Earthquake Resistant and Resilient Tall Buildings using Seismic Isolation and Rocking Core Walls

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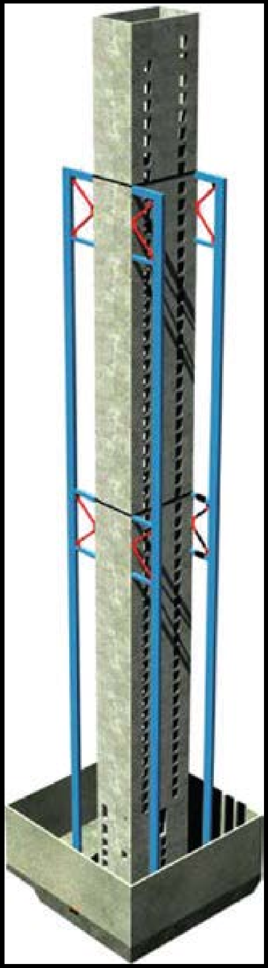
Tall Buildings in Regions of High Seismicity

One Rincon Hill - San Francisco

Schematic of Lateral Force Resisting System



Reinforced concrete core walls for lateral force resistance

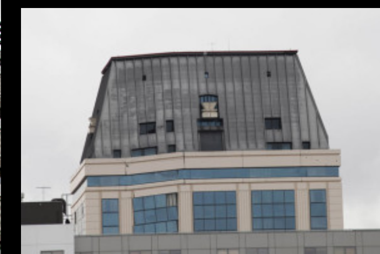
Moehle (2007)

Damage in Tall Buildings in Recent Earthquakes

2010 M8.8 Chile Earthquake

Partial collapse of 21-story O'Higgins building, tallest in Conception, threatens the surrounding built environment. Courtesy of J. Restrepo.

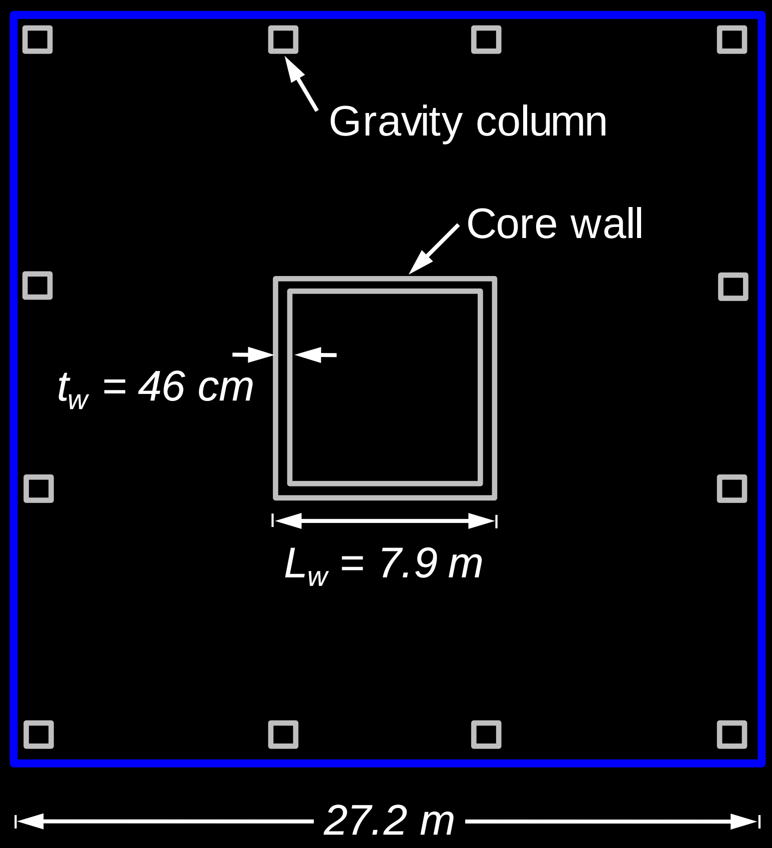
2011 M6.1 NZ Earthquake



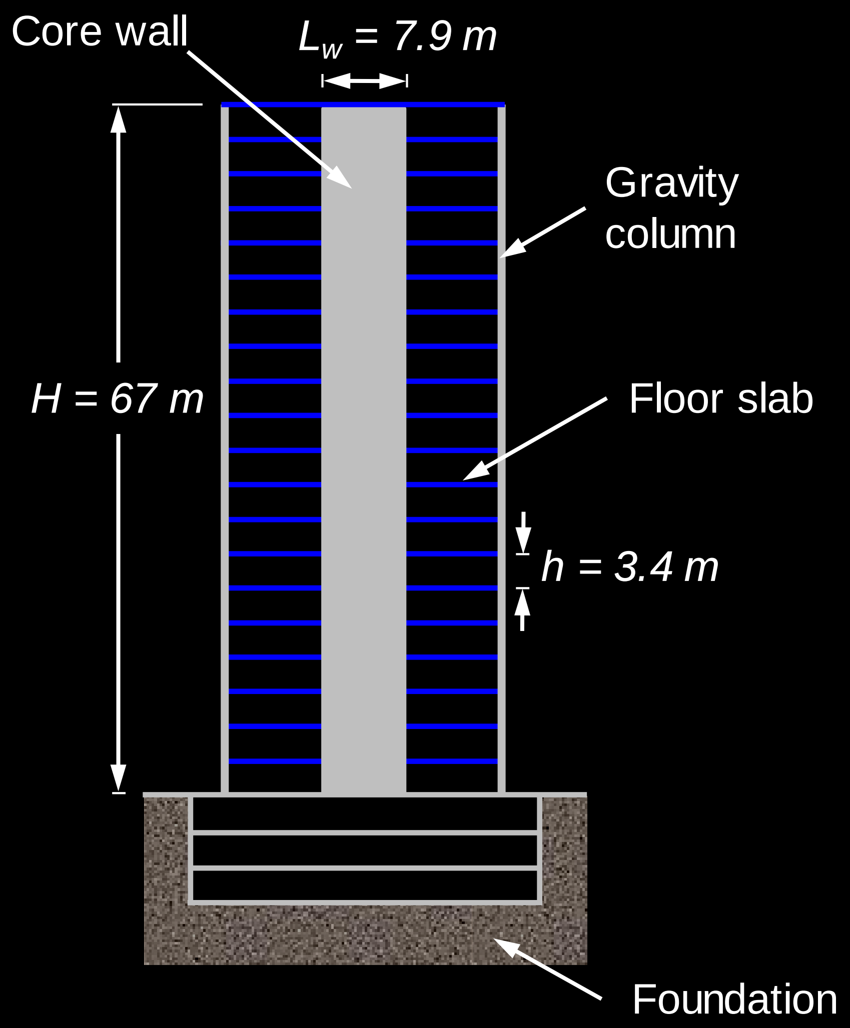
http://en.wikipedia.org

Grand Chancellor Hotel 26-story, tallest building in Christchurch
Currently under demolition

20-story Building Layout



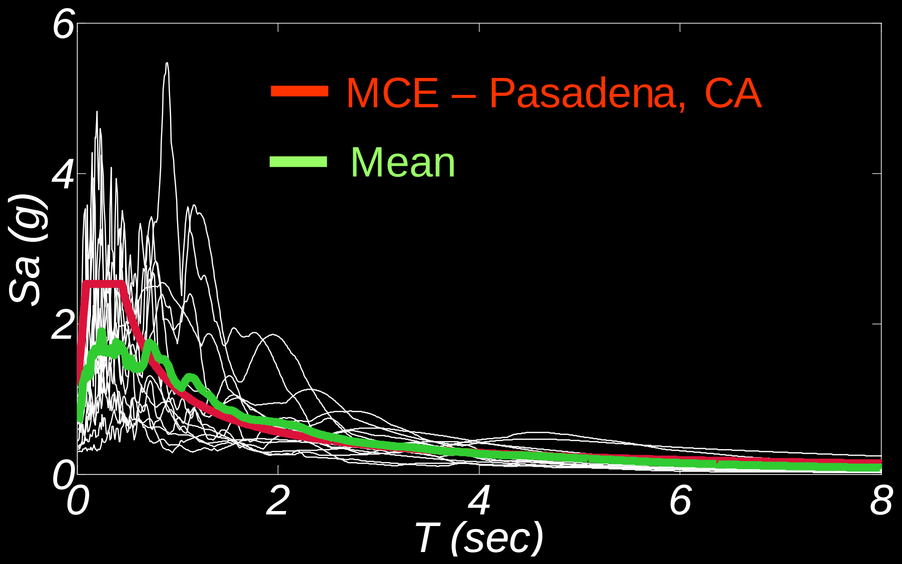
Plan View

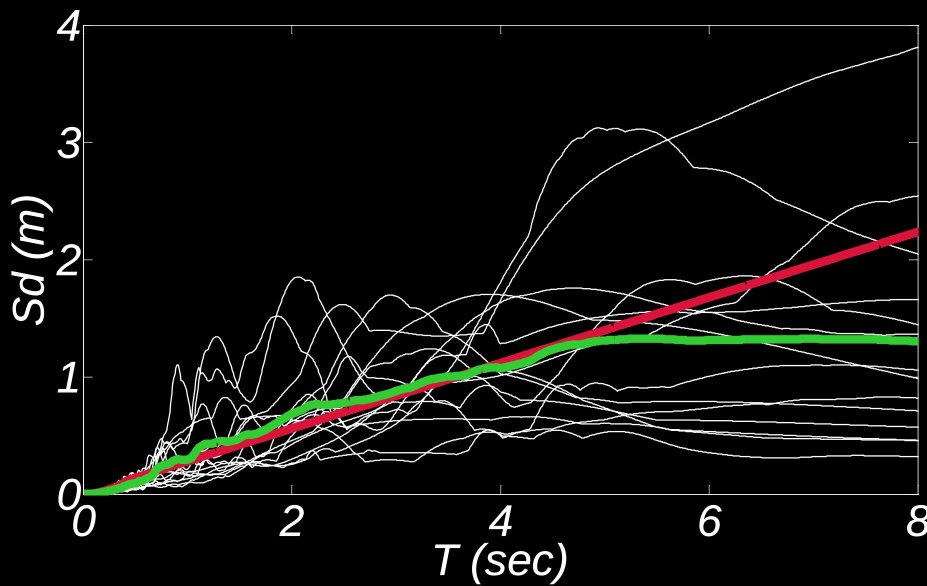


Elevation

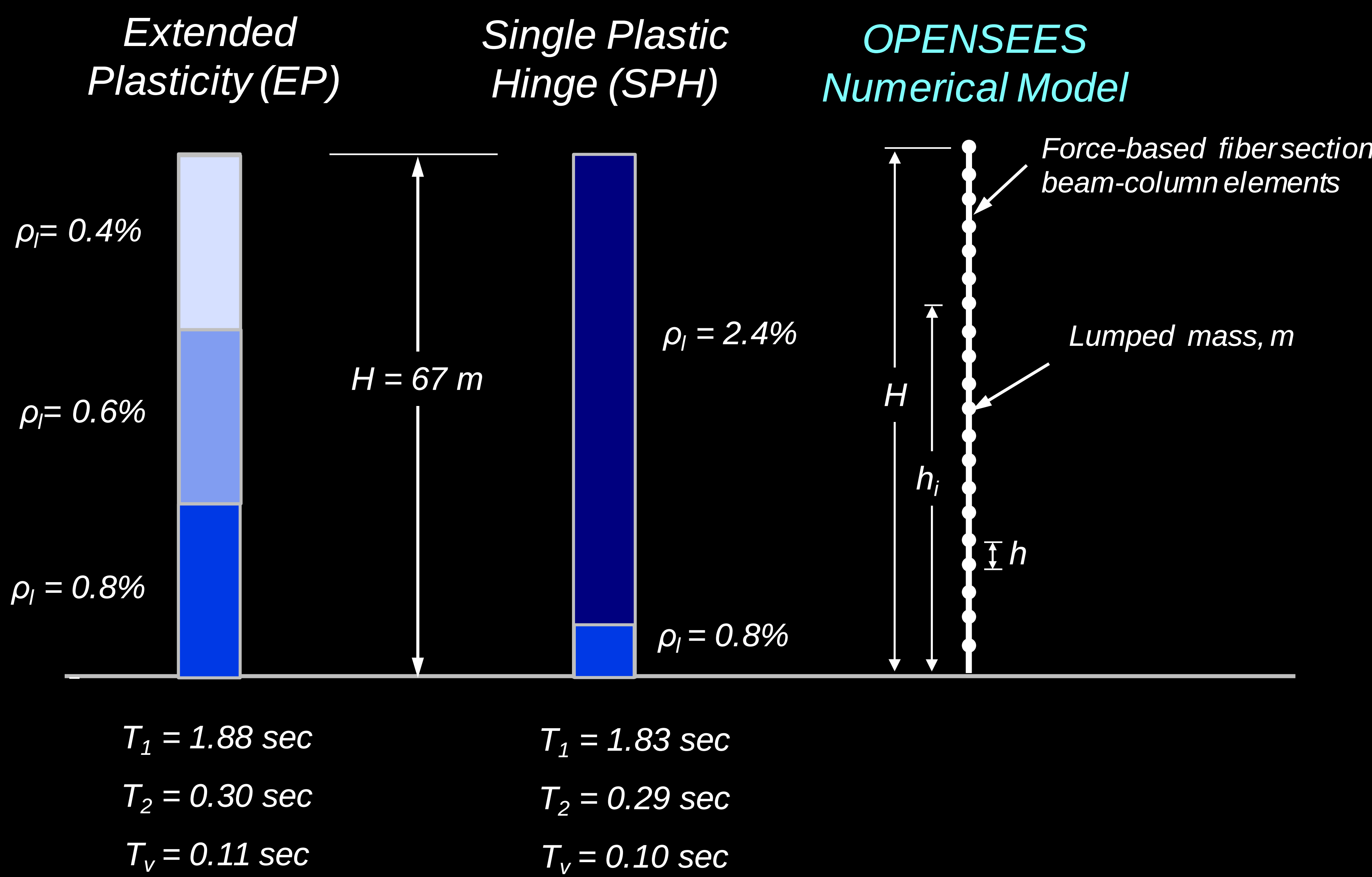
Ground Motions

14 strong pulse-type near-fault ground motions from the Tabas (1978), Imperial Valley (1979), Loma Prieta (1989), Landers (1992), Northridge (1994), Kobe (1995), Chi-Chi (1999), and Duzce (1999) earthquakes.

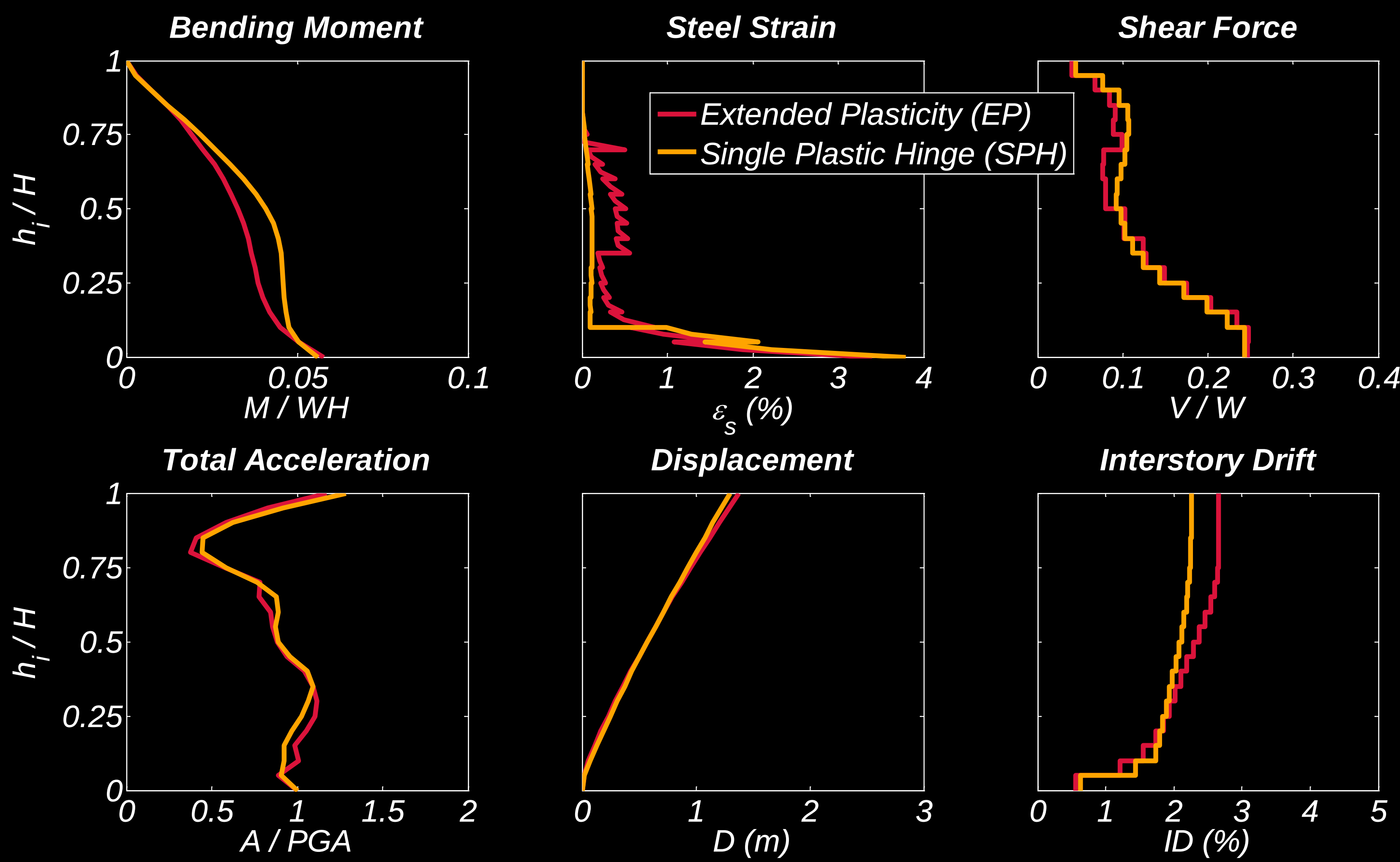




Fixed-Base Buildings – Design of Core Walls



Mean Results for 14 Near-Fault Ground Motions



Fixed-Base Buildings:

- *Undergo significant inelastic deformations*
- *Develop large forces (bending moment and shear forces)*
- *Develop large floor accelerations*
- *Experience significant post-earthquake damage*

Use Seismic Isolation or / and Rocking Walls to:

- *Control deformations in one or two robust planes*
- *Reduce floor accelerations, and forces*
- *Reduce post-earthquake damage and make building adaptable*

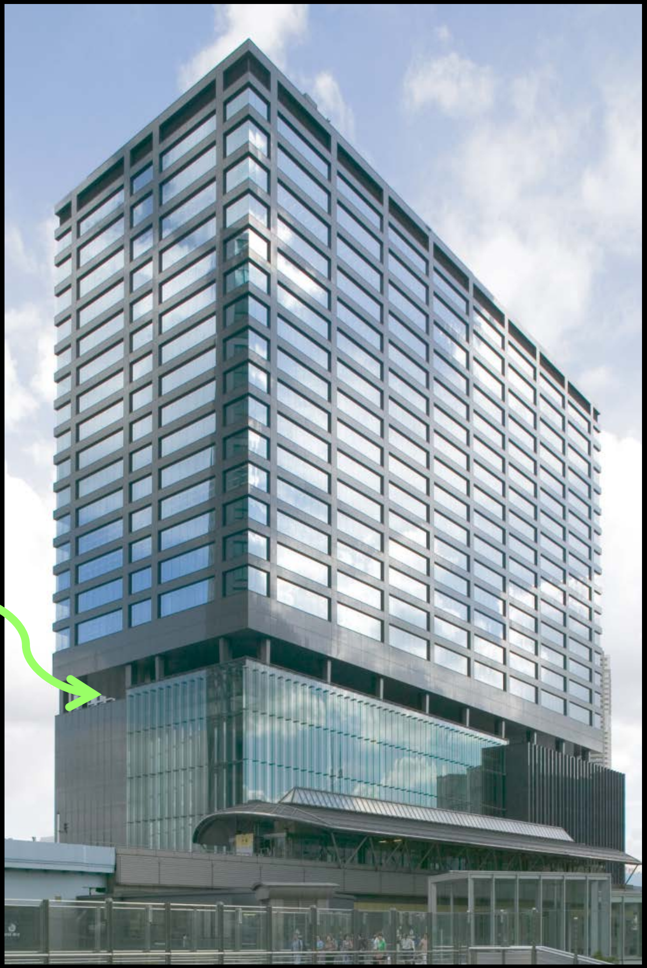
Isolated Tall Buildings

Thousand Tower
Kawasaki city, 41-story, base isolated

Komuro et al. (2005)

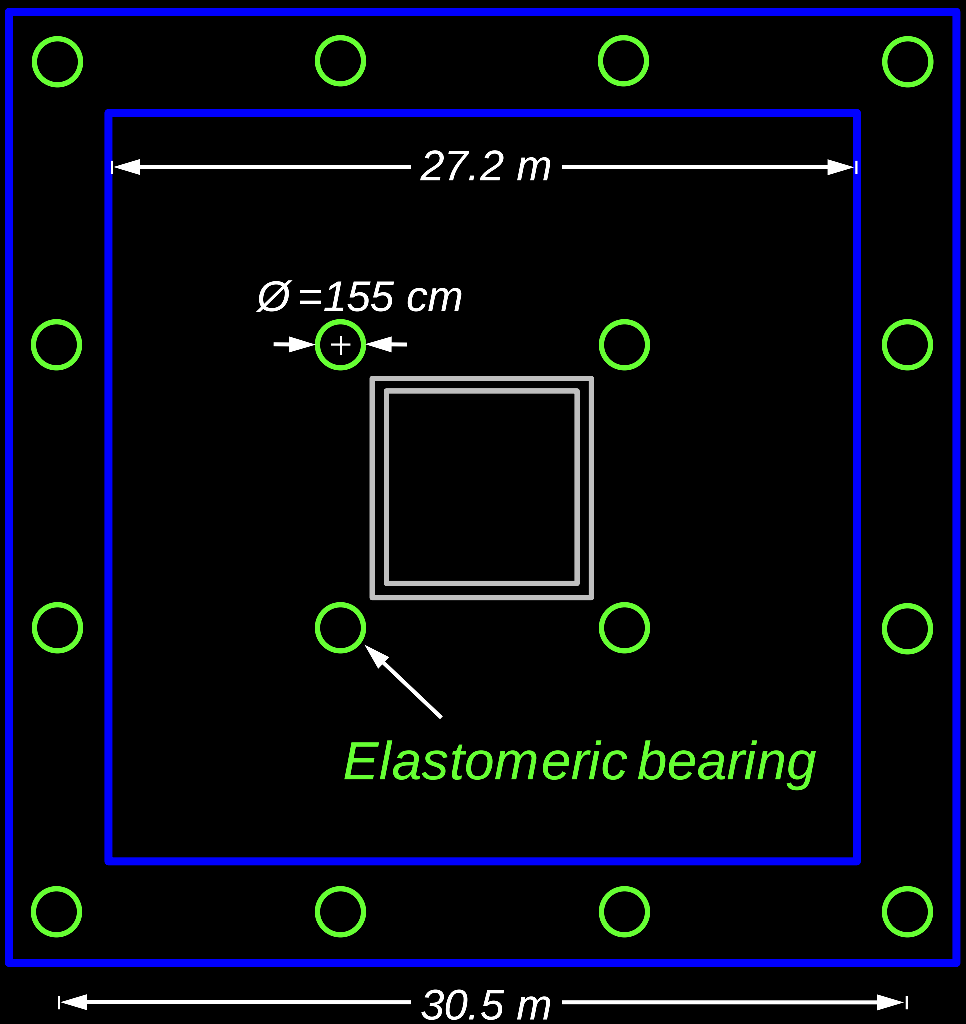
Shiodome Sumitomo Building
Tokyo, 25-story

Isolation layer at 40% of the height

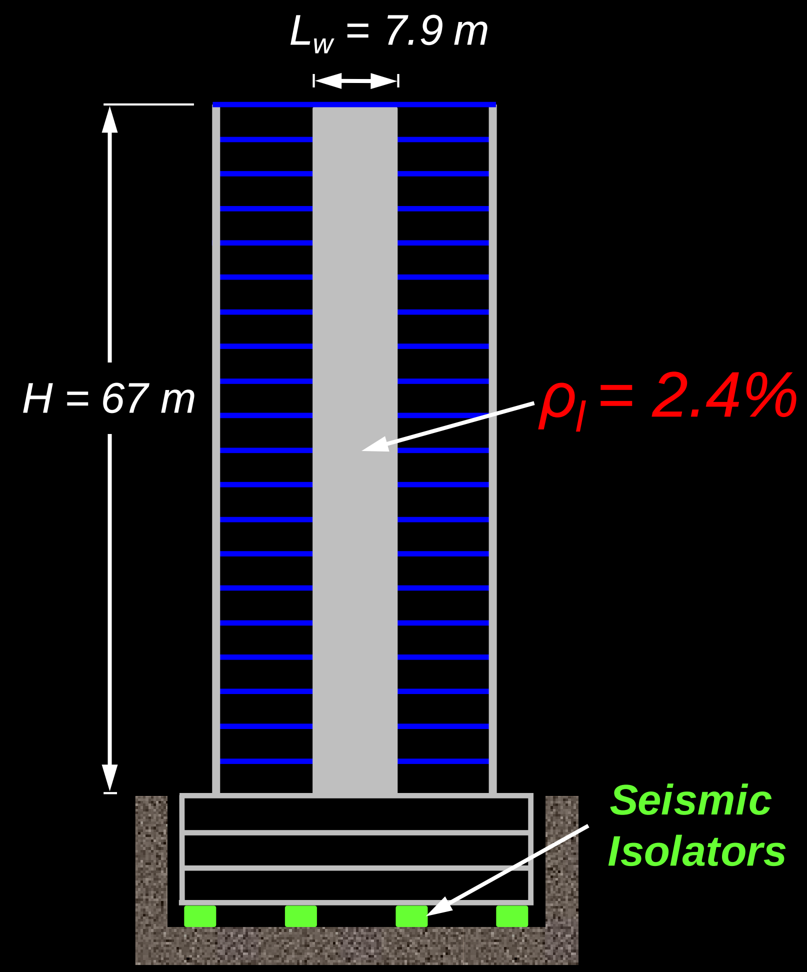


Tsuneki et al. (2009)

Isolated Building Designs

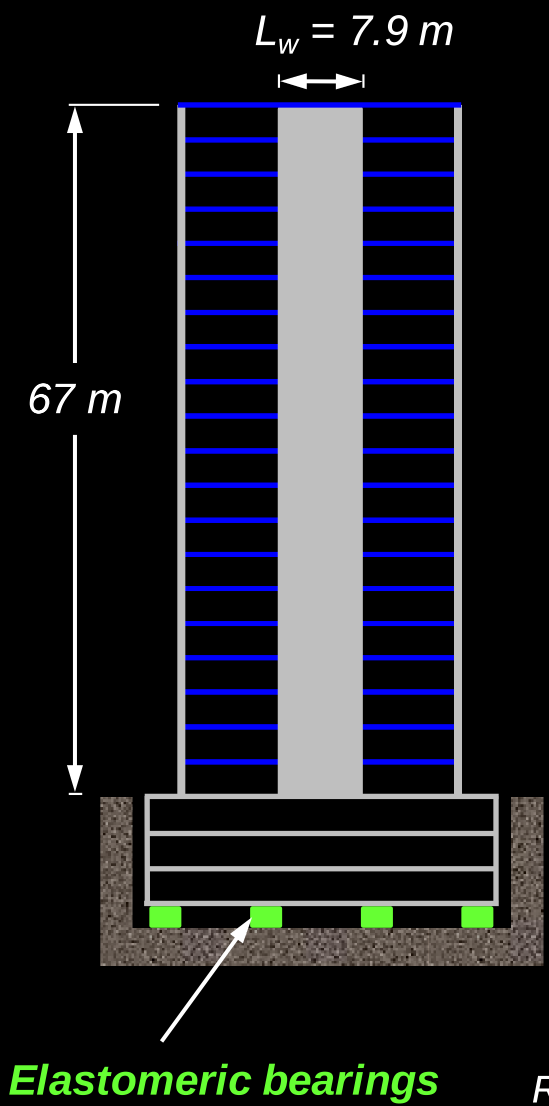


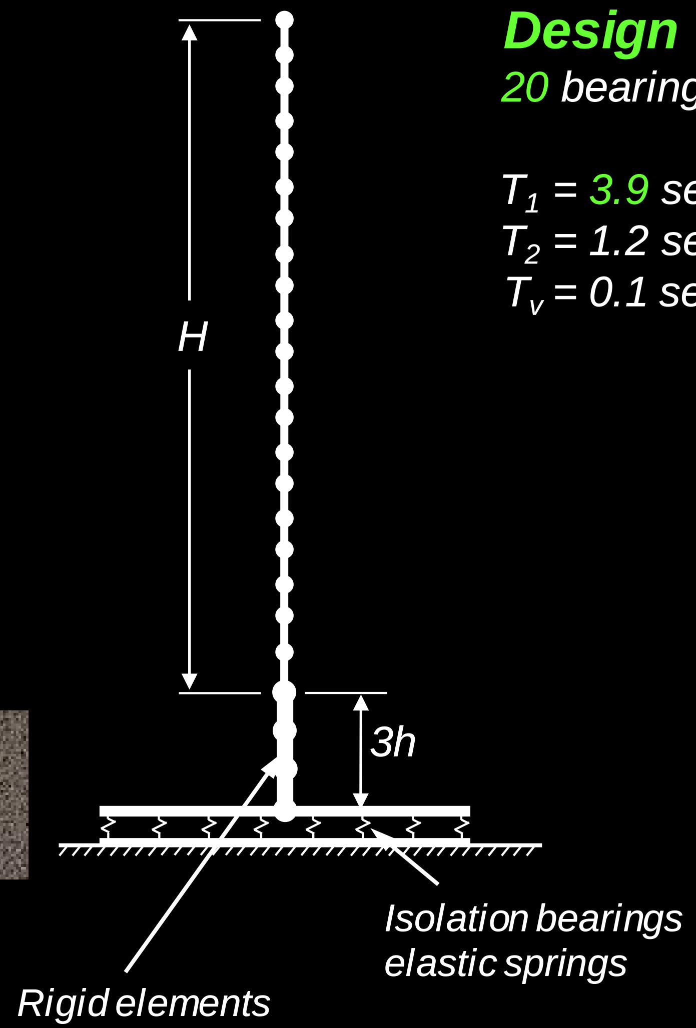
Plan View Below Ground



Elevation

Isolated Building Designs





Design 1
20 bearings

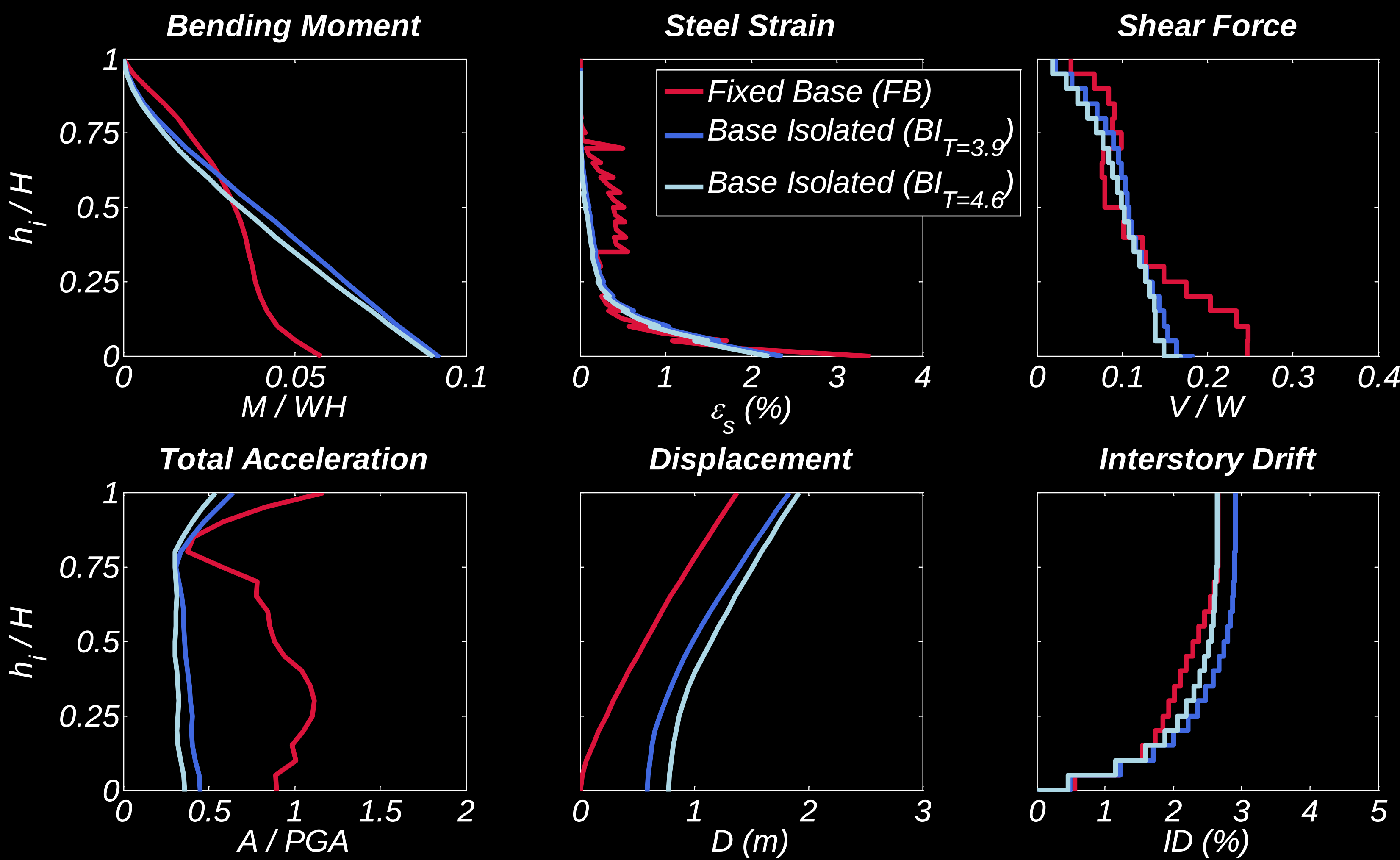
T_1 = 3.9 sec
T_2 = 1.2 sec
T_v = 0.1 sec

Design 2
16 bearings

T_1 = 4.6 sec
T_2 = 1.3 sec
T_v = 0.1 sec

Mean Results for 14 Near-Fault Ground Motions

$T_{1,BI}$ (sec)	3.9	4.6
Isolator displacement [mean and (max) in cm]	59 (82)	77 (118)



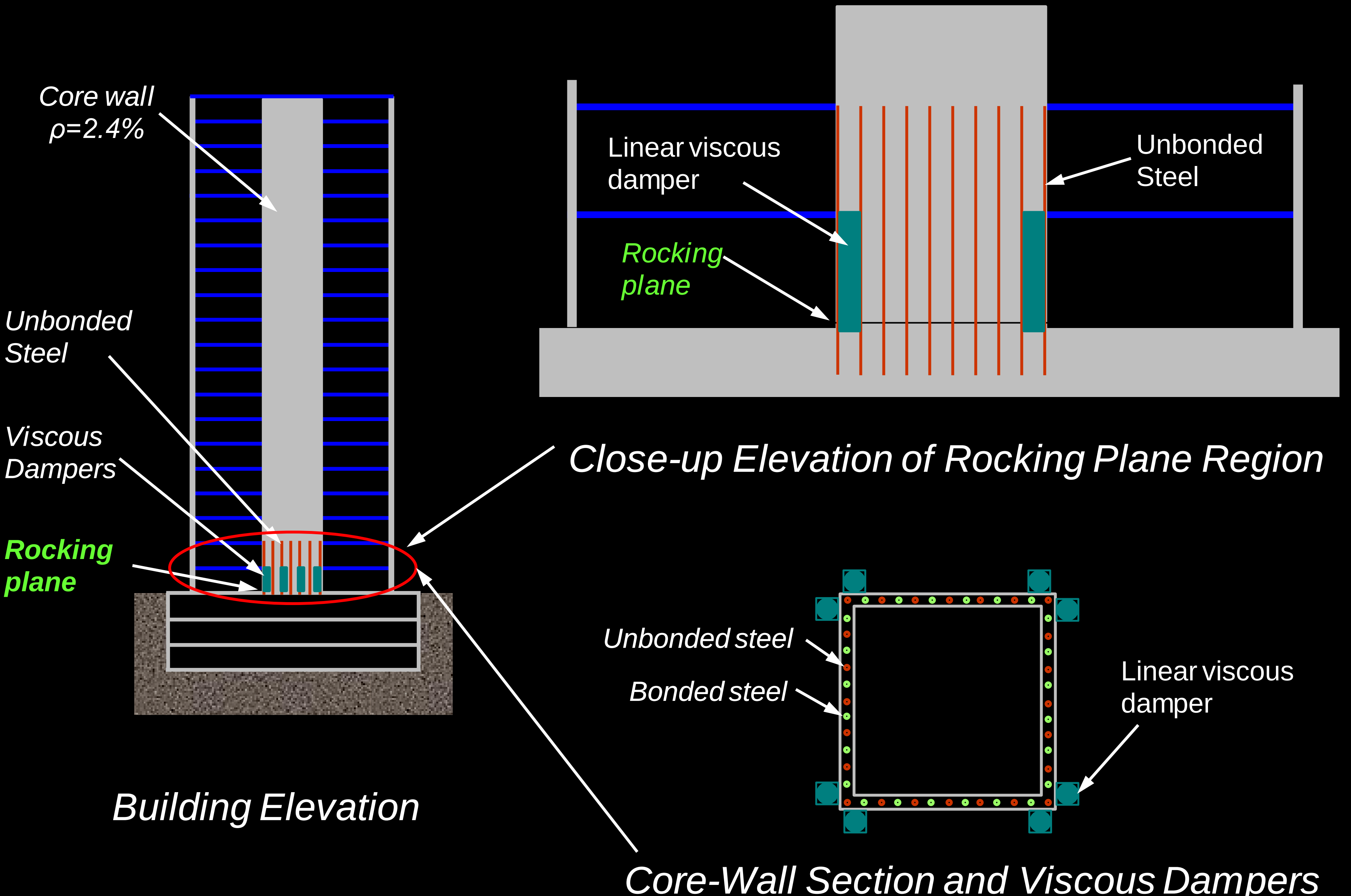
Seismic Isolation Design:

- ***Reduced** floor accelerations, and base shear force by about 2 times*
- ***Increased** base moment demand and resulted in significant **inelastic** response at the base of the wall*

Use Rocking Core-Wall to:

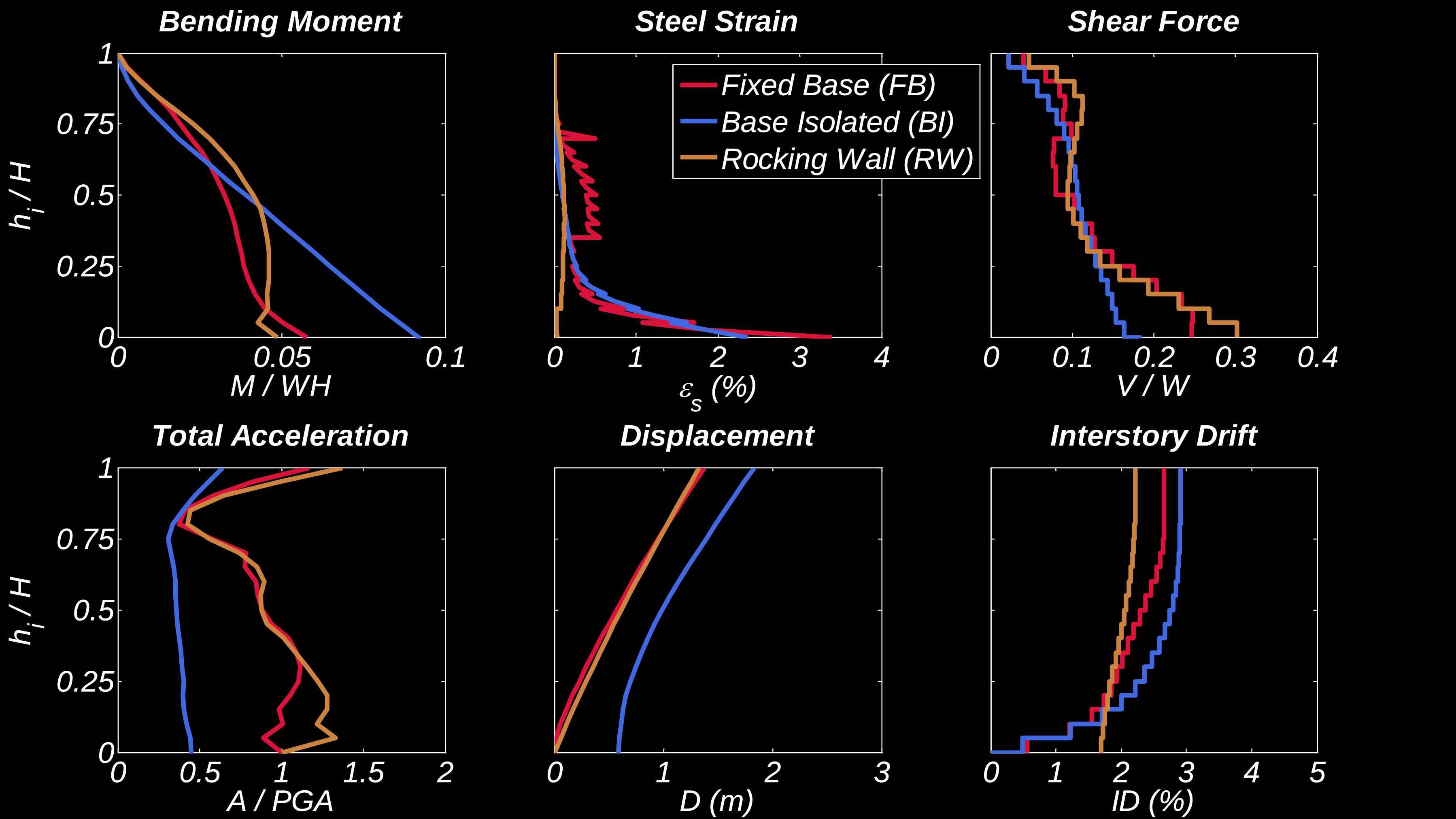
- *Avoid the formation of a flexural plastic hinge and **reduce damage** in wall in comparison with **fixed-base** building*

Rocking Core-Wall Building Design



Mean Results for 14 Near-Fault Ground Motions

Rocking plane rotation: mean=1.7% , max=3.8%



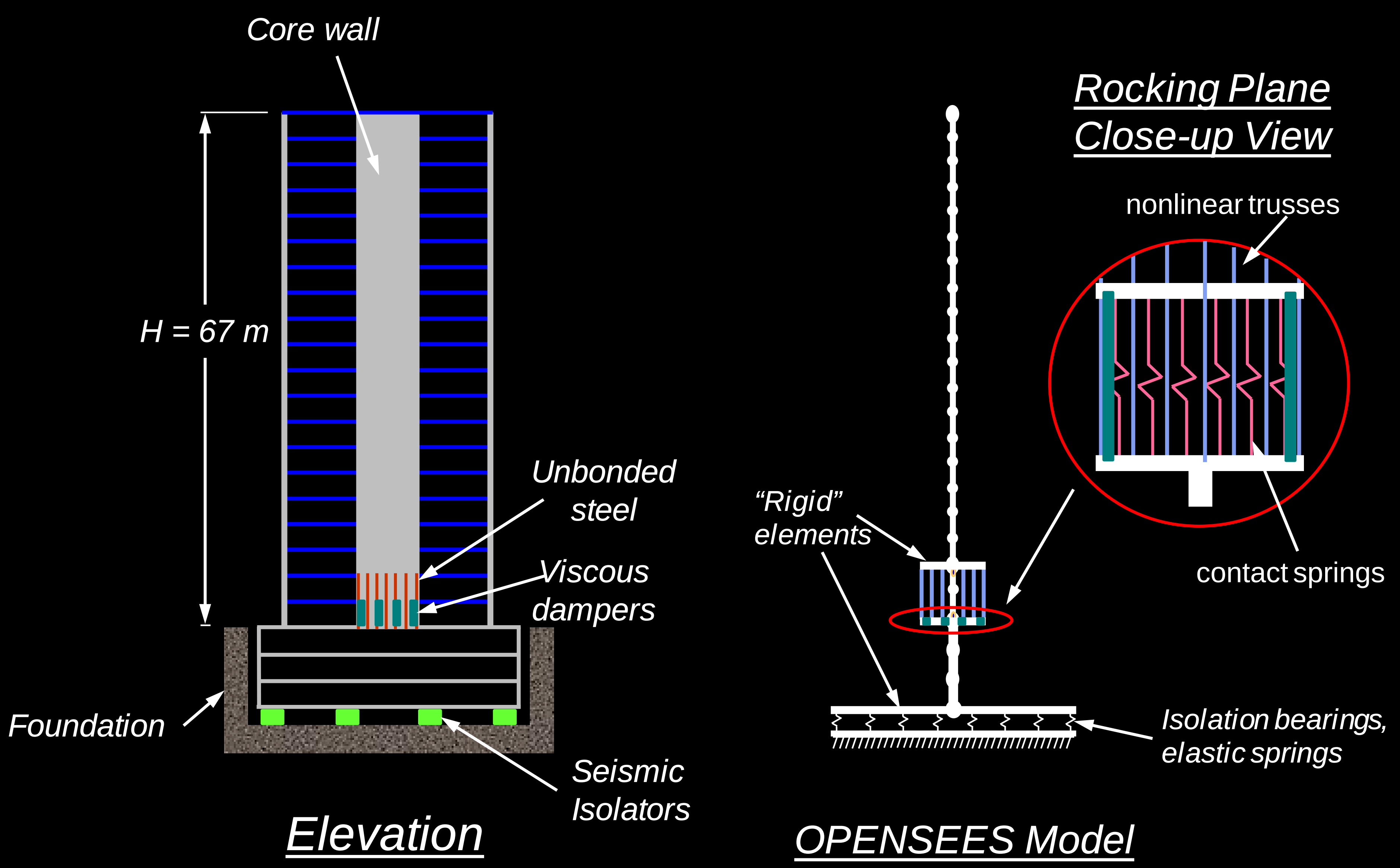
Seismic Isolation:

- ***Reduced** floor accelerations, and shear forces by about 2 times*
- ***Increased** base moment demand and resulted in significant inelastic response at the base of the wall*

Rocking Core Wall :

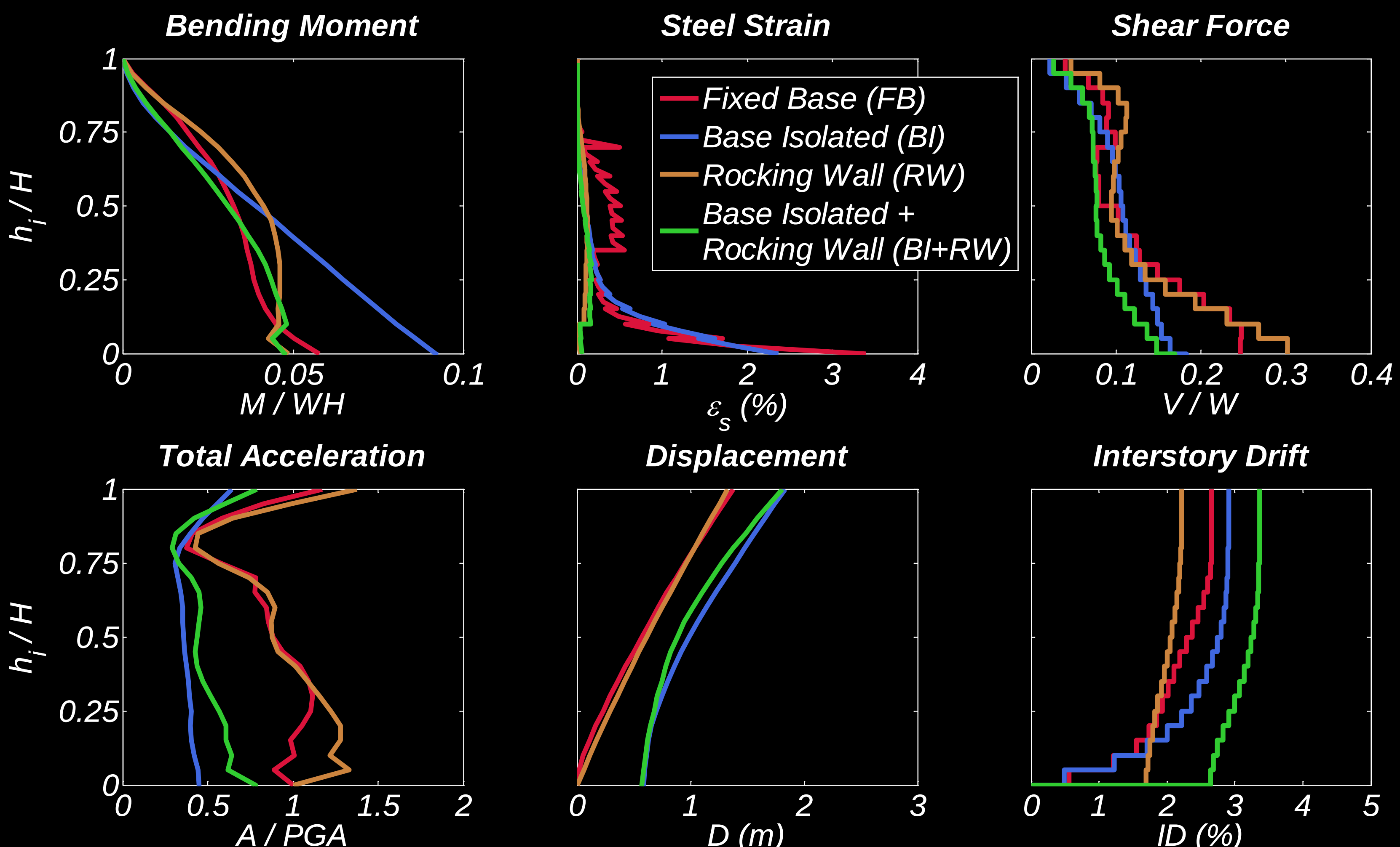
- ***Reduced** damage in core wall*
- *Forces and accelerations similar to **fixed-base** building*

Base Isolation and Rocking Core Wall Building



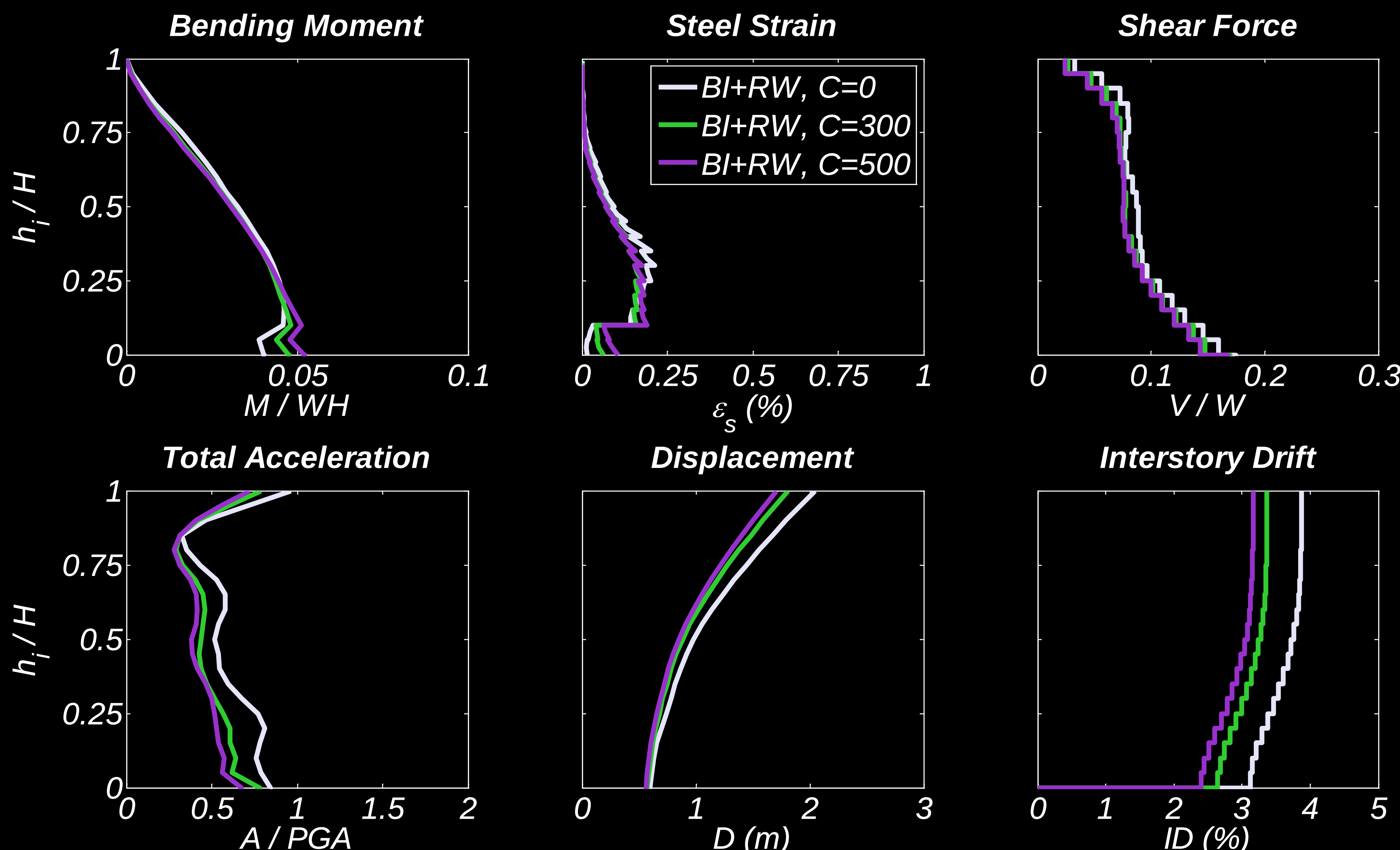
Mean Results for 14 Near-Fault Ground Motions

Mean rocking plane rotation uplift = 2.6% (max = 5%)
Mean isolator displacement = 57 cm (max = 102 cm)



Effect of Viscous Dampers

C	0	300	500
Uplift (cm)	24 (49)	20 (42)	18 (38)
Isolator Disp. (cm)	60 (117)	57 (102)	56 (94)



Conclusions

In comparison with the fixed-base buildings:

- ***The base isolated building reduced about 2 times base shear force and floor accelerations but resulted in significant inelastic response at the base of the wall***
- ***The rocking wall building prevented the formation of a flexural plastic hinge at the base of the wall without reducing forces and accelerations***
- ***The building with base isolation and rocking core wall had a superior performance reducing about 2 times base shear forces and floor accelerations while it prevented the formation of a plastic hinge at the base of the wall***

End

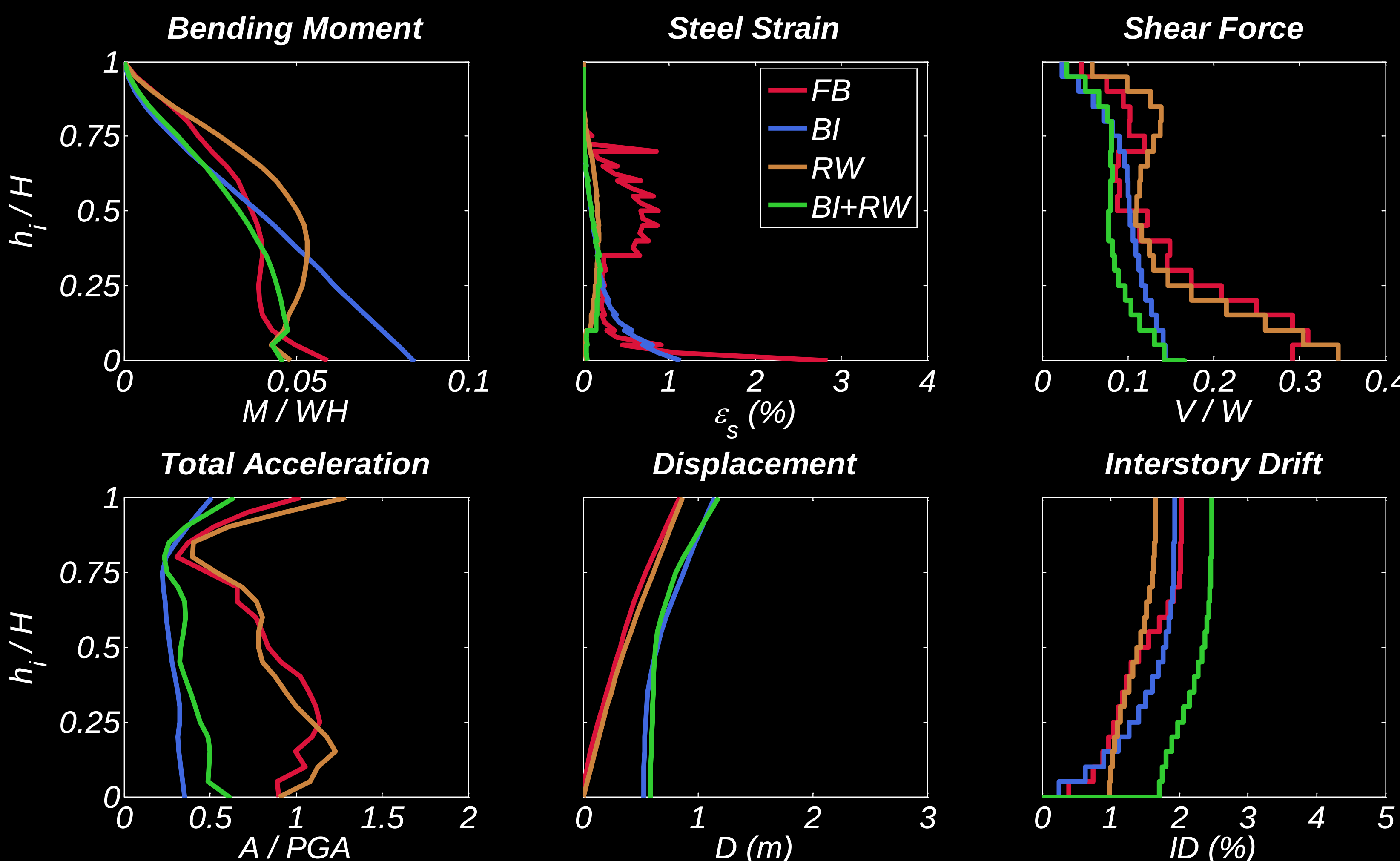
Kobe 1995 Earthquake
12-story building

EQE (1995)

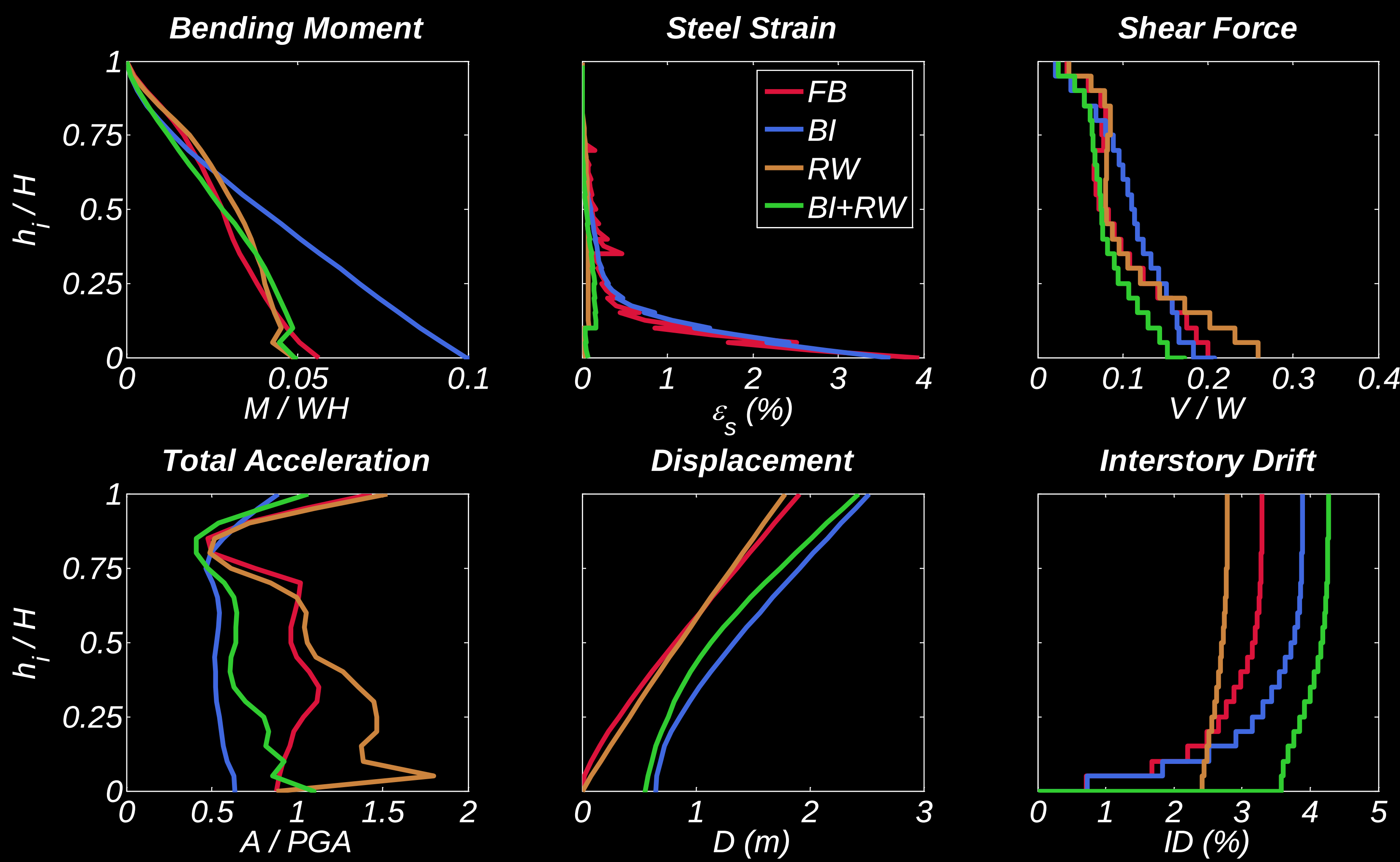
Chile 2010 Earthquake
23-story O'Higgins 241 tower

EERI (2010)

Mean Results for High Frequency (Bin 1) Near-Fault Ground Motions



Mean Results for Low Frequency (Bin 2)
Near-Fault Ground Motions



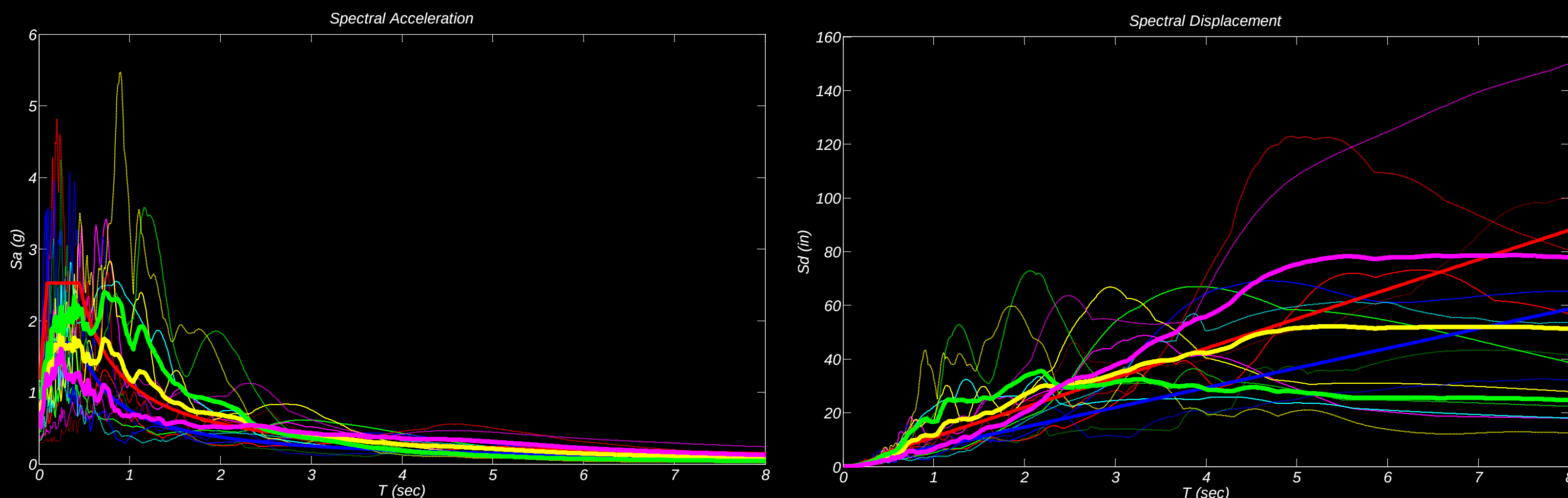
Mean Peak Responses

Peak Response. Mean of 14GM (Max of 14GM)	EP	SPH	BI	RW	BI+RW
Base shear (V/W)	0.25 (0.38)	0.24 (0.41)	0.22 (0.31)	0.30 (0.54)	0.15 (0.20)
Roof acceleration (A/PGA)	1.35 (2.67)	1.42 (2.12)	0.80 (1.48)	1.52 (2.95)	1.00 (2.05)
Steel strain at wall base (%)	3.40 (5.25)	3.80 (6.29)	2.37 (5.42)	0.04 (0.07)	0.06 (0.12)
Steel strain anywhere along building height (%)	3.40 (5.25)	3.80 (6.29)	2.37 (5.42)	0.15 (0.28)	0.20 (0.69)
Concrete compression Strain at wall base (%)	0.20 (0.26)	0.21 (0.28)	0.20 (0.28)	0.50 (0.98)	0.73 (1.42)
Wall uplift (cm)				13 (29)	20 (42)
Isolator displacement (cm)			59 (82)		57 (101)

Ground Motions

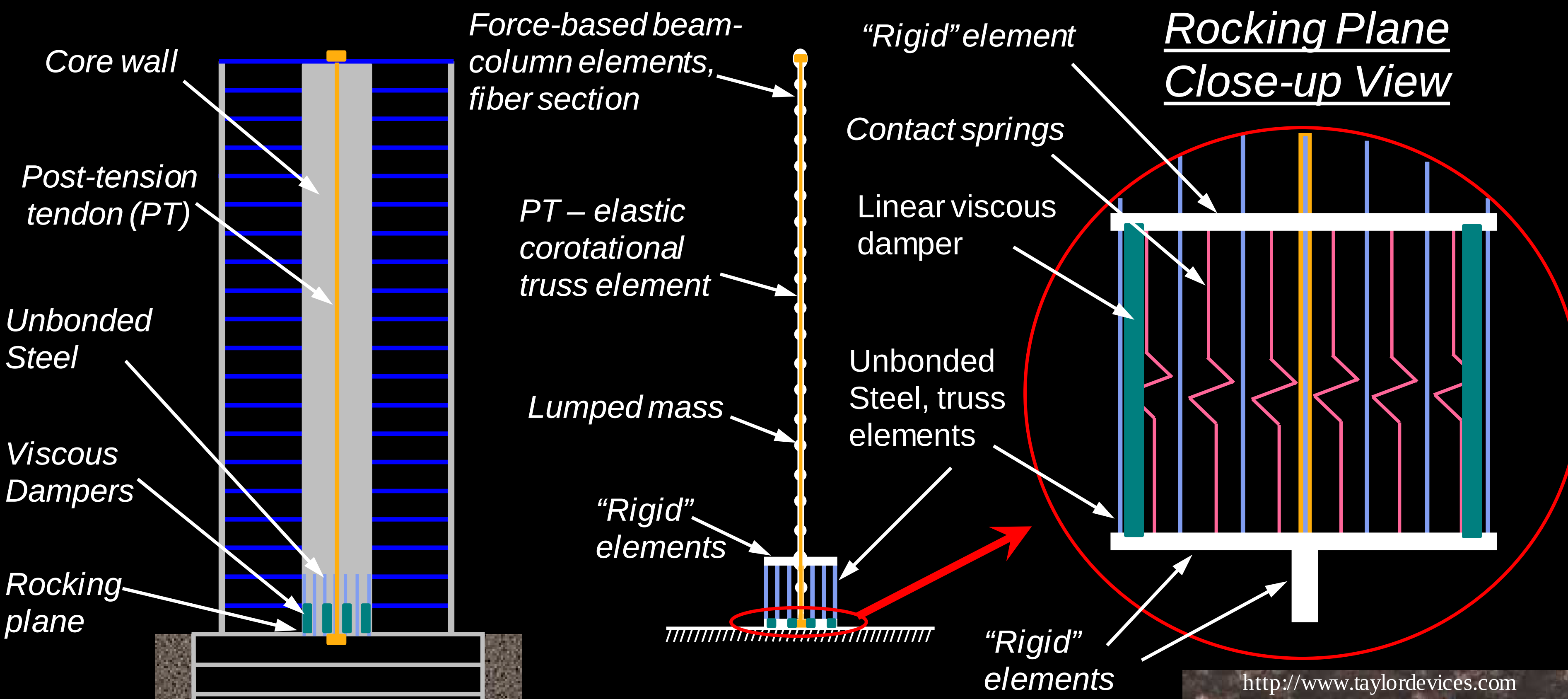
The study considers 14 strong near-fault ground motions from the Tabas (1978), Imperial Valley (1979), Loma Prieta (1989), Landers (1992), Northridge (1994), Kobe (1995), Chi-Chi (1999), and Duzce (1999) earthquakes.

EXPLAIN BINs HERE



High Frequency (Bin 1) – LGP, RRS, SCS, TAK, TARZANA, TCU084, TCU129
Low Frequency (Bin 2) – DUZCE, ELCEN6, LCN, TABAS, TCU052, TCU075, TCU102

Rocking Plane Detail

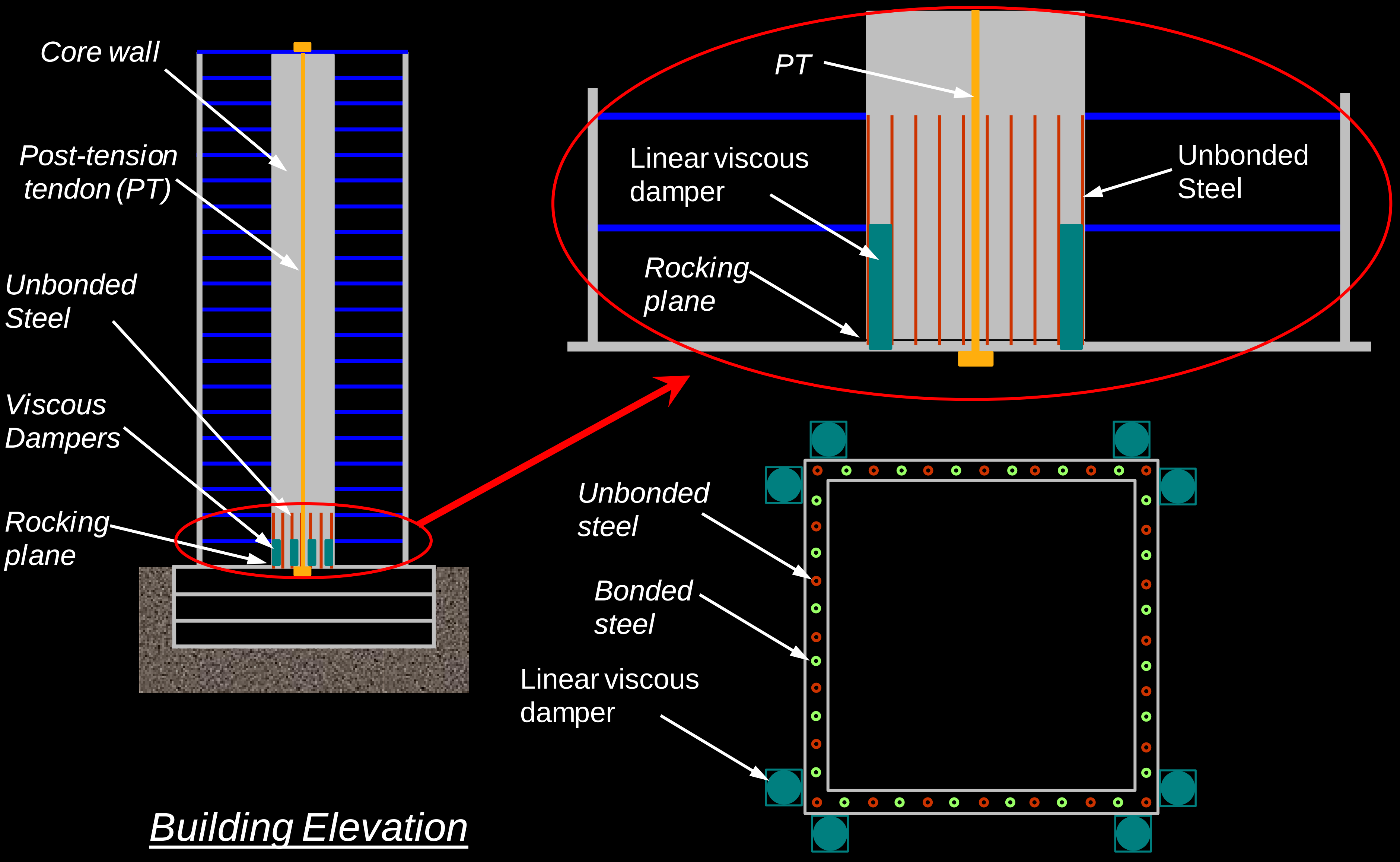


Building Elevation

OpenSees Model

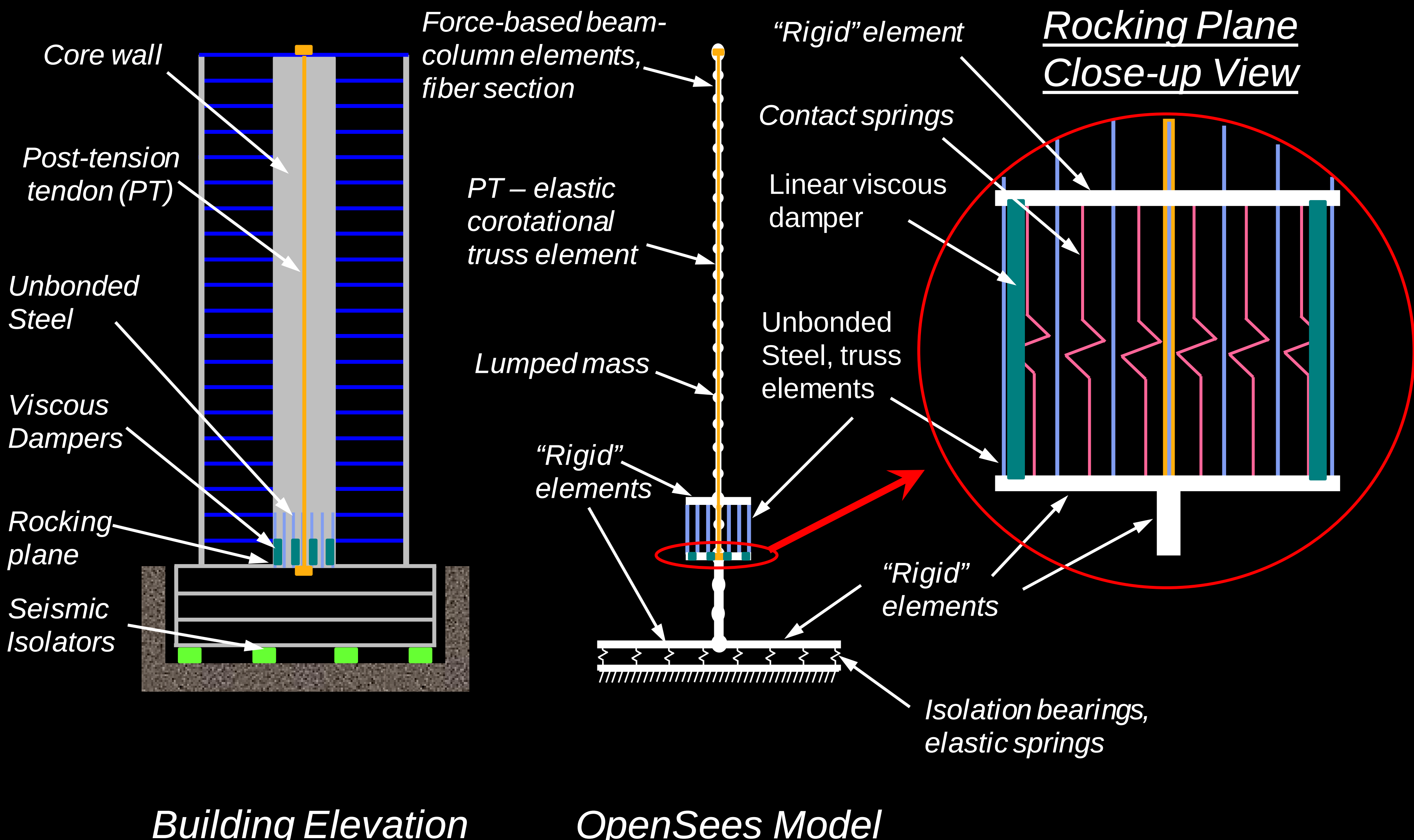
Seismic fluid viscous dampers for large highway bridge, 1.5 million pounds output force.

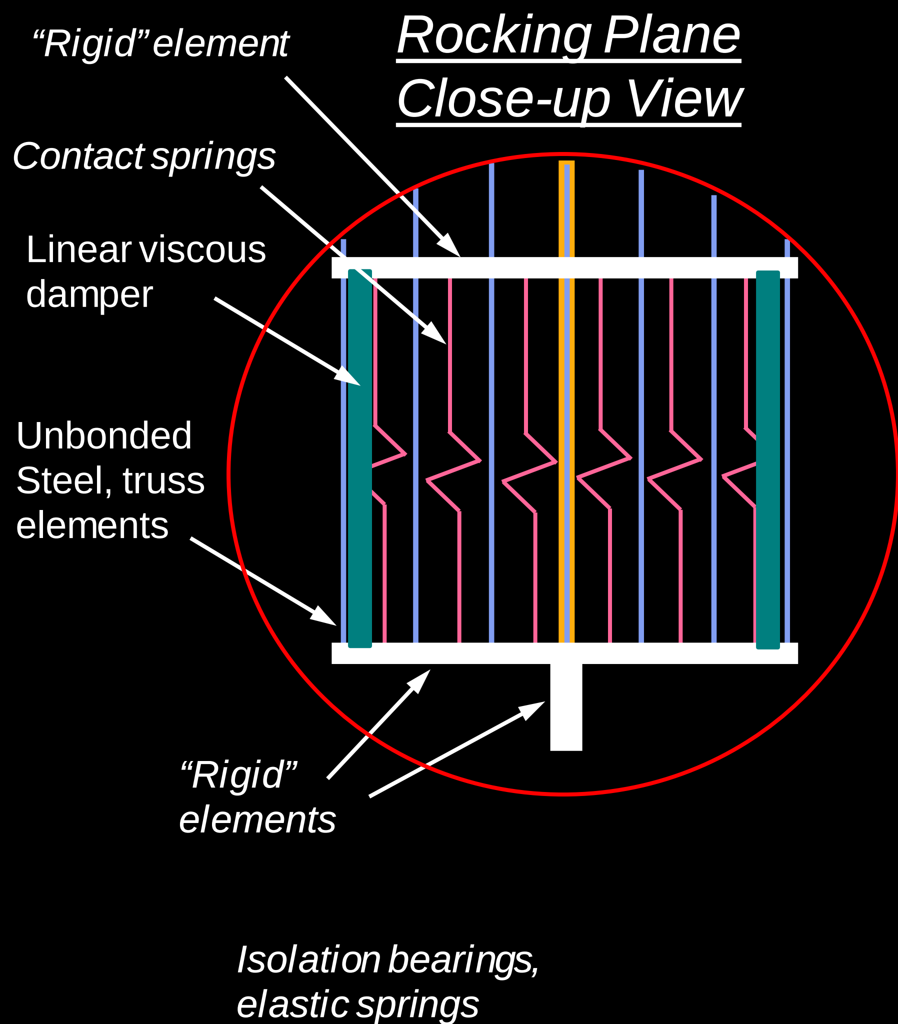
Base of Rocking Wall Detail



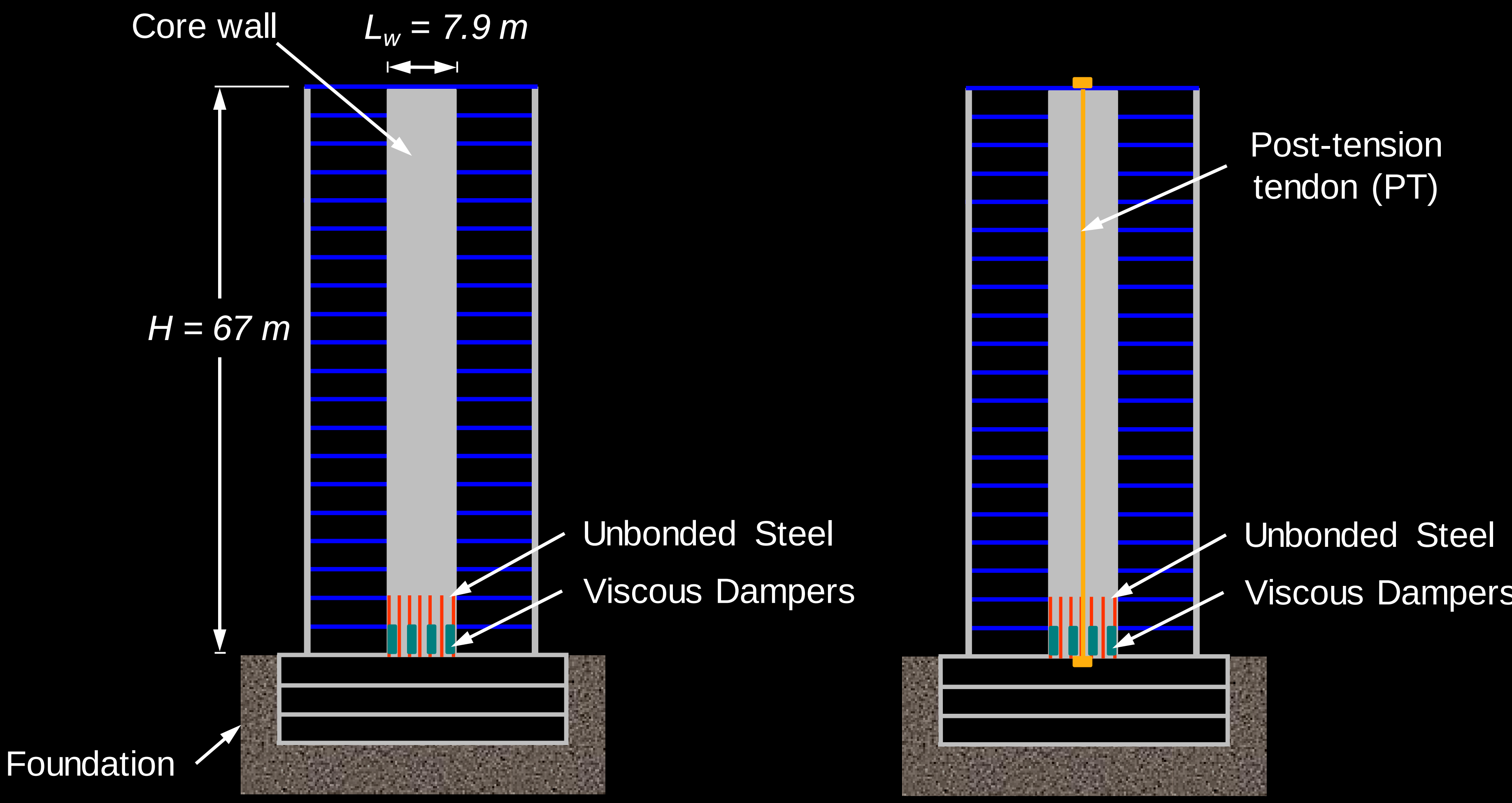
Building Elevation

Base Isolation and Rocking Core Wall (BI+RW) Building




Rocking Plane
Close-up View
"Rigid" element
Contact springs
Linear viscous damper
Unbonded Steel, truss elements
"Rigid" elements
Isolation bearings, elastic springs

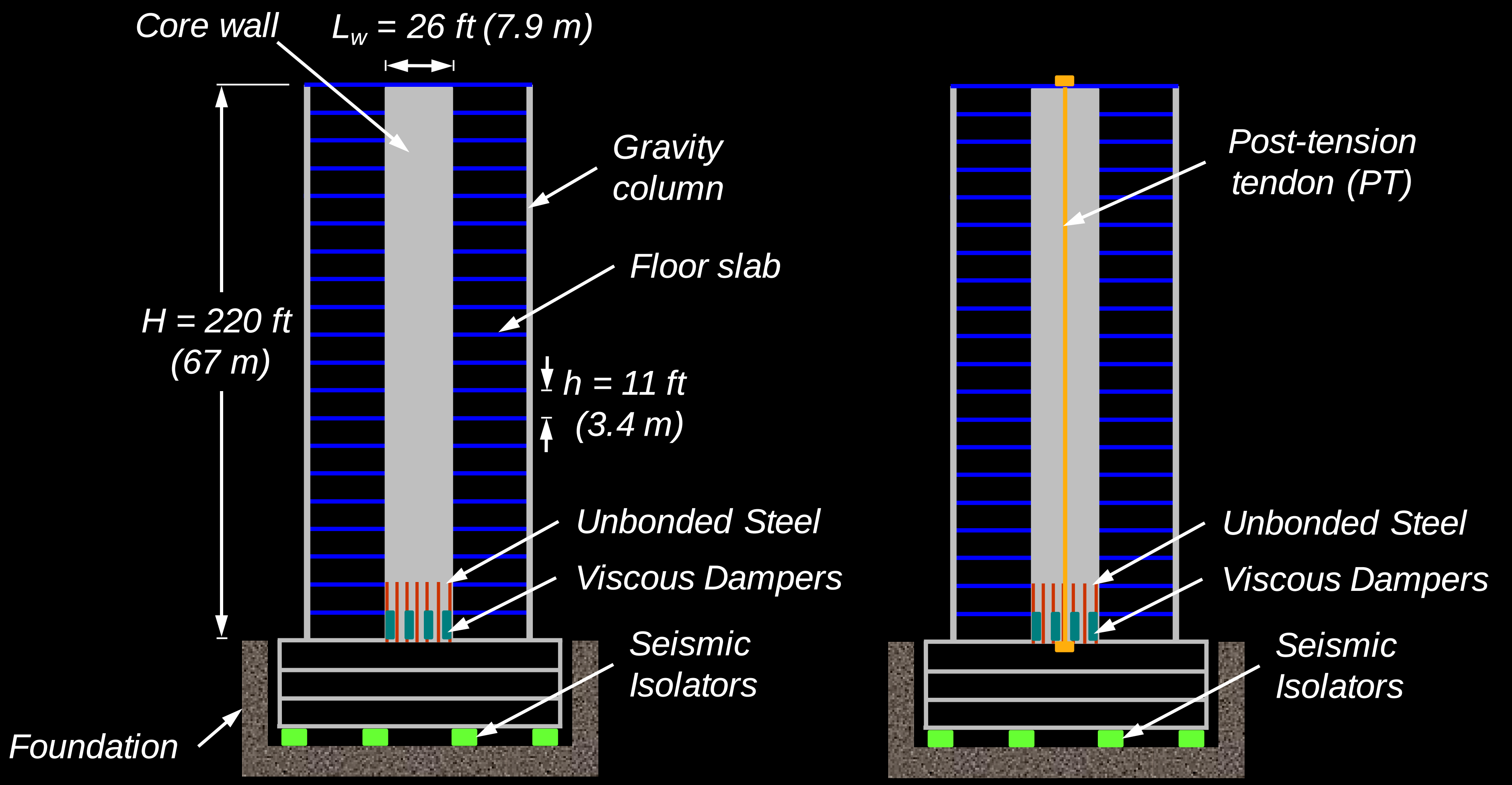
Rocking Core Wall (RW) Building



Elevation (no PT)

Elevation (with PT)

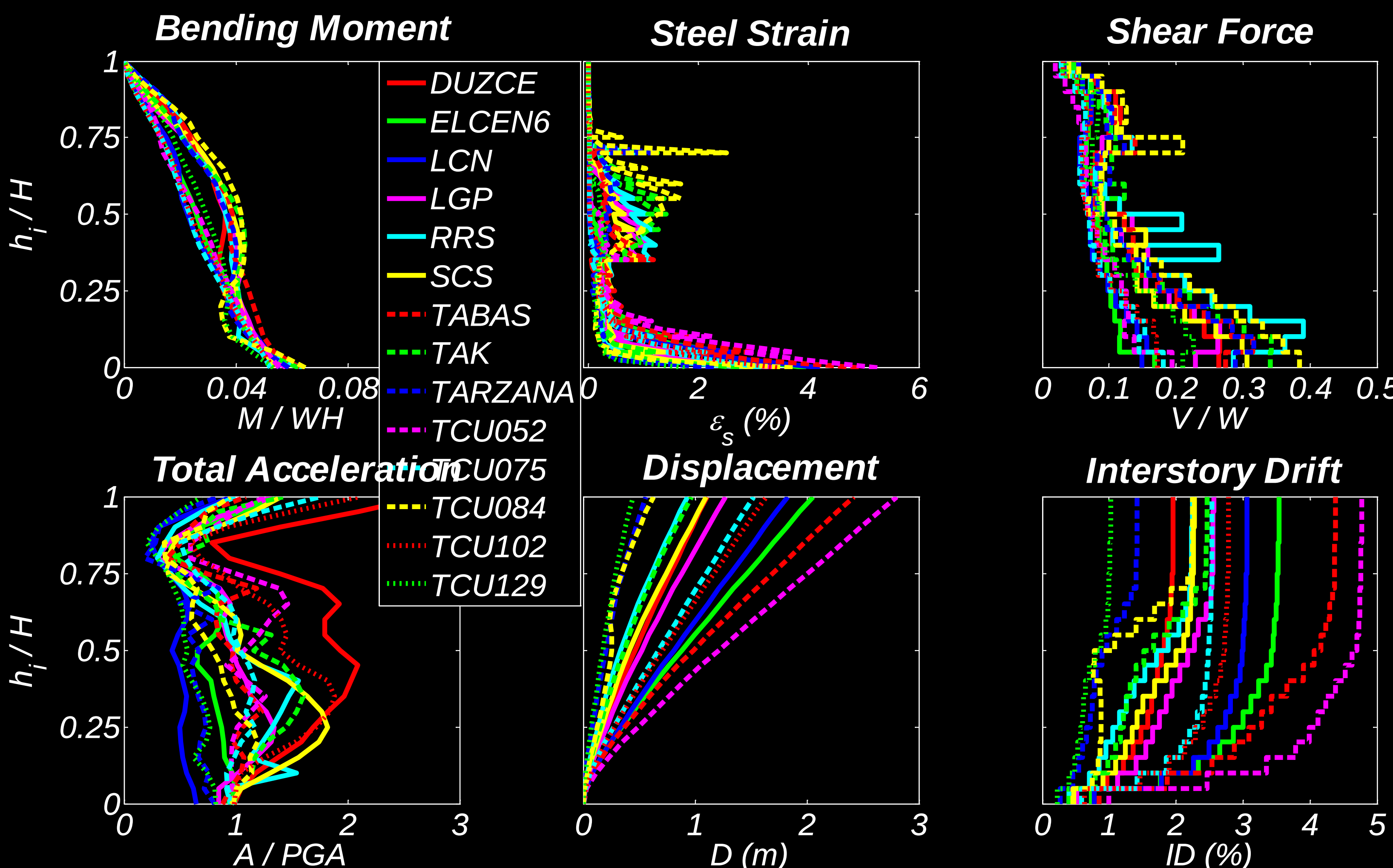
Base Isolation and Rocking Core Wall (BI+RW) Building



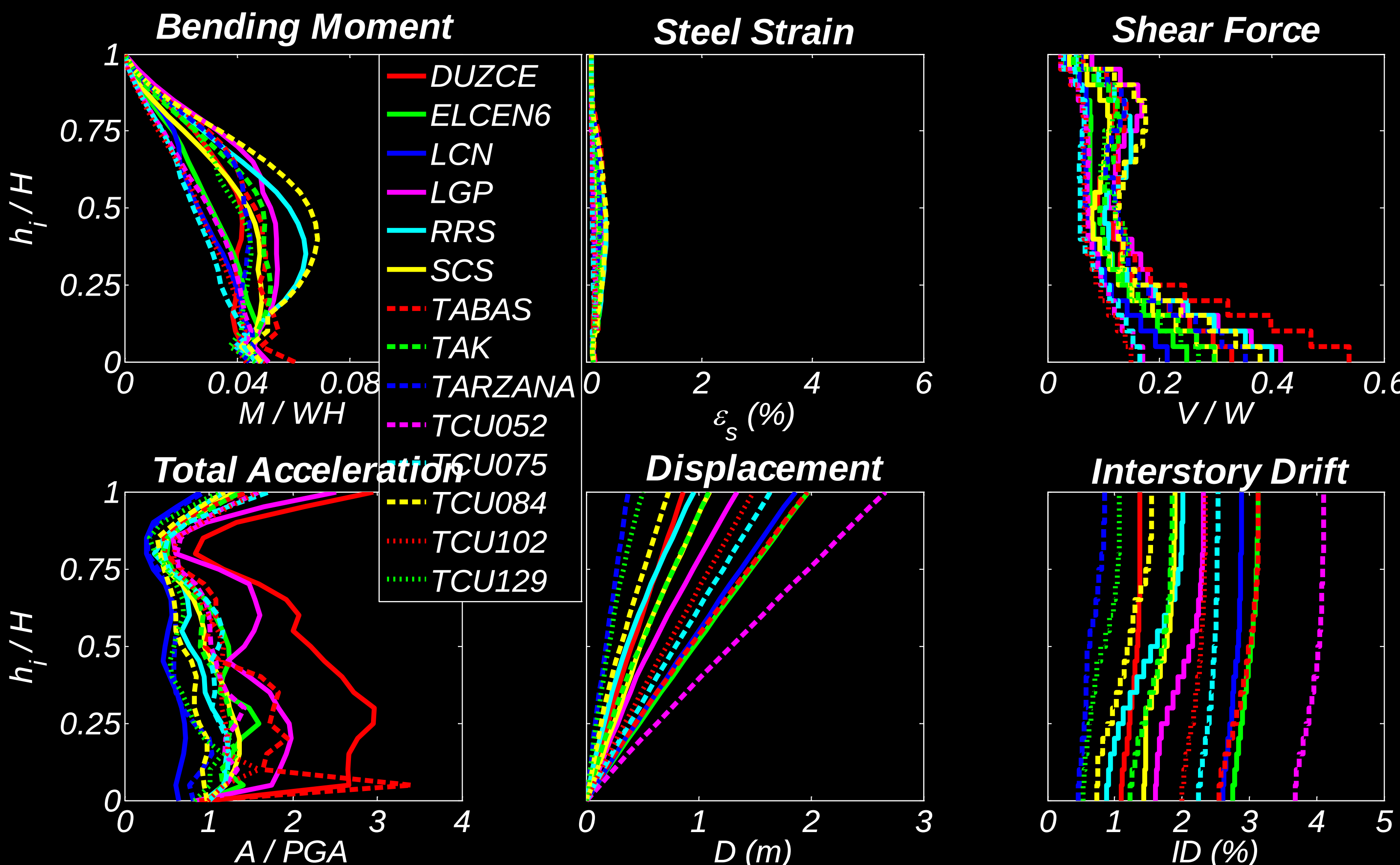
Elevation (no PT)

Elevation (with PT)

EP Response Envelopes for 14 ground motions

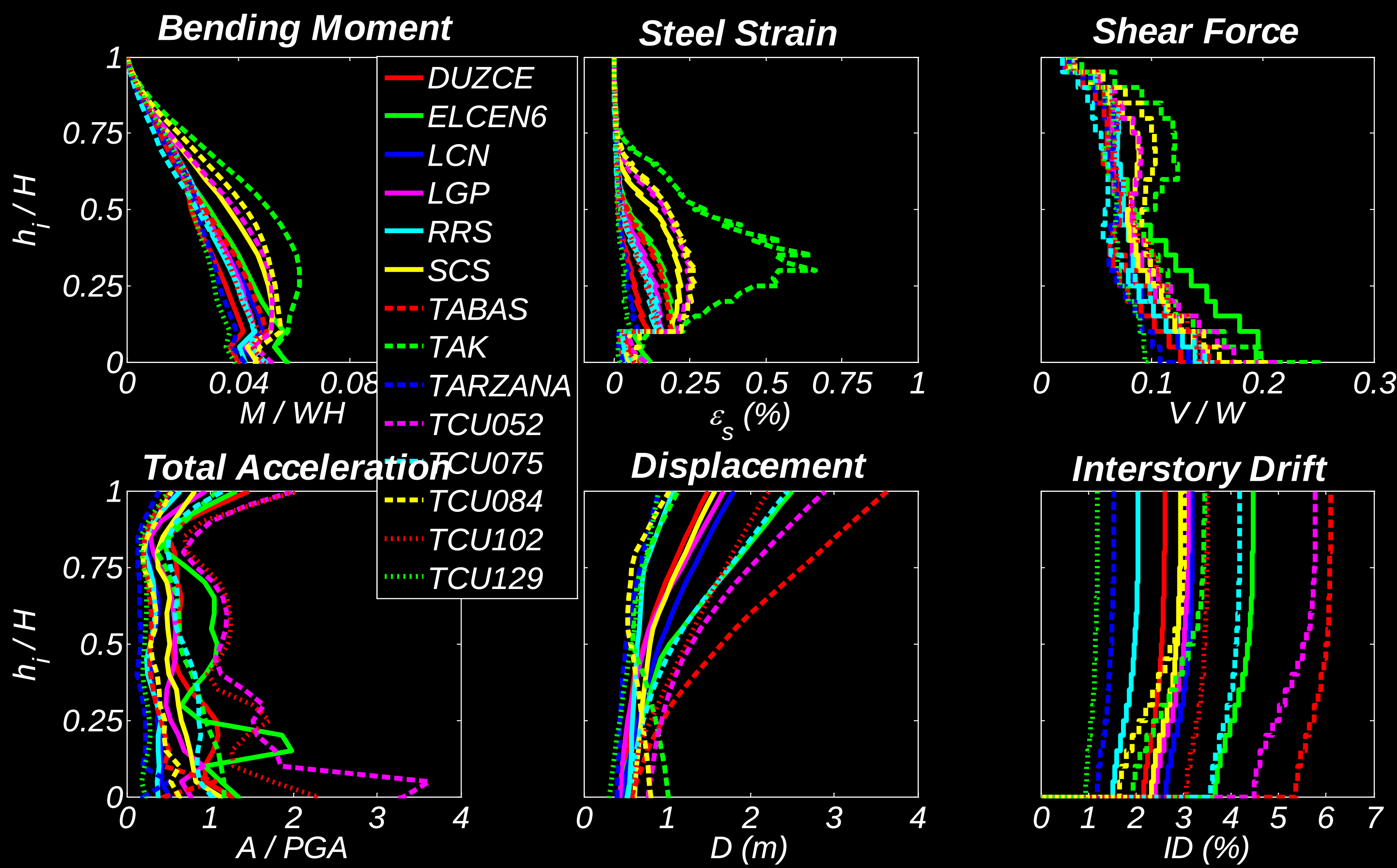


RW Response Envelopes for 14 ground motions



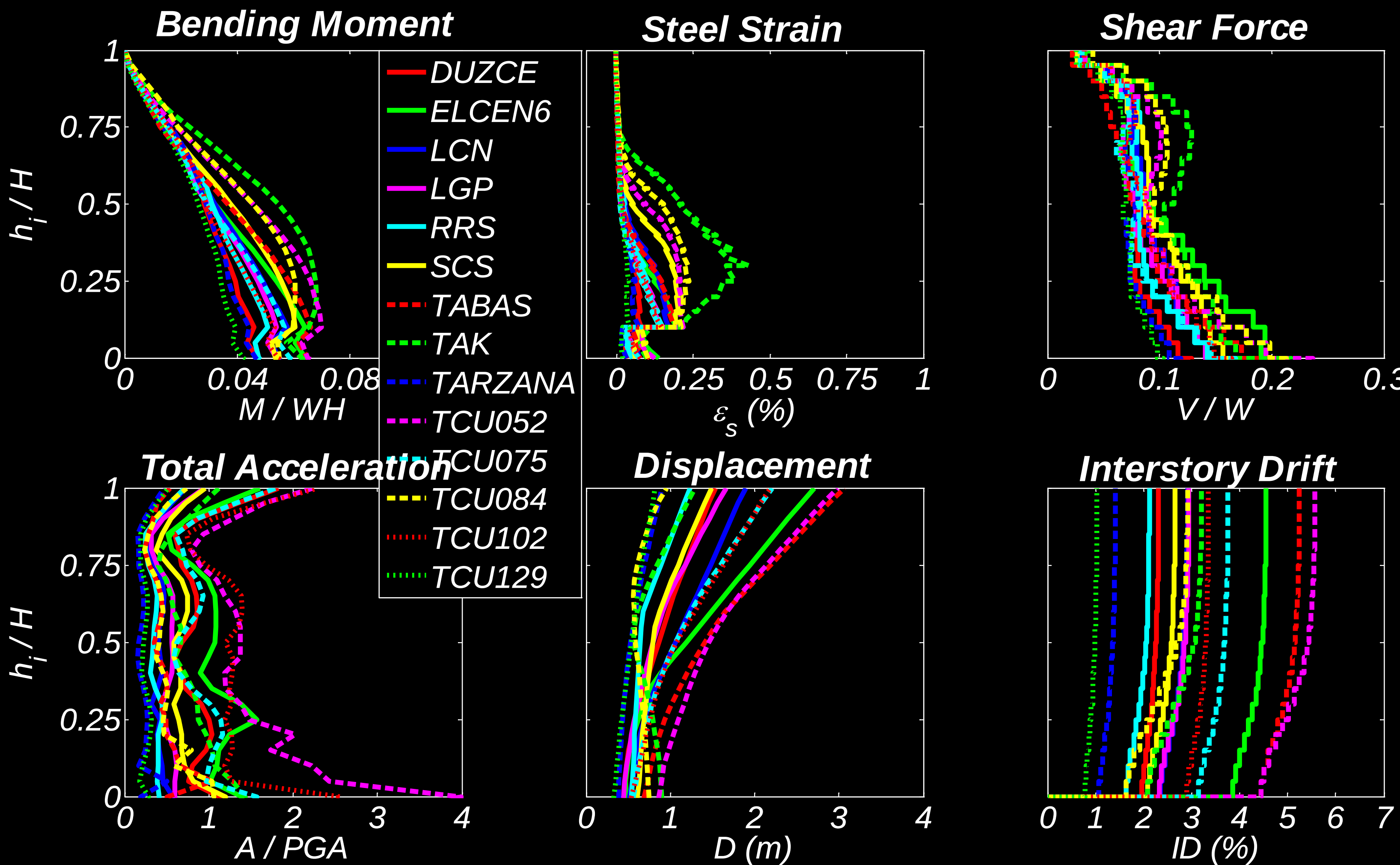
BI+RW Response Envelopes for 14 ground motions

No PT



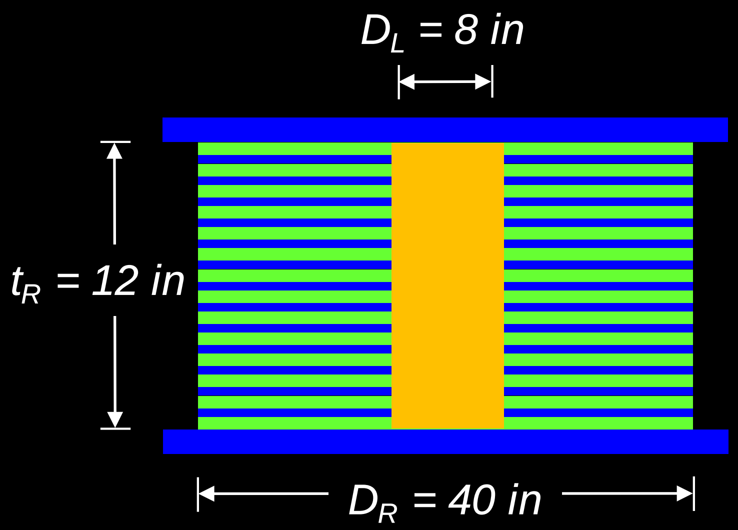
BI+RW Response Envelopes for 14 ground motions

0.4% PT 30ksi prestress



Seismic Isolator Design

20-story

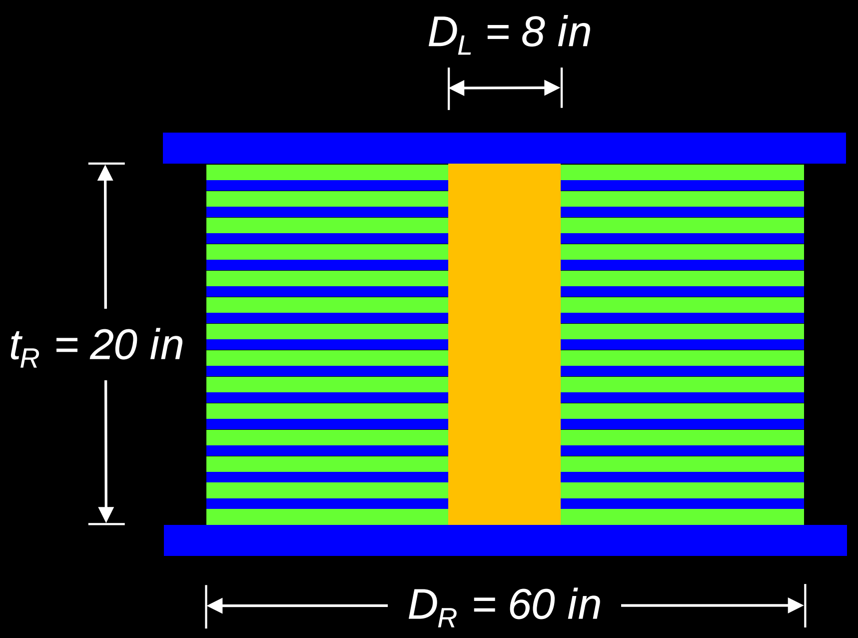


$K_{hor} = 28$ kip / in

$K_{ver} = 12100$ kip / in

$F_y = 106$ kip

40-story

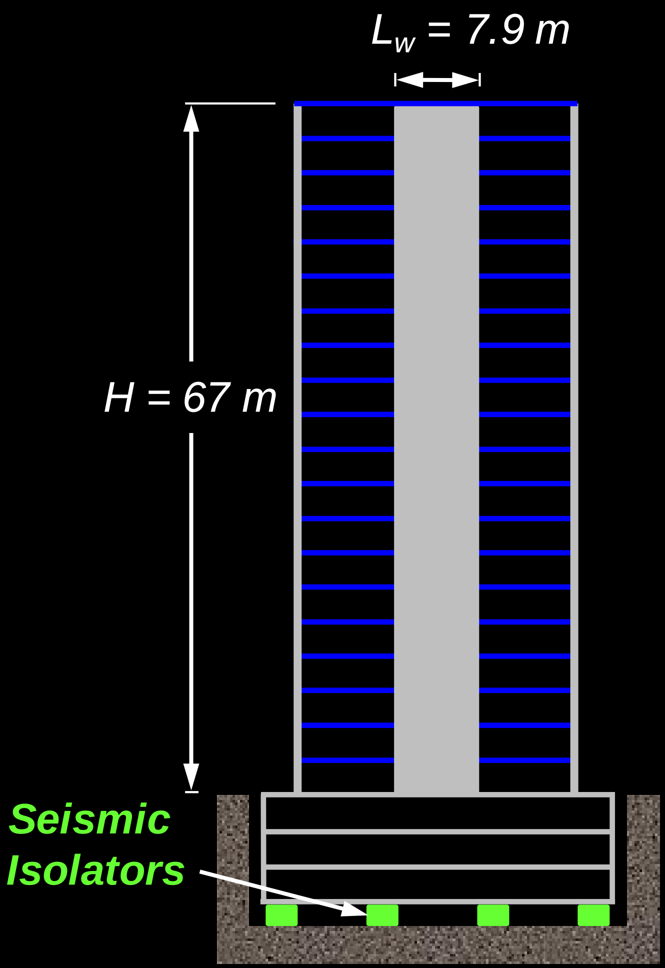


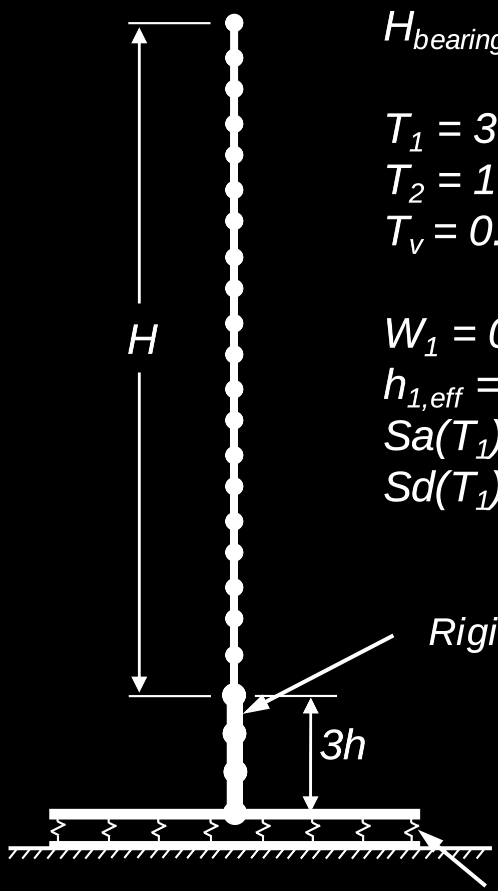
$K_{hor} = 23$ kip / in

$K_{ver} = 17400$ kip / in

$F_y = 146$ kip

Isolated Building Designs





$H_{bearing}$ = 32 cm	$H_{bearing}$ = 47 cm
T_1 = 3.9 sec	T_1 = 4.6 sec
T_2 = 1.2 sec	T_2 = 1.3 sec
T_v = 0.1 sec	T_v = 0.1 sec
$W_1 = 0.91W_t$	$W_1 = 0.92W_t$
$h_{1,eff}$ = 35.8 m	$h_{1,eff}$ = 36.7 m
$Sa(T_1)$ = 0.29 g	$Sa(T_1)$ = 0.24 g
$Sd(T_1)$ = 1.08 m	$Sd(T_1)$ = 1.26 m