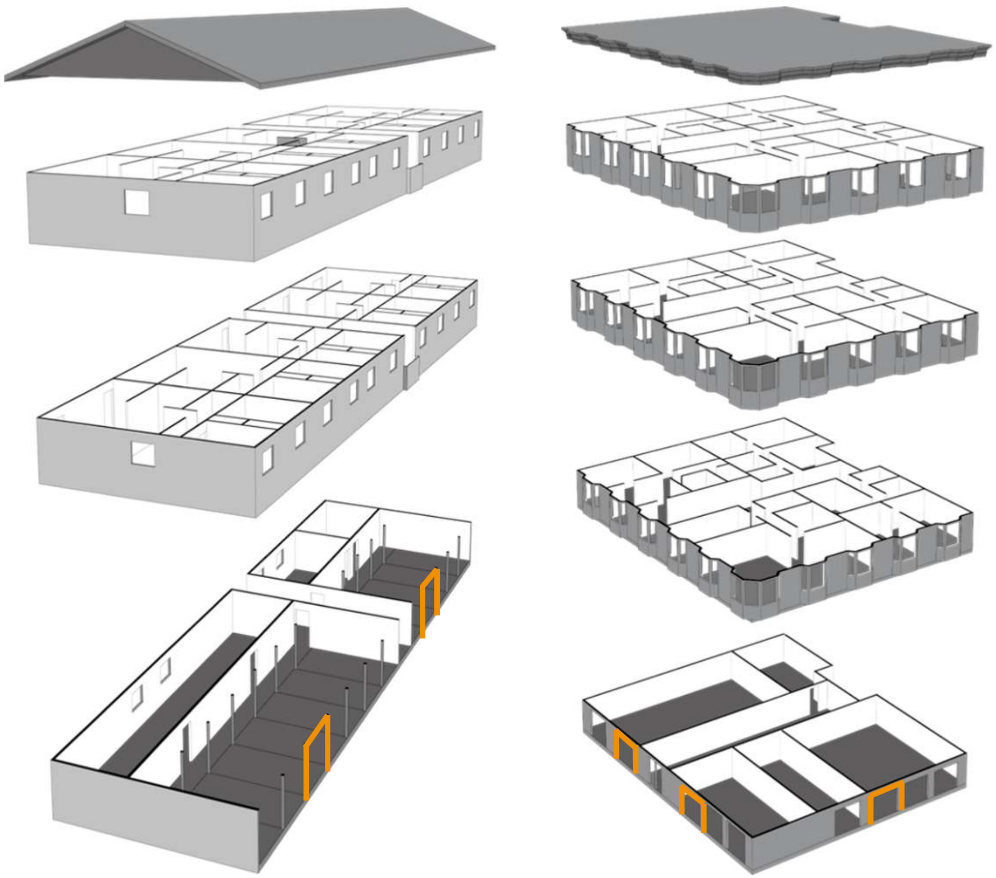
Before Retrofit



After Retrofit



FEMA 807: Soft-story Retrofit Guidelines




G-12

Code System Values

$$R, C_d$$

+ lots of prescriptive rules

Find the Optimal Strategy

&

IT 13 Design Method

purpose

Facilitate Creation of Novel Lateral Systems

Outline Design Steps and Design Checks

Remove Code Impediments

Method Outline

1 Simplified NL Displacement Demands

⇩

2 Mechanisms Validated w. Capacity Design

⇩

3 Account for (not prevent) Localization (including P-delta)

⇩

4 Account for Distribution Systems (spines)

⇩

5 Use Plastic Hinge Capacities from ASCE 41 (component modularity)

⇩

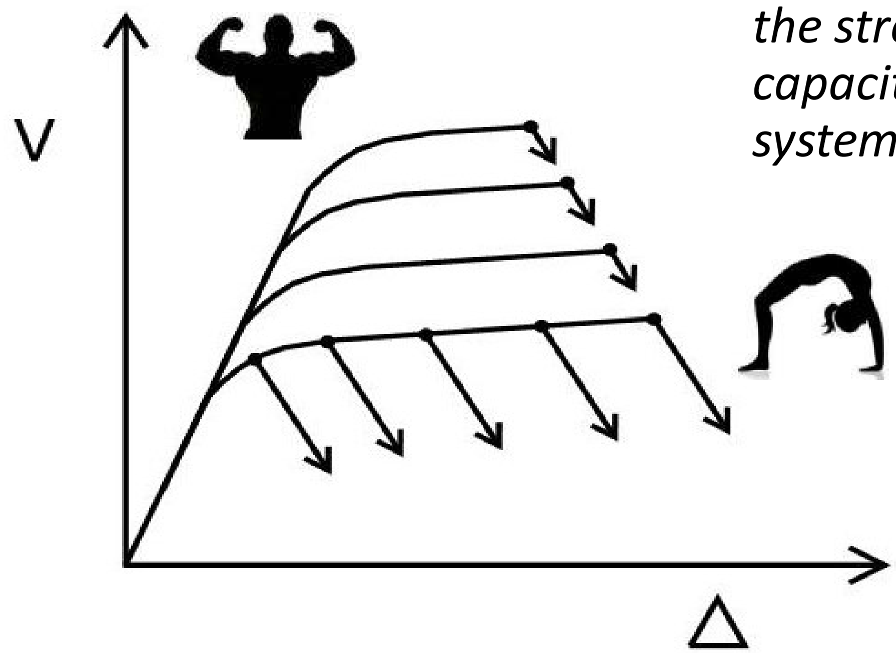
6 Account for and Utilize Foundation Mechanisms

⇩

7 Enhance Gravity Deflection Compatibility Checks

Simplified NL Displacement Demands

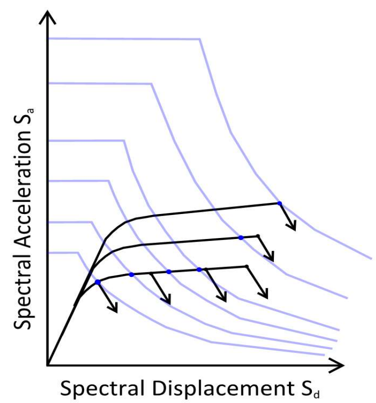
1



Goal: Allow designers to determine the strength and displacement capacity requirements for any system.

Simplified NL Displacement Demands

Determine strength & displacement demands for any system in any seismic environment
(SDOF using only strength, stiffness, equivalent damping)



Displacement Based Design

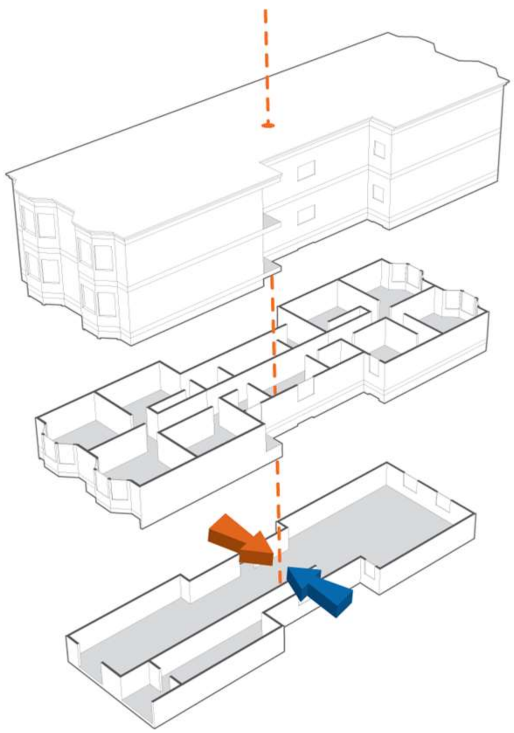
Capacity Spectra Method

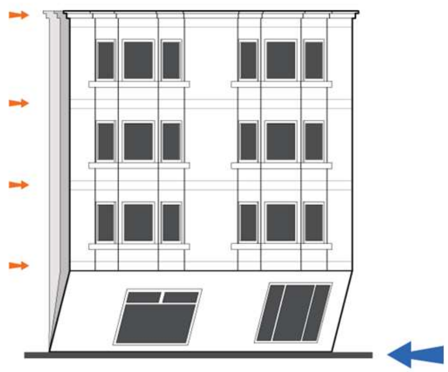
Coefficient Method

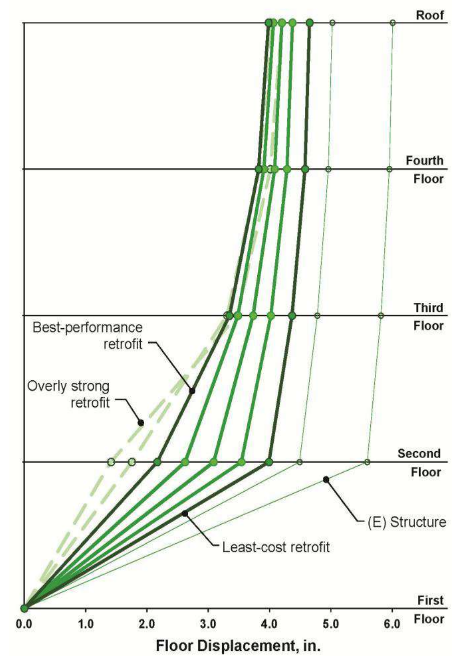
Code: System Table 12.2-1 ASCE 7 or FEMA P-695

Weak-story Localization

(FEMA P-807)

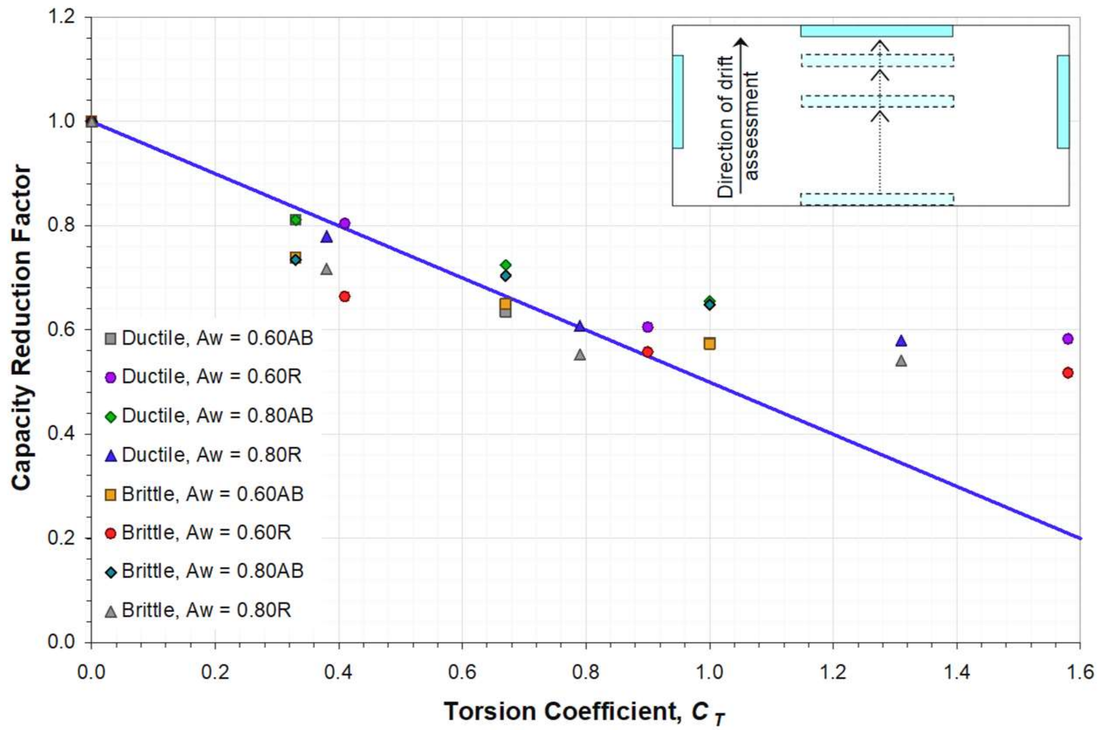




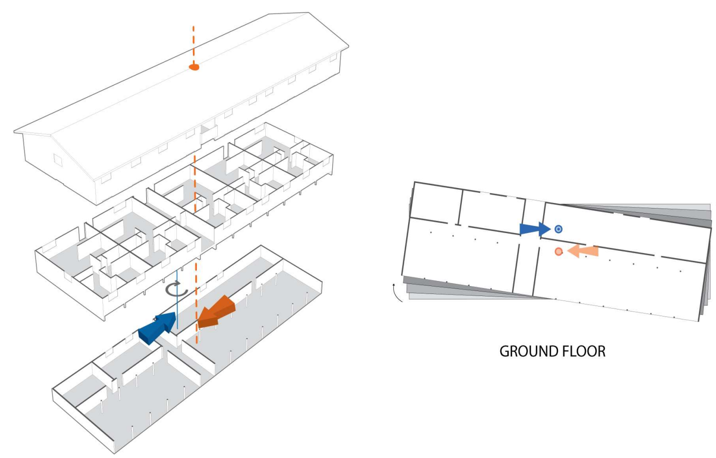


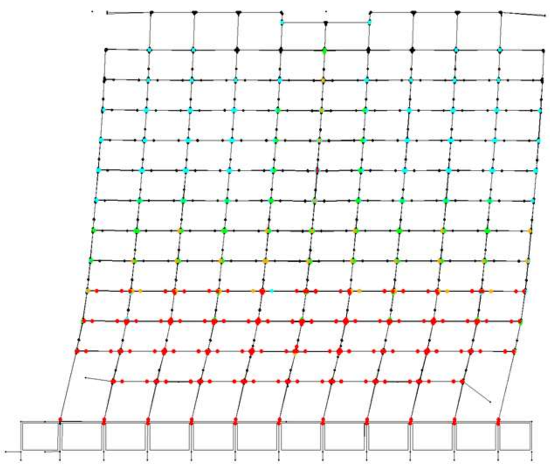
Torsion Localization

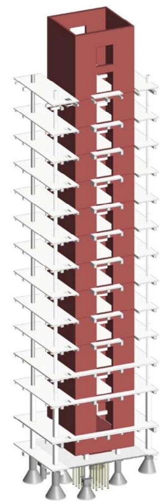
(FEMA P-807)

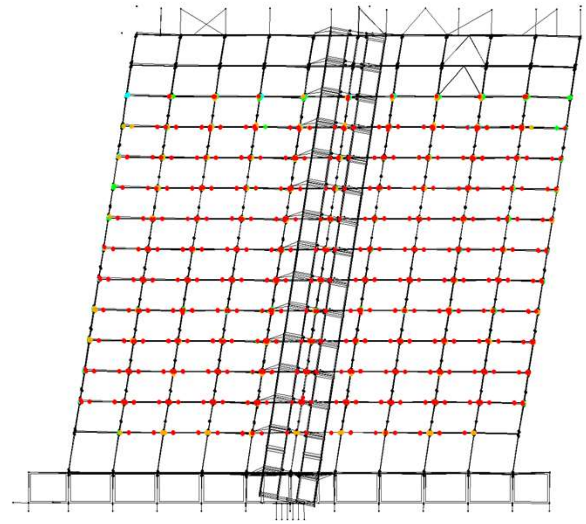


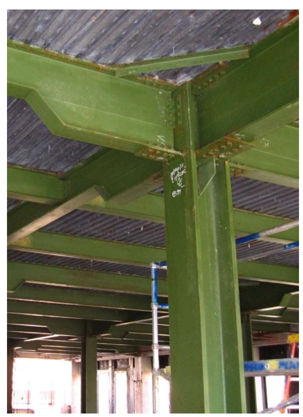
Localization requires fewer elements to do more work, resulting in increased ductility demand.

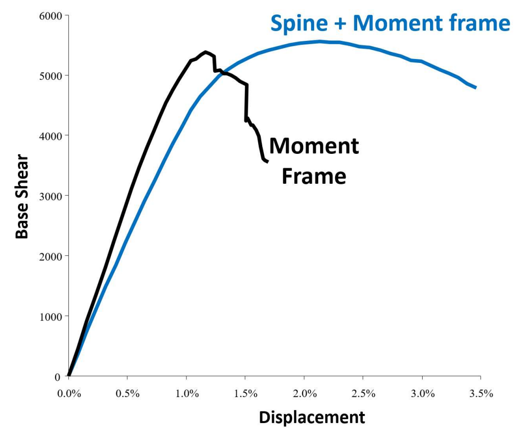




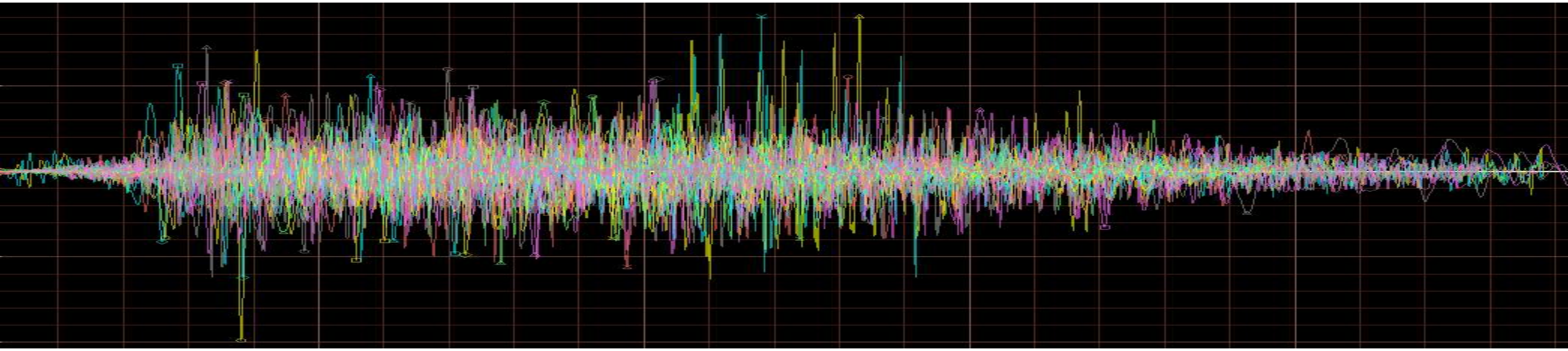







Spine + Moment frame
Moment
Frame
Base Shear
Displacement
6000
5000
4000
3000
2000
1000
0
0.0%
0.5%
1.0%
1.5%
2.0%
2.5%
3.0%
3.5%

FEMA P-695 Validation



Universal Table of Design Coefficients


Strength/Ductility Couplets

~ensures that designs would meet the collapse performance under the MCE hazard~

Run P-695 validation on SDOF models

~builds on FEMA 440a~

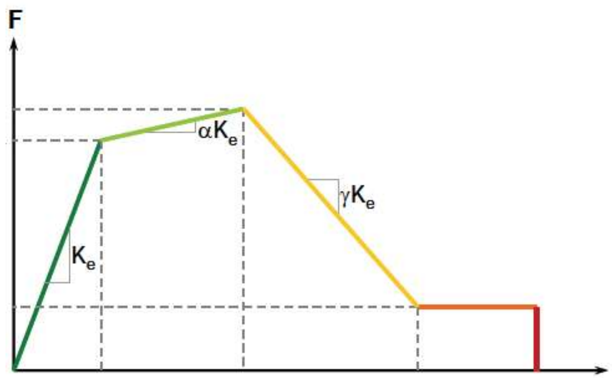
Basic parameters

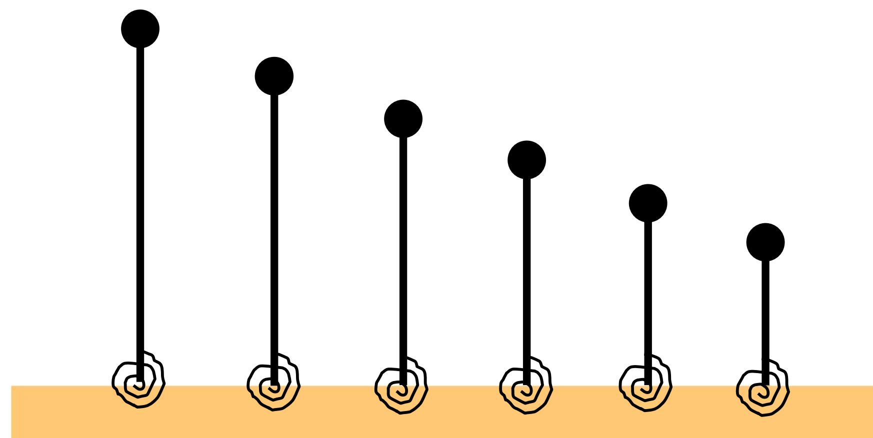
~strength, elastic stiffness, post-yield stiffness, ductility, “pinchiness” ~

Backbone requirements

~stable yield plateau, limit degradation, no abrupt strength loss (cliff), anything else that is needed~

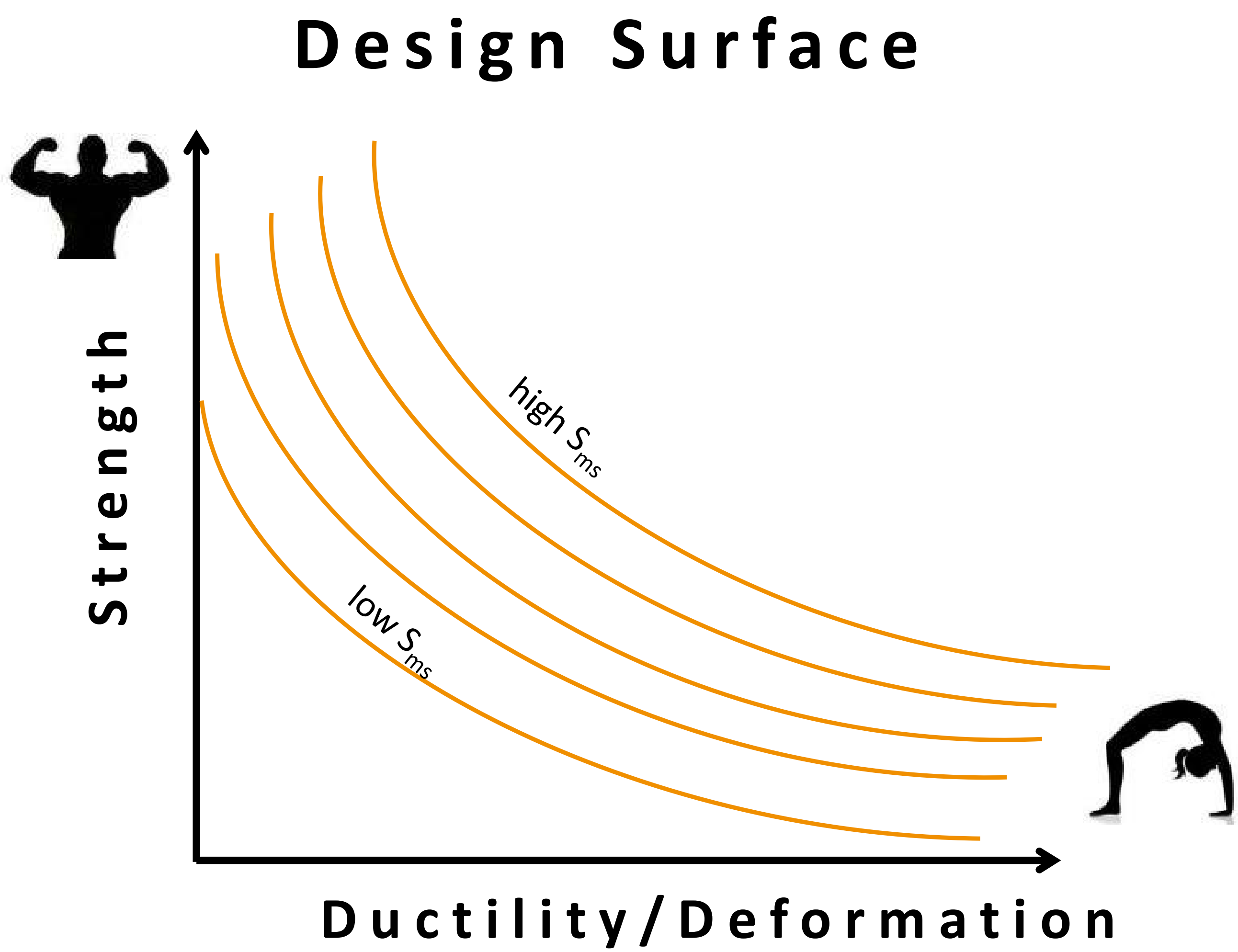
Design Space of Surrogate Structures



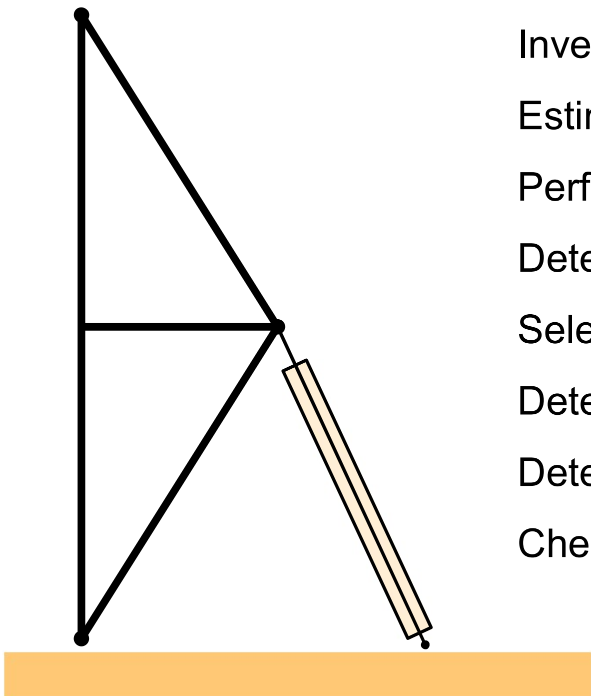


Run FEMA P-695 analyses on surrogate SDOF models

Vary stiffness, ductility, degradation, plateau


Design Surface
Strength
high S_{ms}
low S_{ms}
Ductility/Deformation

Determine Lateral Demands



Invent a novel lateral system & define mechanism

Estimate stiffness, yield strength

Perform pushover analysis

Determine backbone parameters

Select best-fit surrogate SDOF that meets performance criteria

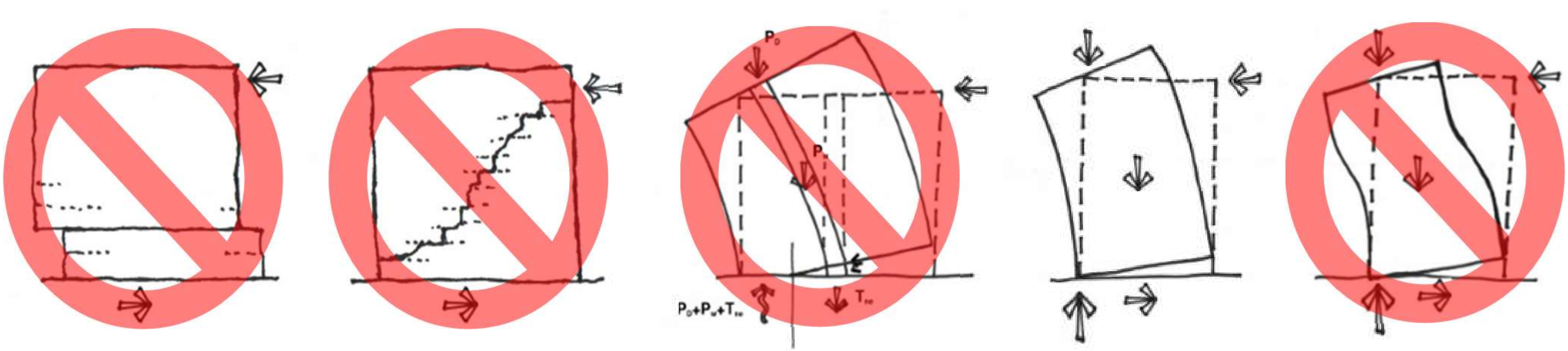
Determine global ductility demand

Determine local ductility demands (step 3…)

Check local ductility capacity … iterate

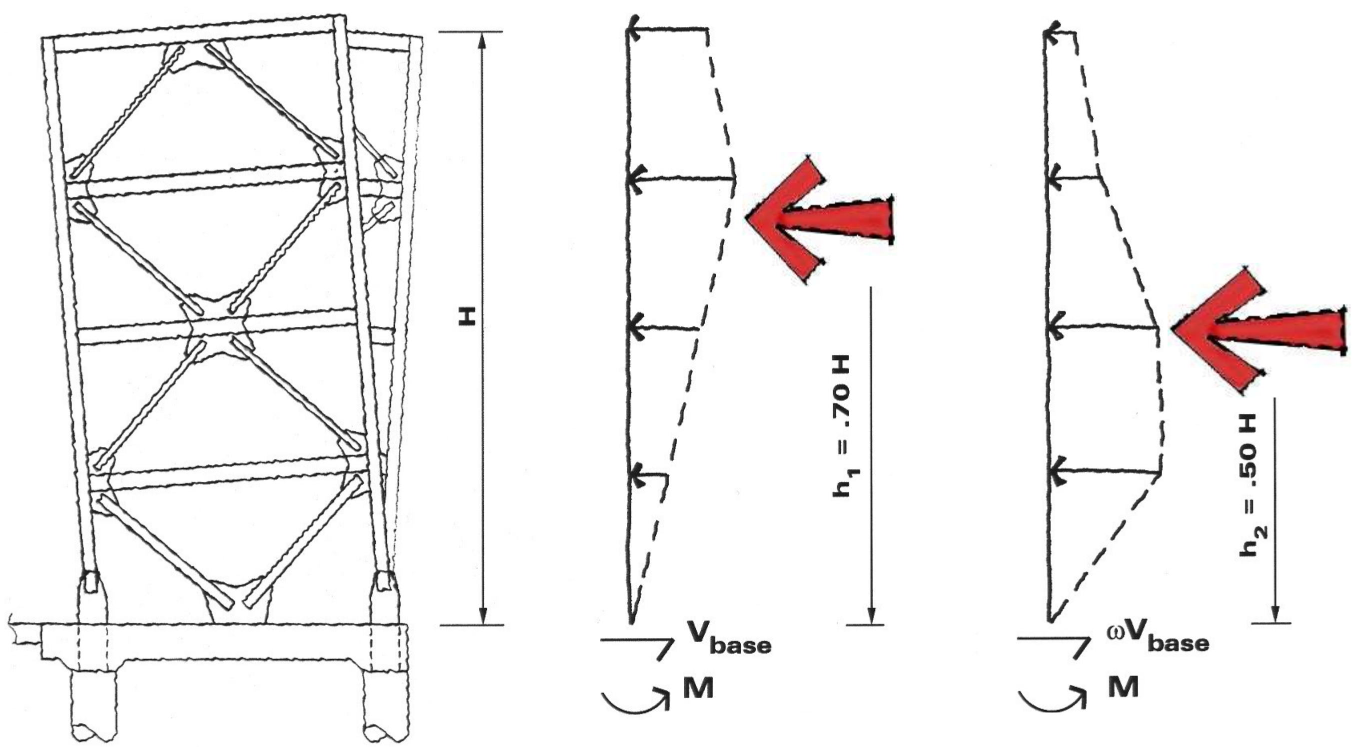
I s s u e s / C o n c e r n s

(rogue mechanisms)



I s s u e s / C o n c e r n s

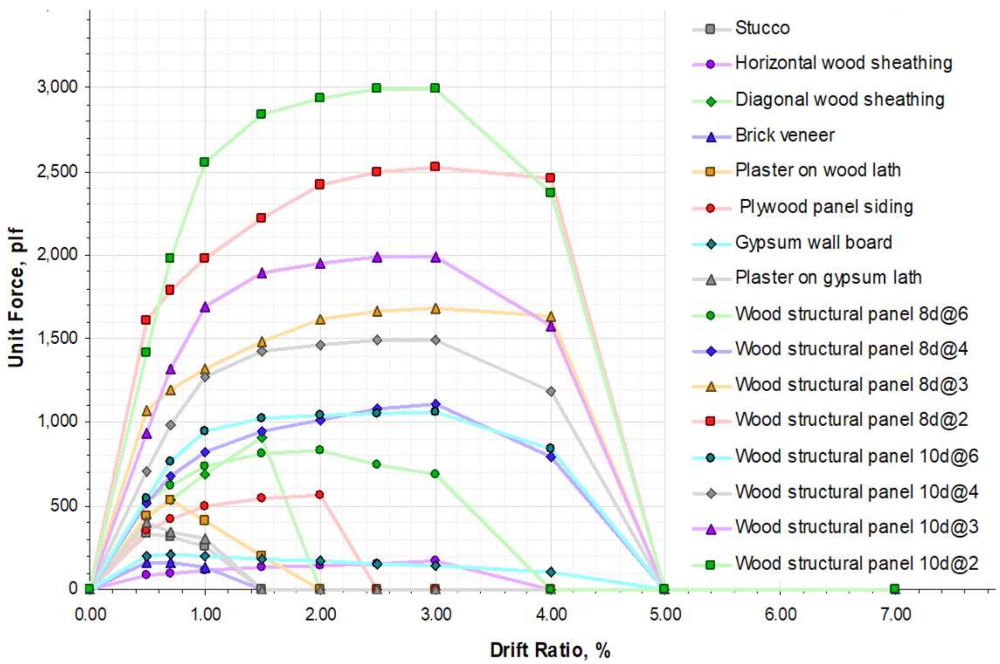
(higher mode effects)

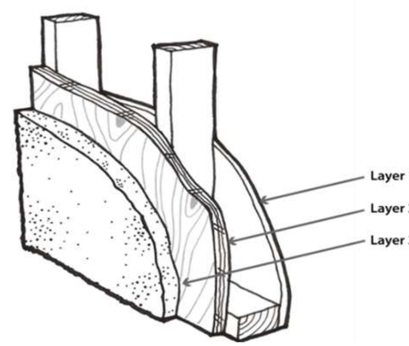


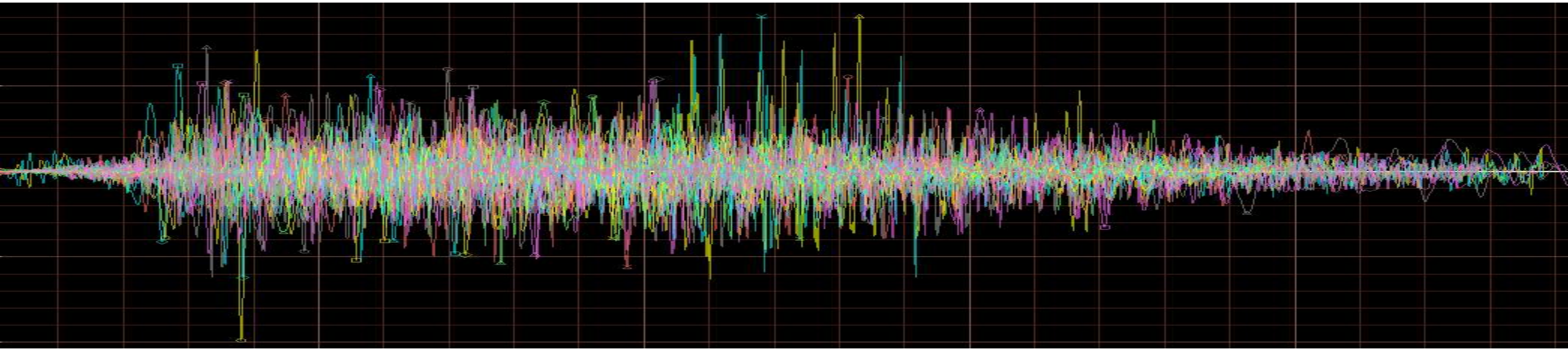
New buildings are very safe, but they are designed to sustain damage.

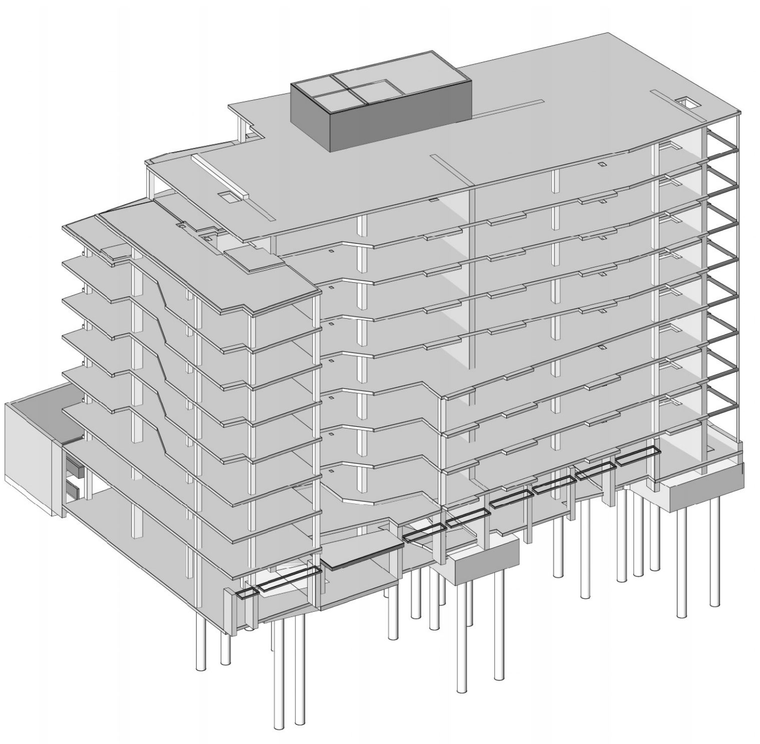
High Repair Costs and Loss of Use

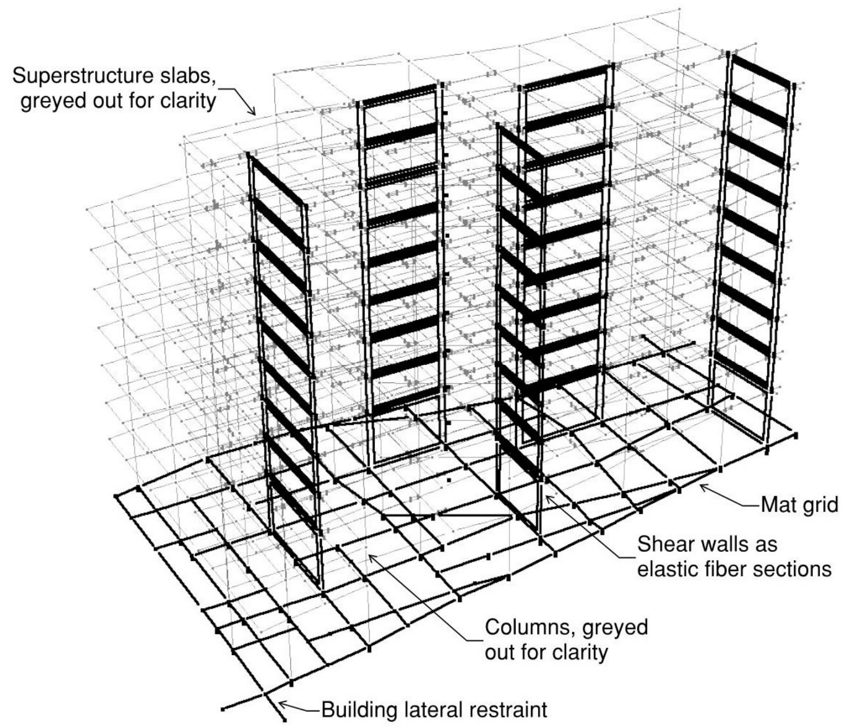
Finishes Are Structure










Superstructure slabs, greyed out for clarity
Mat grid
Shear walls as elastic fiber sections
Columns, greyed out for clarity
Building lateral restraint

US Resilience Council

Gold Rating

First Ever Rating for Multi-Unit Housing

National Council of Structural Engineers Associations

2020 Outstanding Project Award

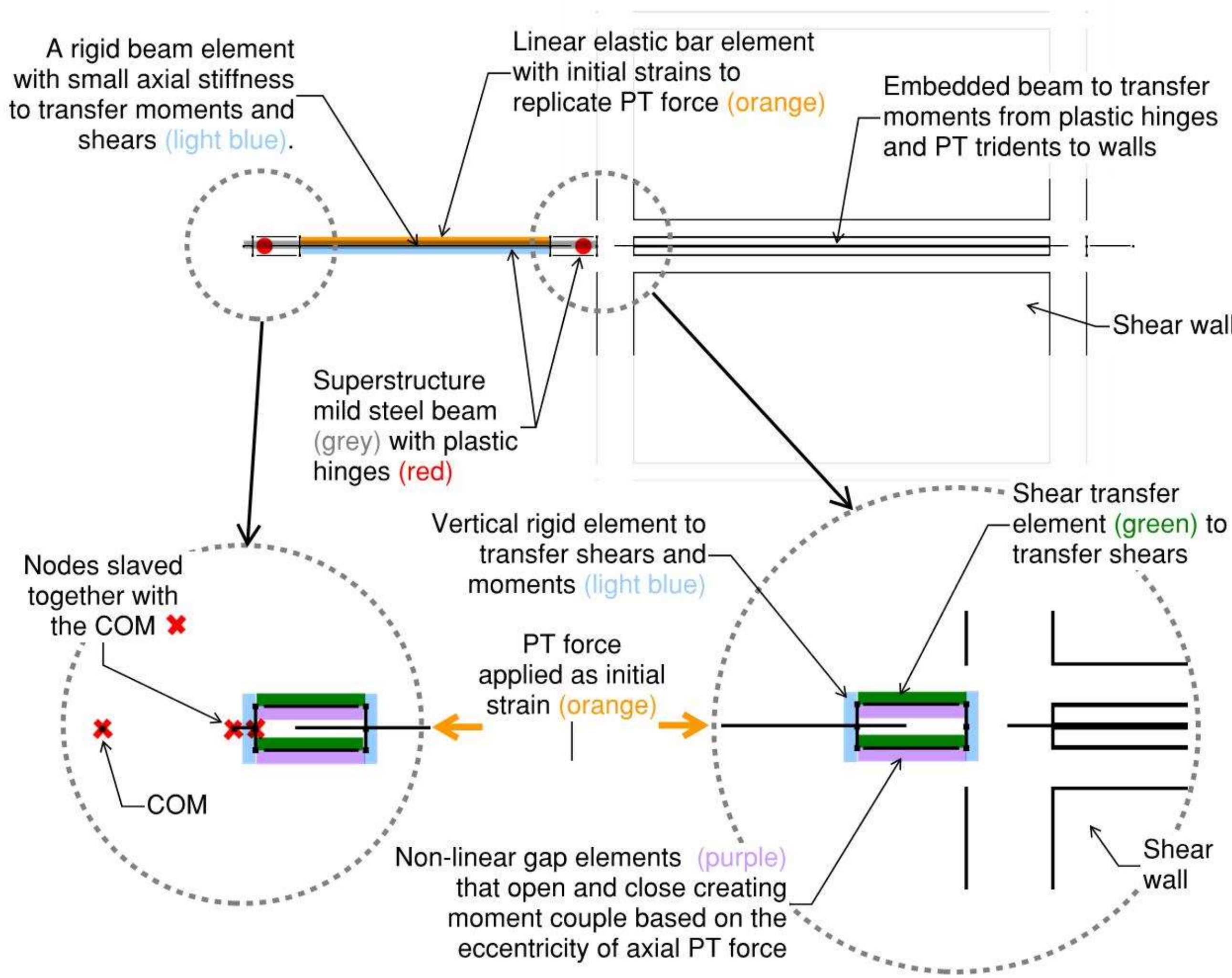
($30M-$80M)

design goal

Achieve Highest Performance Possible

for

No Additional Cost

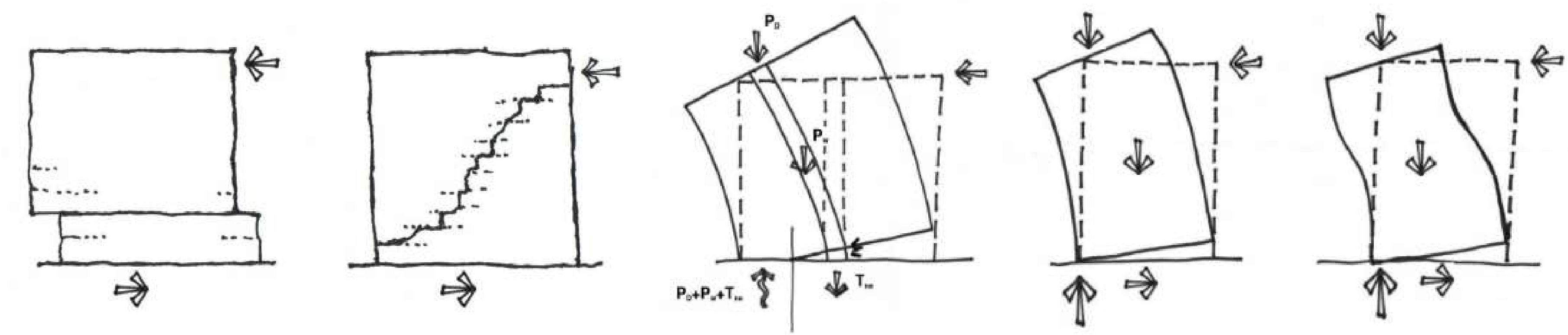

A rigid beam element with small axial stiffness to transfer moments and shears (light blue).
Linear elastic bar element with initial strains to replicate PT force (orange)
Embedded beam to transfer moments from plastic hinges and PT tridents to walls
Shear wall
Superstructure mild steel beam (grey) with plastic hinges (red)
Shear transfer element (green) to transfer shears
Vertical rigid element to transfer shears and moments (light blue)
Nodes slaved together with the COM
PT force applied as initial strain (orange)
COM
Shear wall
Non-linear gap elements (purple) that open and close creating moment couple based on the eccentricity of axial PT force

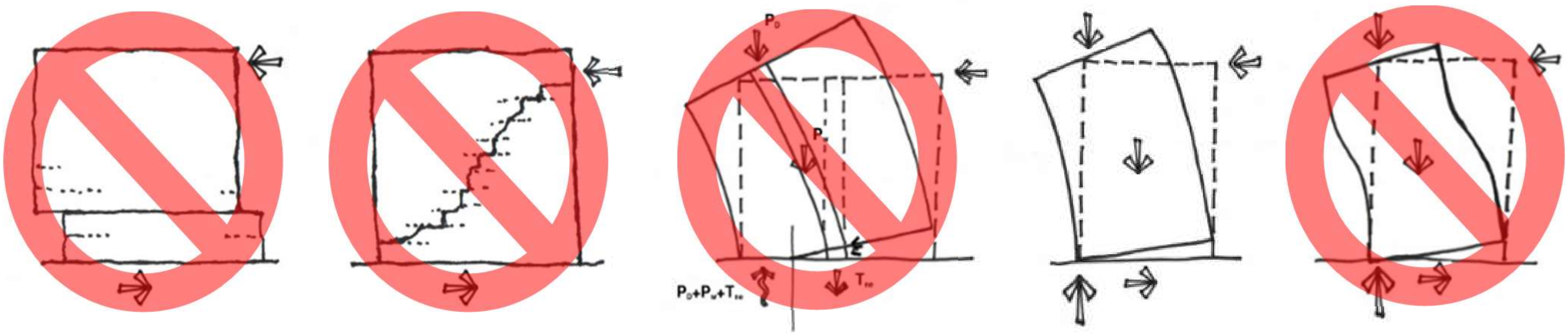
PT Concrete Rocking Walls

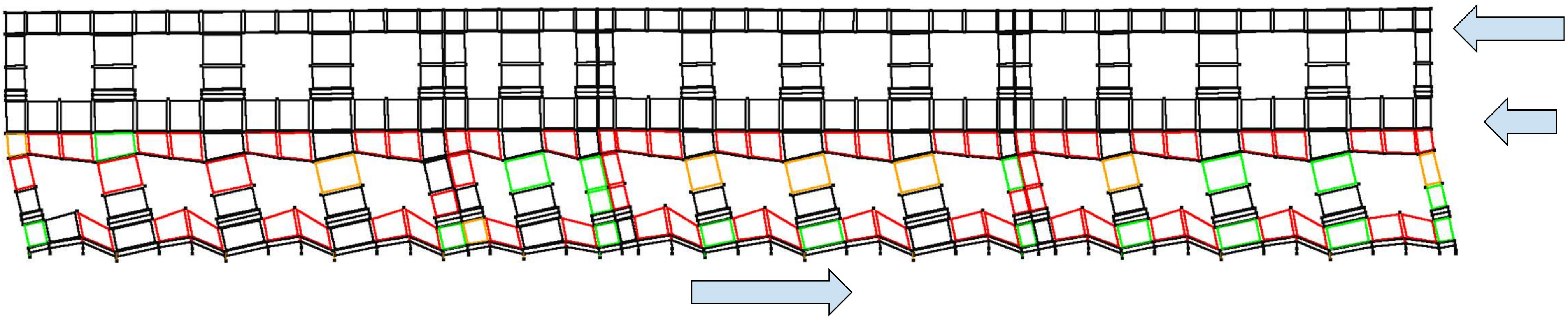
SF Public Utilities HQ
San Francisco

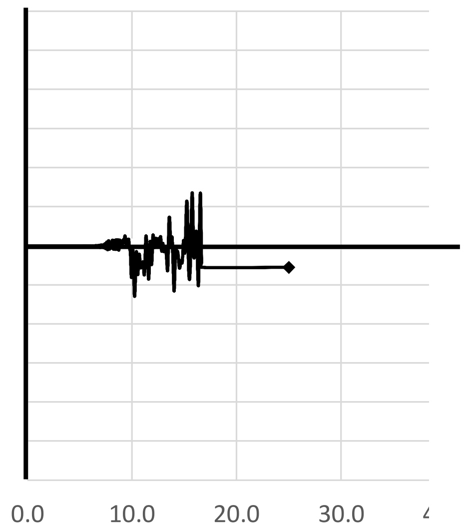
Architect: KMD/Stevens

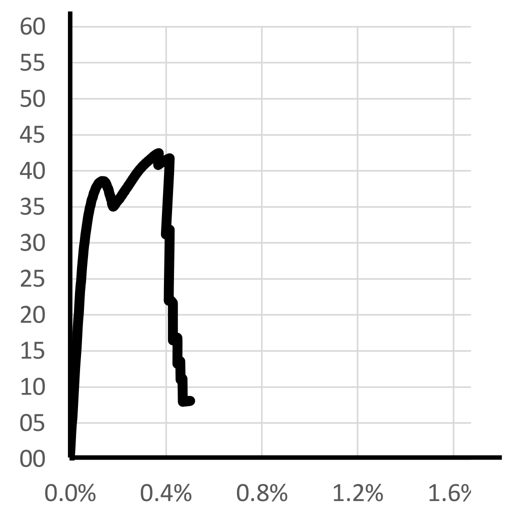
Complex Masonry Typology

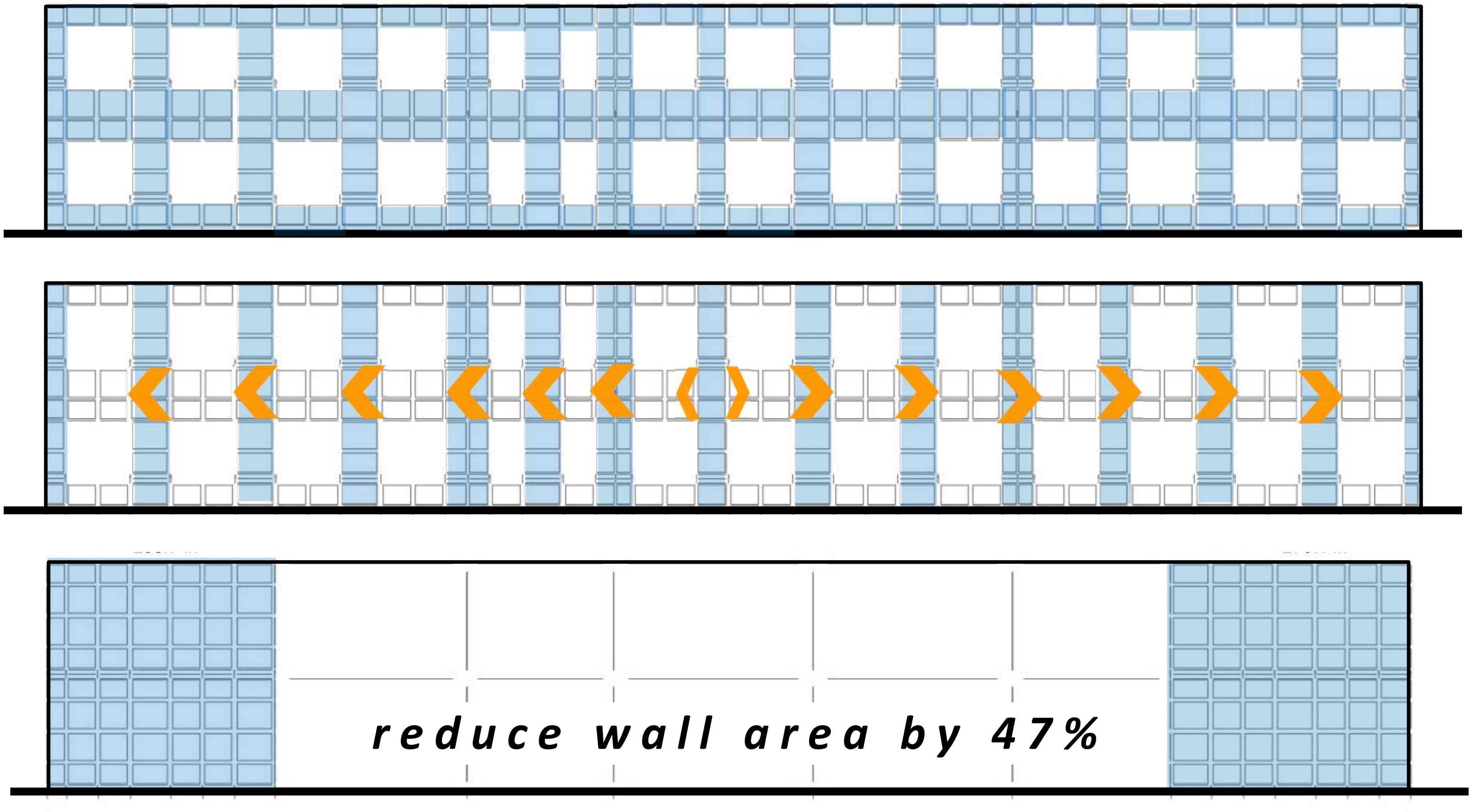

P_D
P_w
$P_D+P_w+T_w$
T_w


P_D

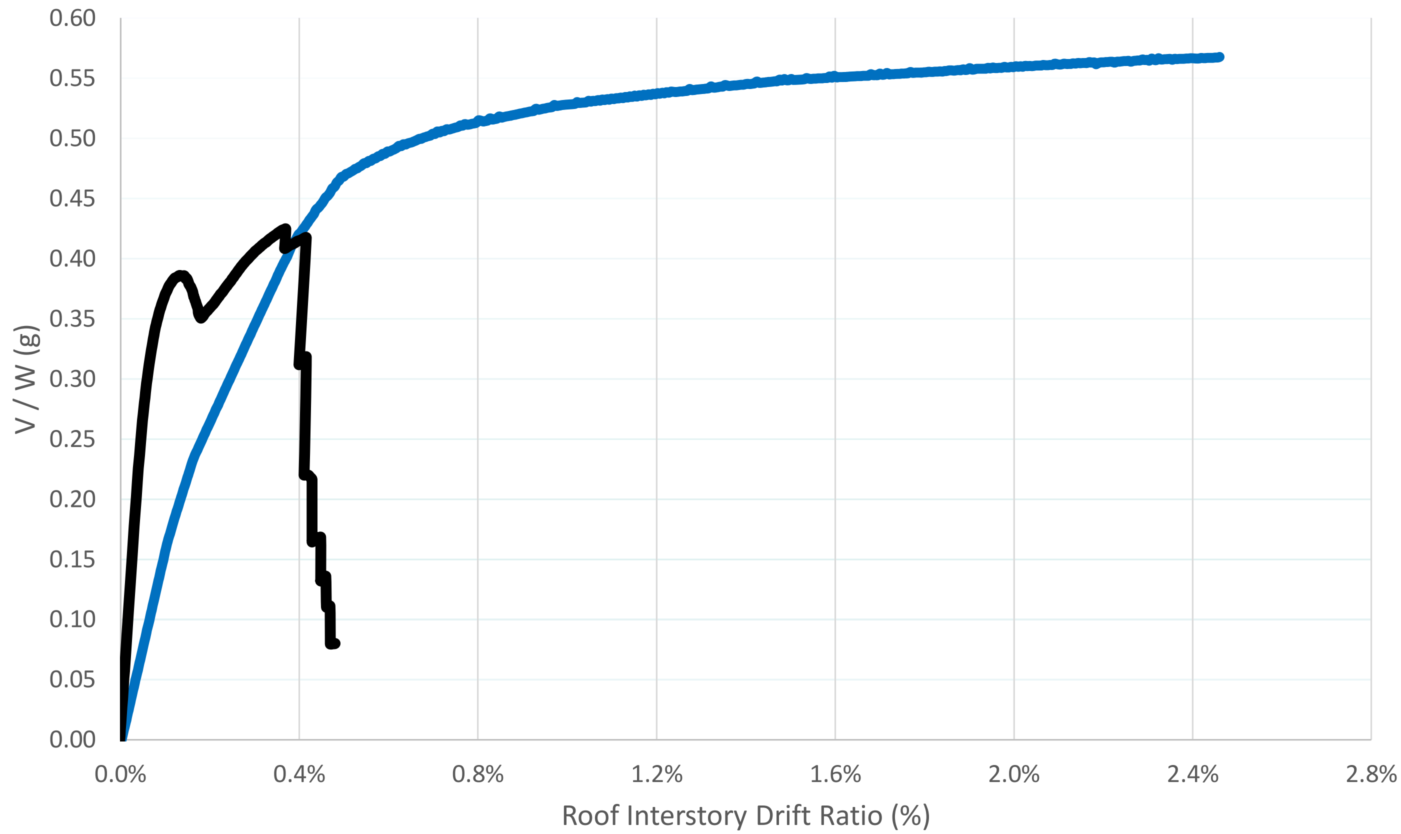


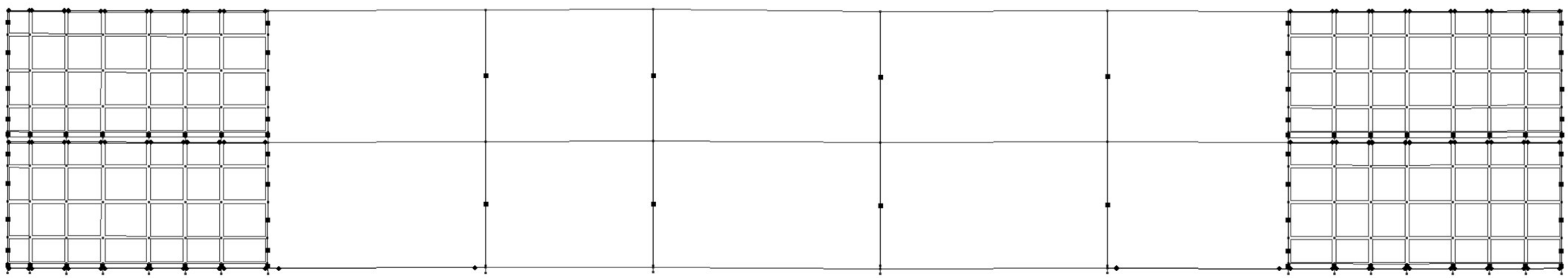

0.0
10.0
20.0
30.0

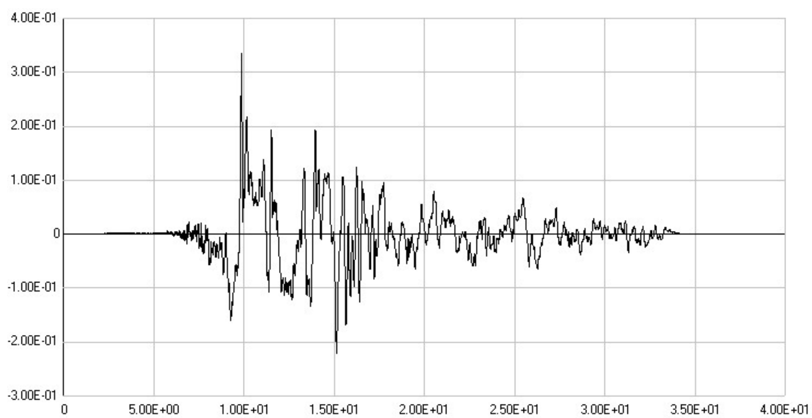

60
55
50
45
40
35
30
25
20
15
10
05
00
0.0%
0.4%
0.8%
1.2%


reduce wall area by 47%

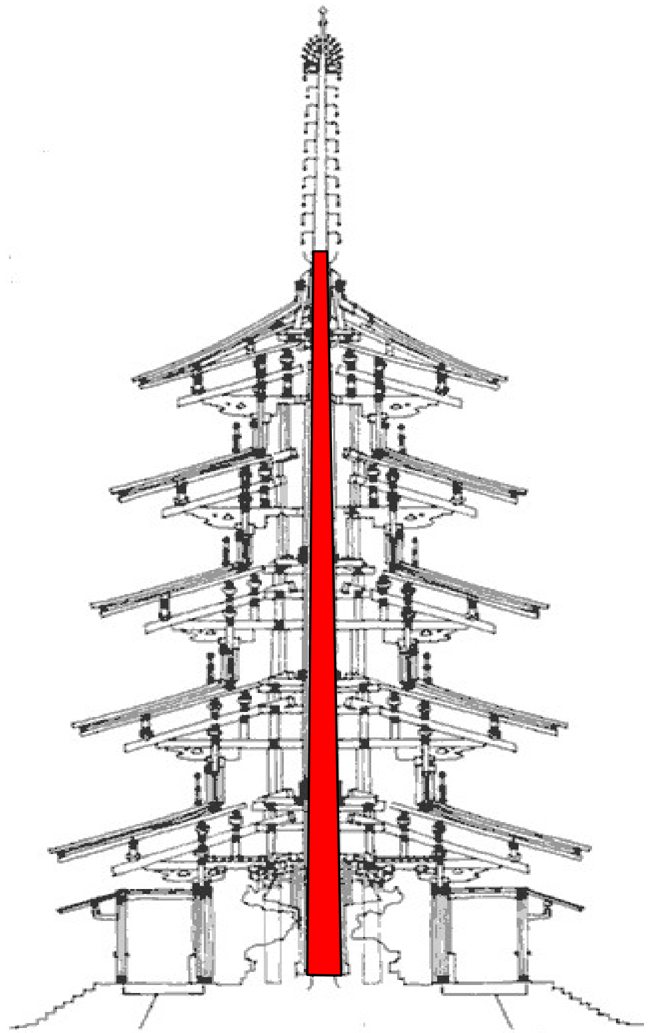
Pushover Curve Comparison

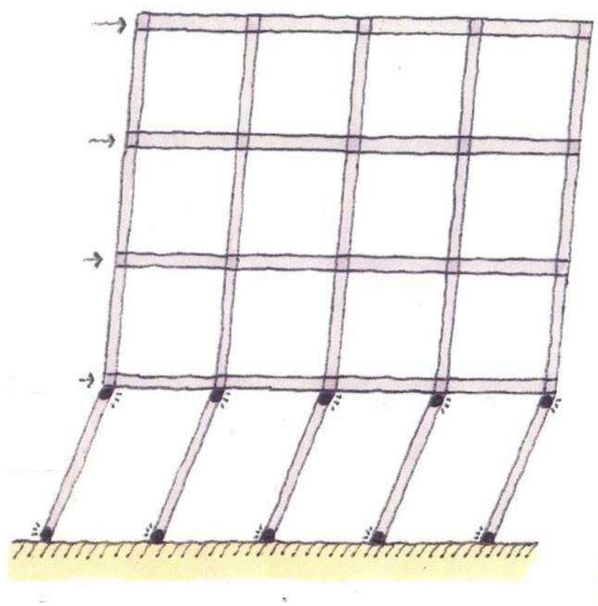


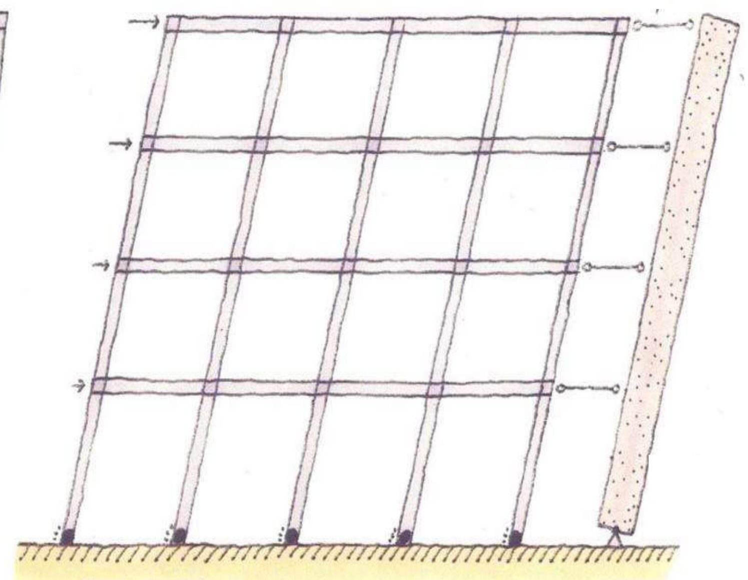


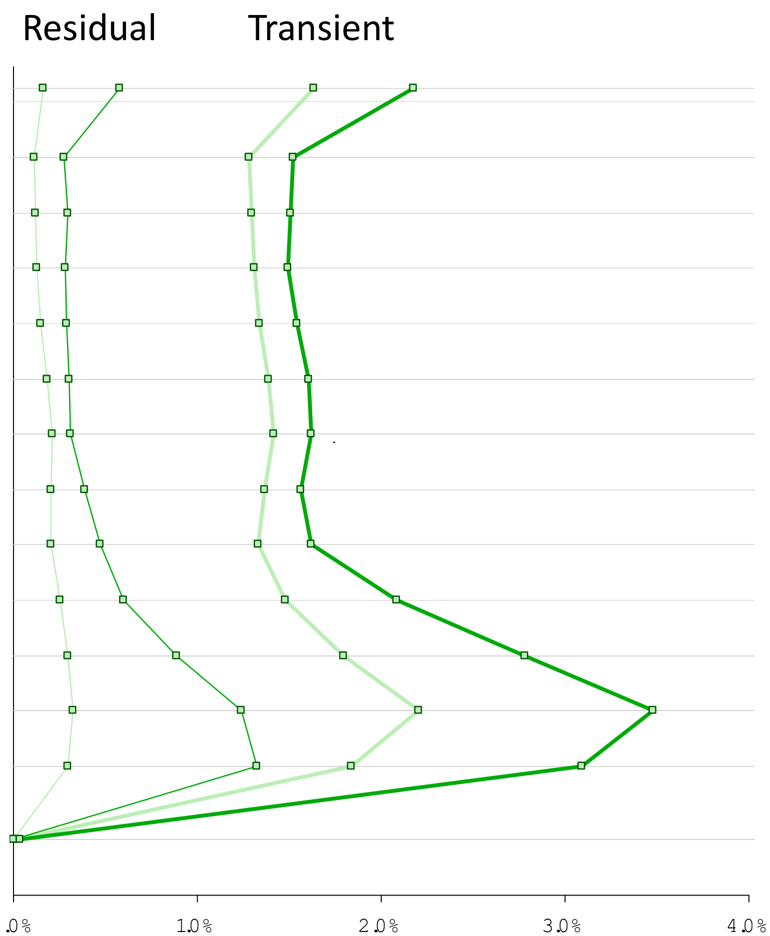


The 1999 İzmit **earthquake** (also known as the **Kocaeli**, Gölcük, or Marmara **earthquake**) occurred on 17 August at 03:01:40 local time in northwestern Turkey. The shock had a moment magnitude of 7.6 and a maximum Mercalli intensity of IX (Violent). ... The nearby city of İzmit was severely damaged.

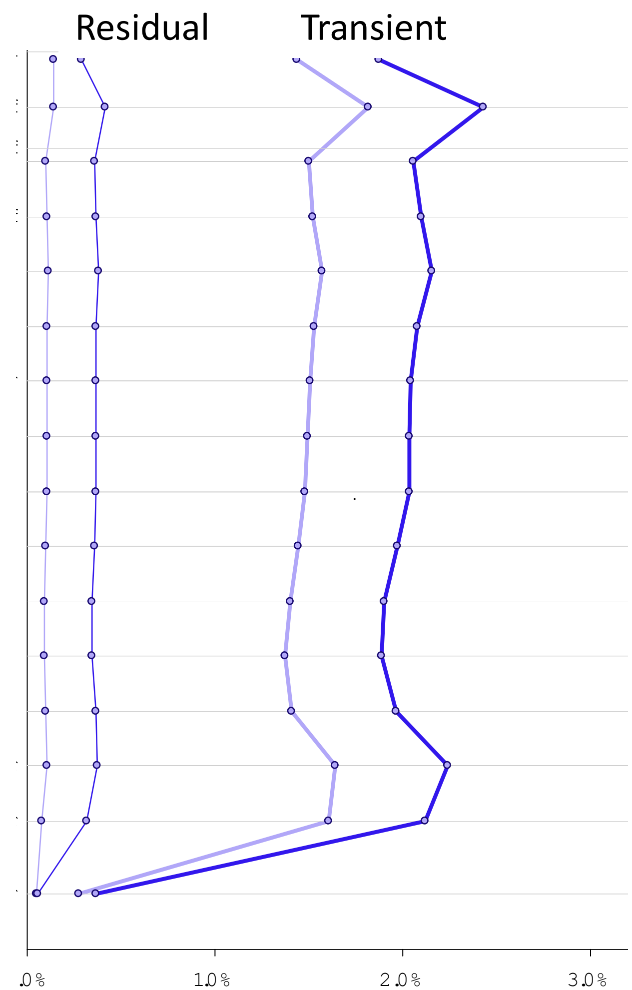






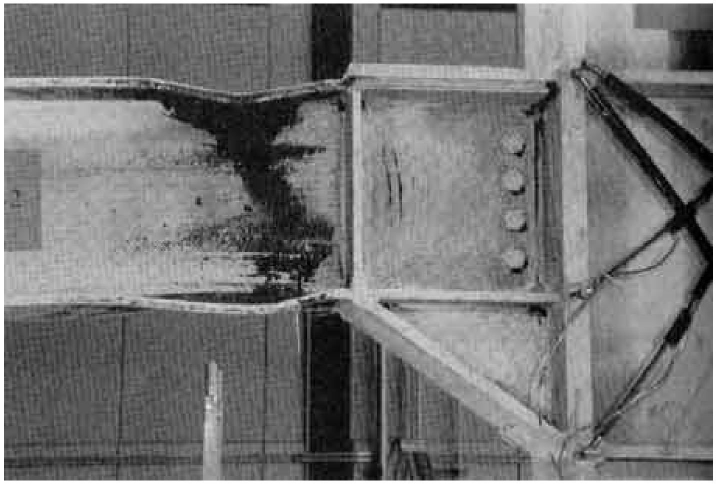


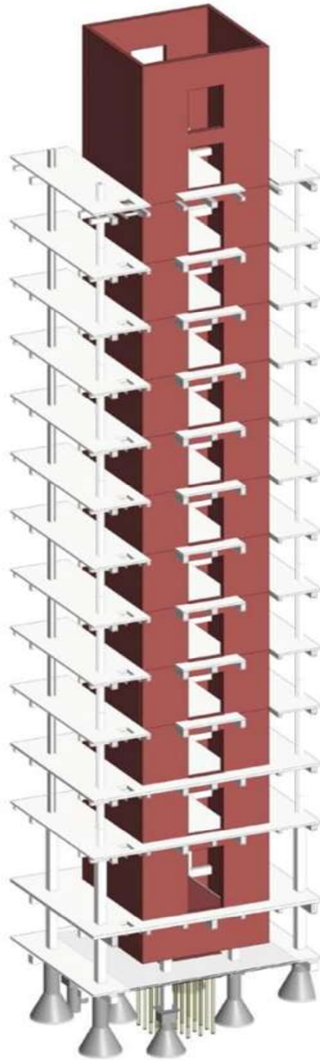
Before Retrofit

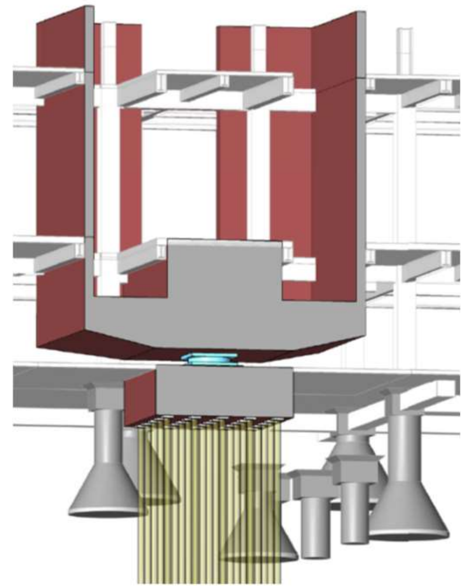


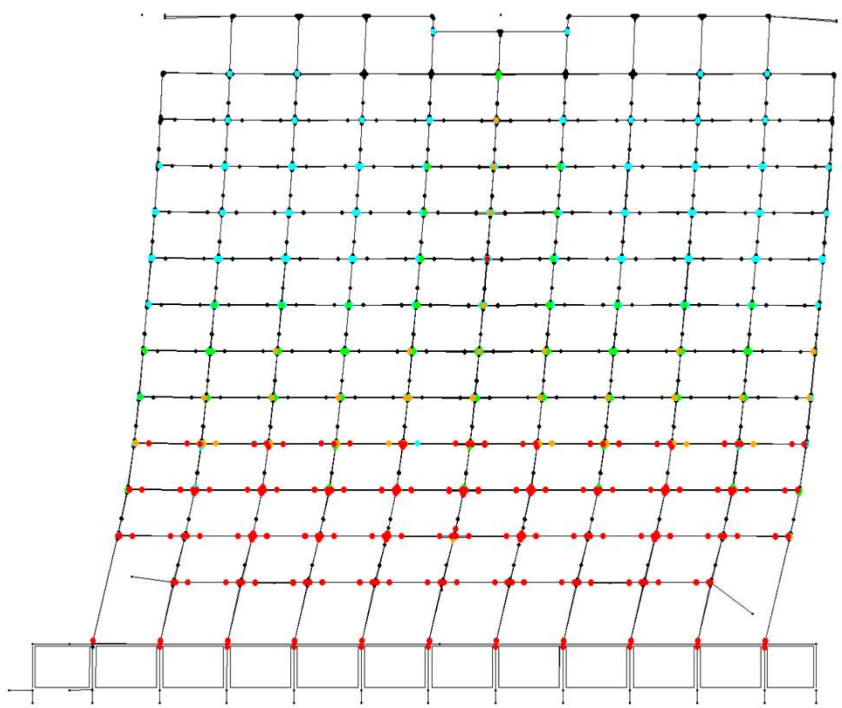
After Retrofit

Architect: SOM

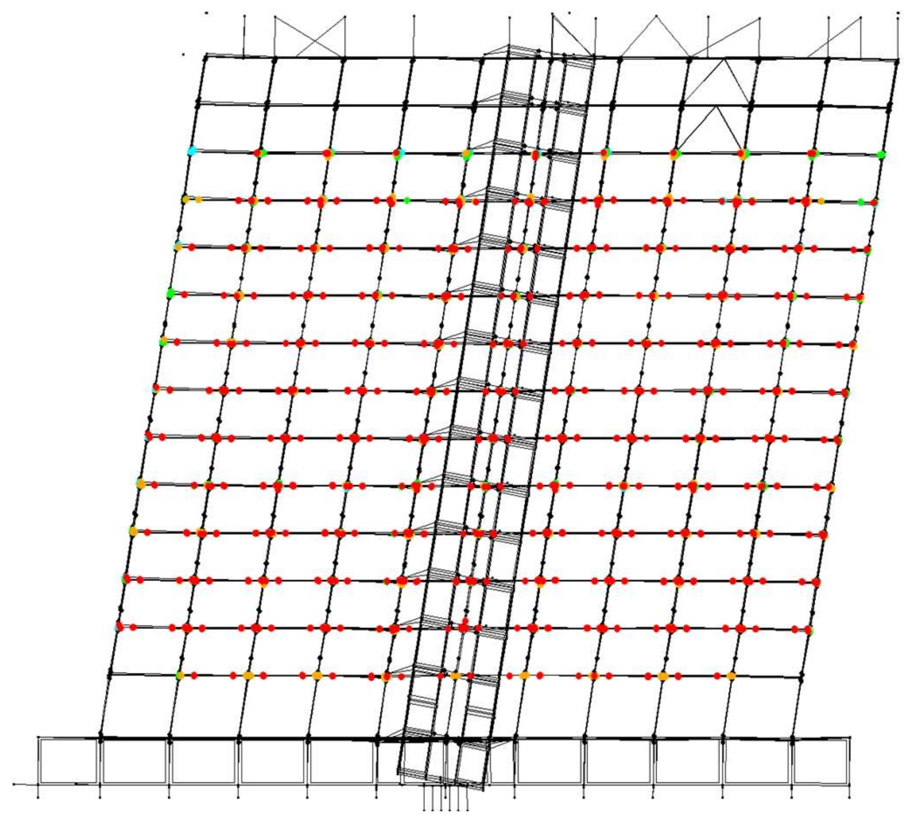




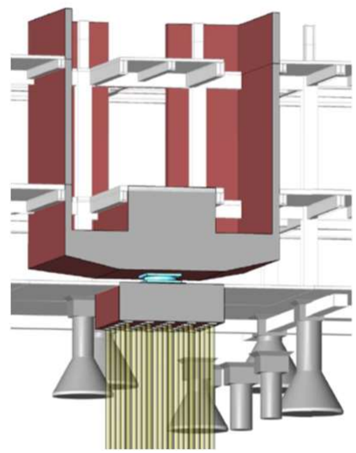


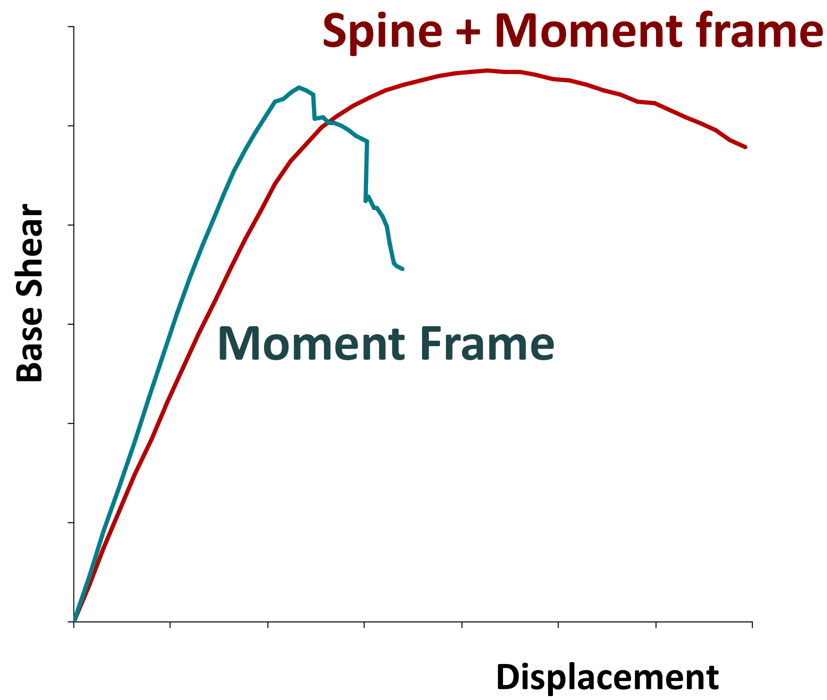


Before Retrofit

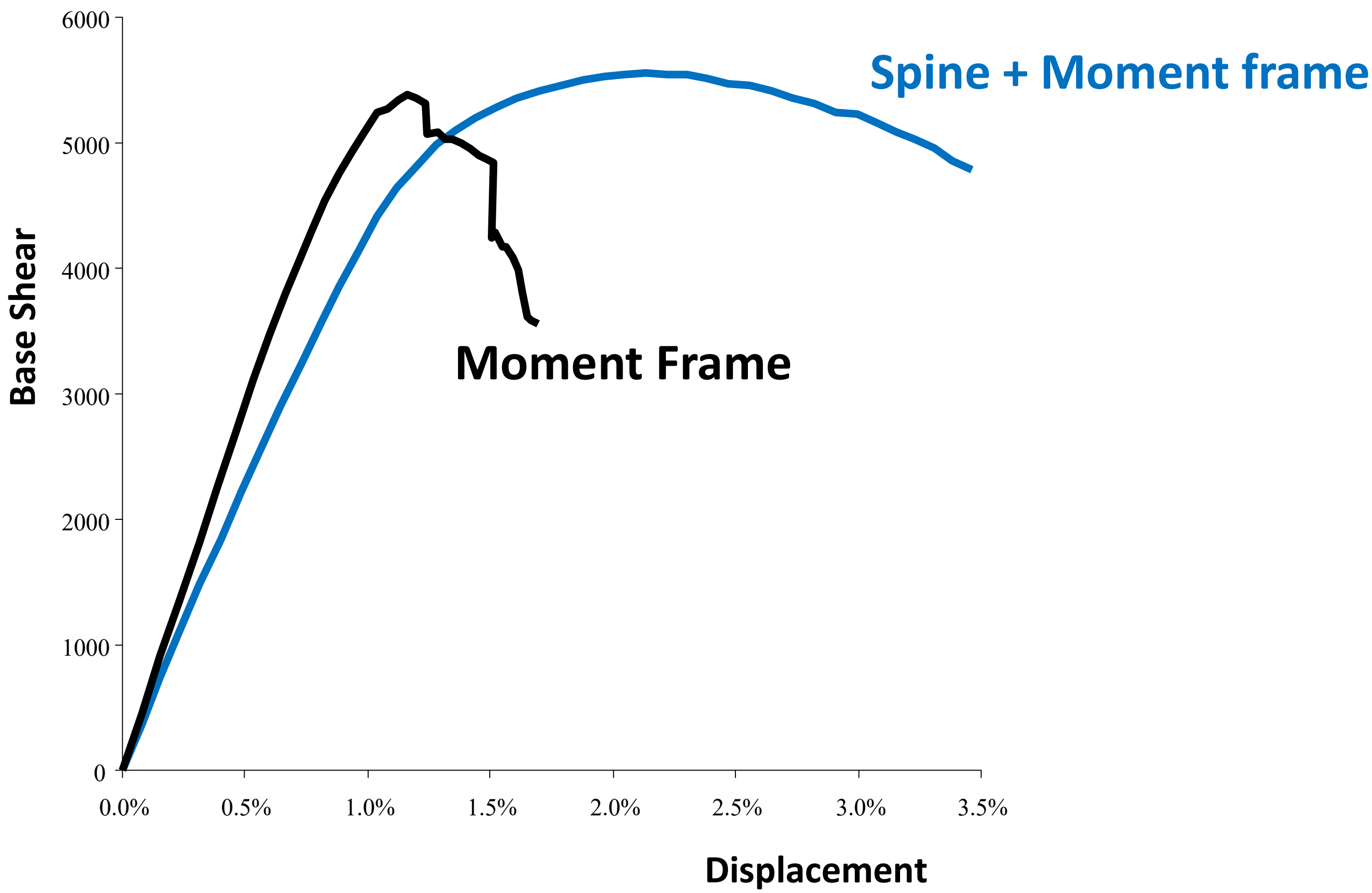


After Retrofit





soft-story frame retrofit with a mode-shaping spine


Spine + Moment frame
Moment Frame
Base Shear
6000
5000
4000
3000
2000
1000
0
0.0%
0.5%
1.0%
1.5%
2.0%
2.5%
3.0%
3.5%
Displacement

Weak-Story Vulnerabilities