Innovative Seismic Lateral Force-Resisting Systems

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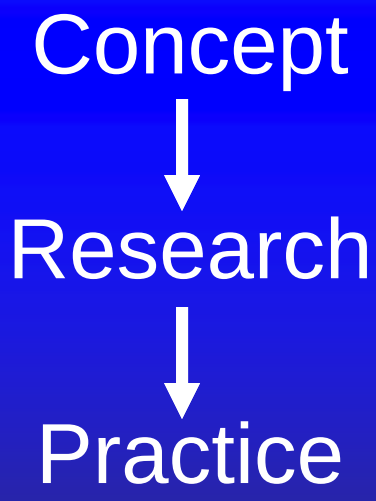
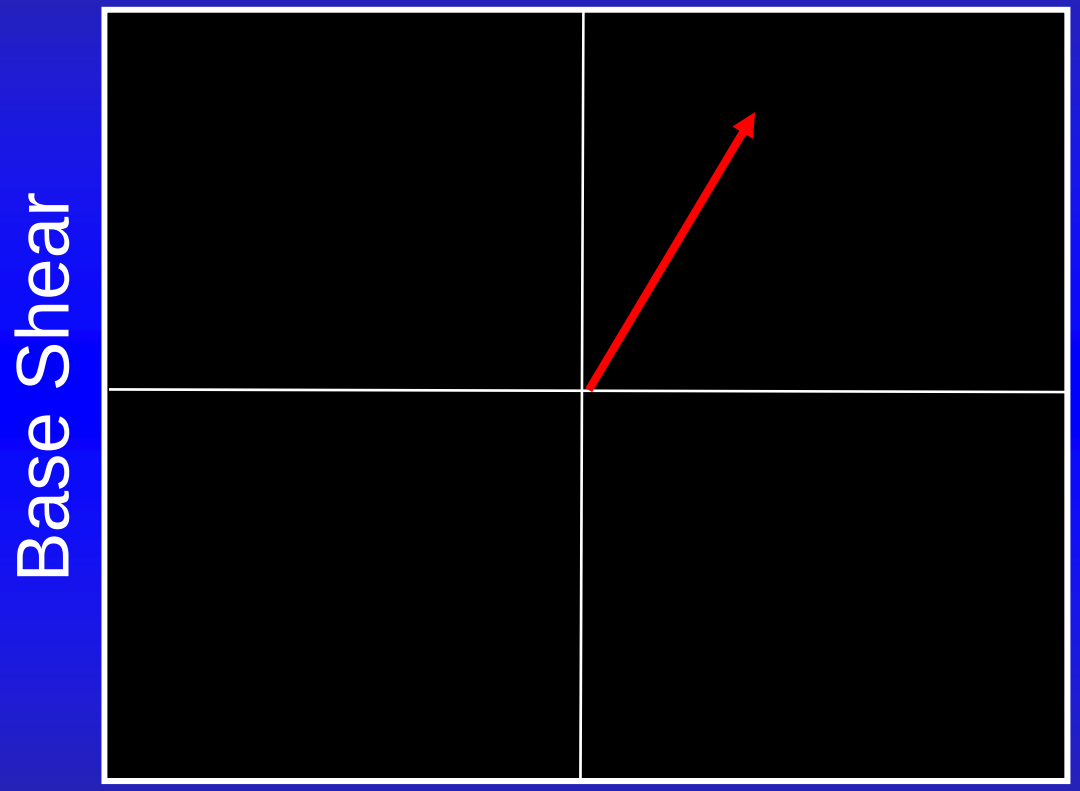
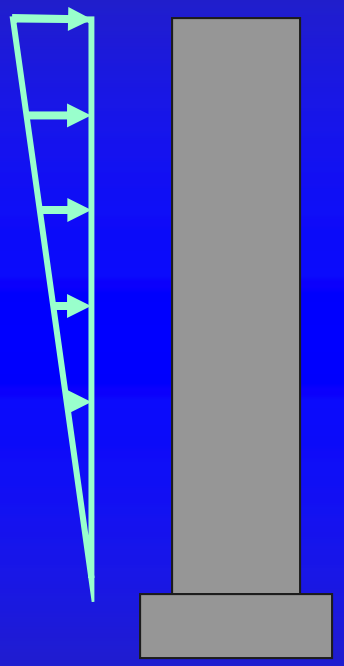
Norfolk VA, 6 May 2014

Innovative Seismic Lateral Force-Resisting Systems

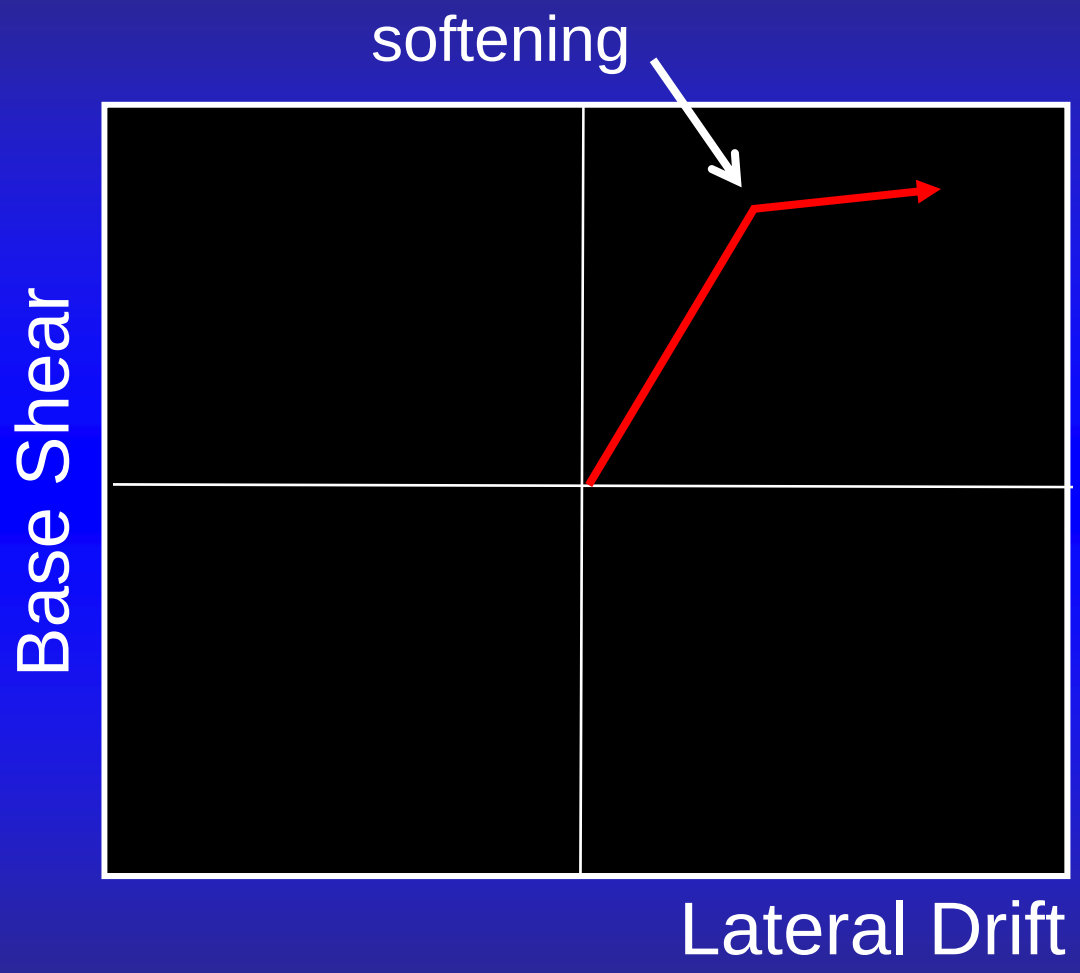


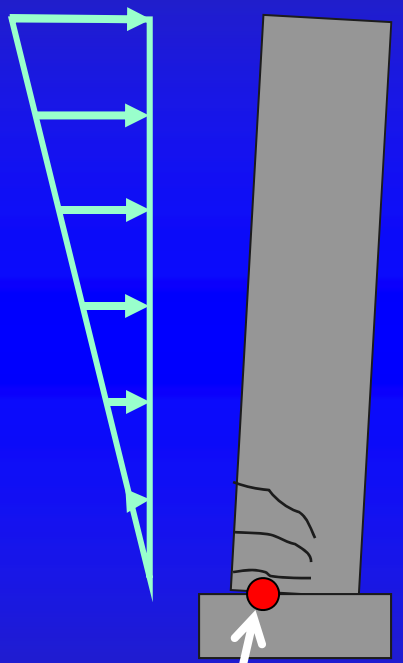
Traditional Systems – Concrete Walls





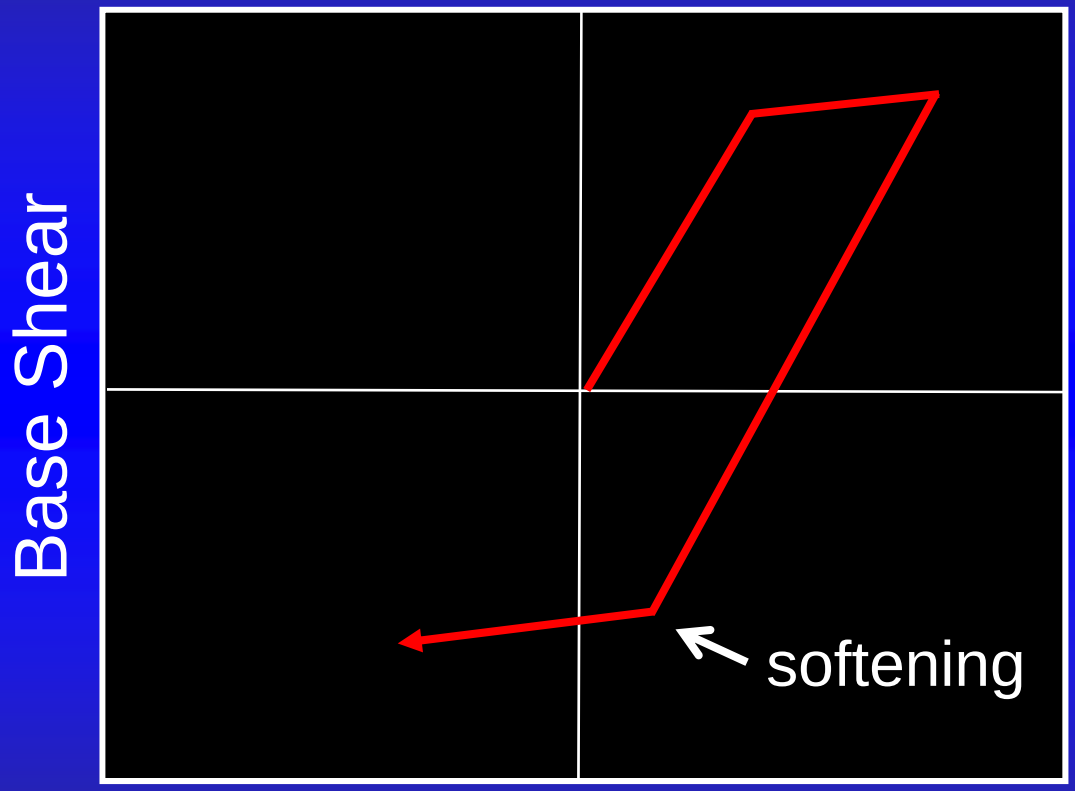
Traditional Systems

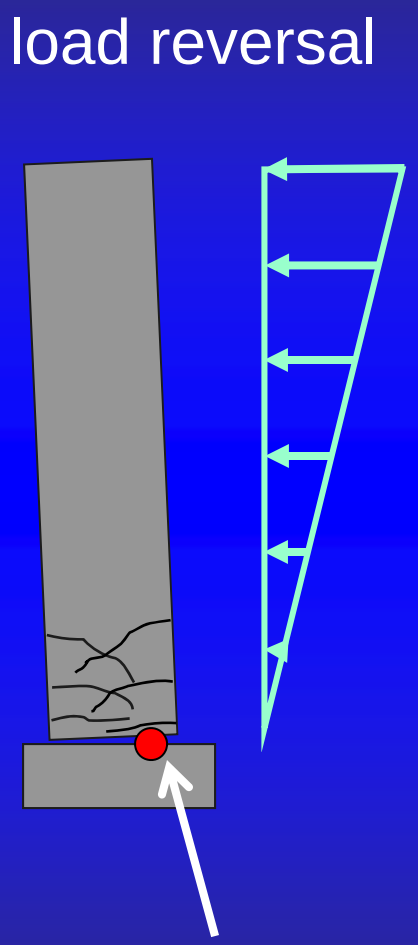




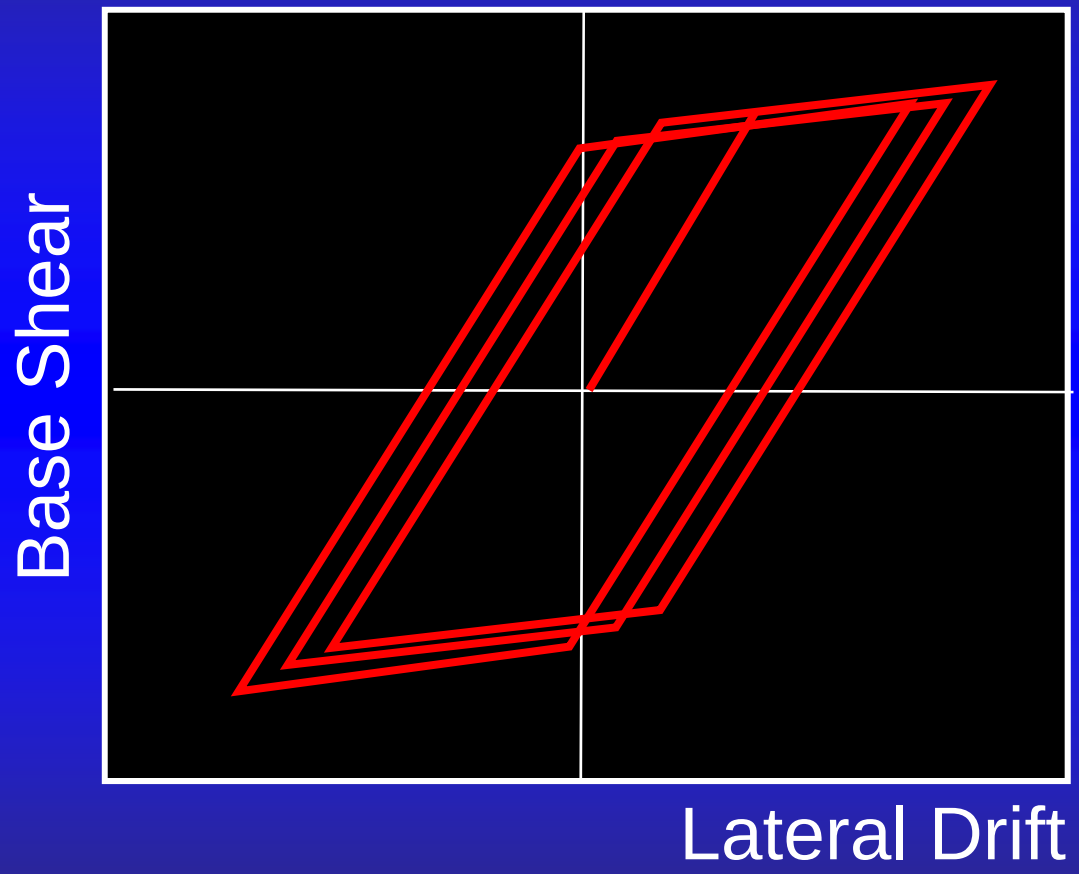
yield of mild steel reinforcing bars at base of wall

Traditional Systems





Traditional Systems

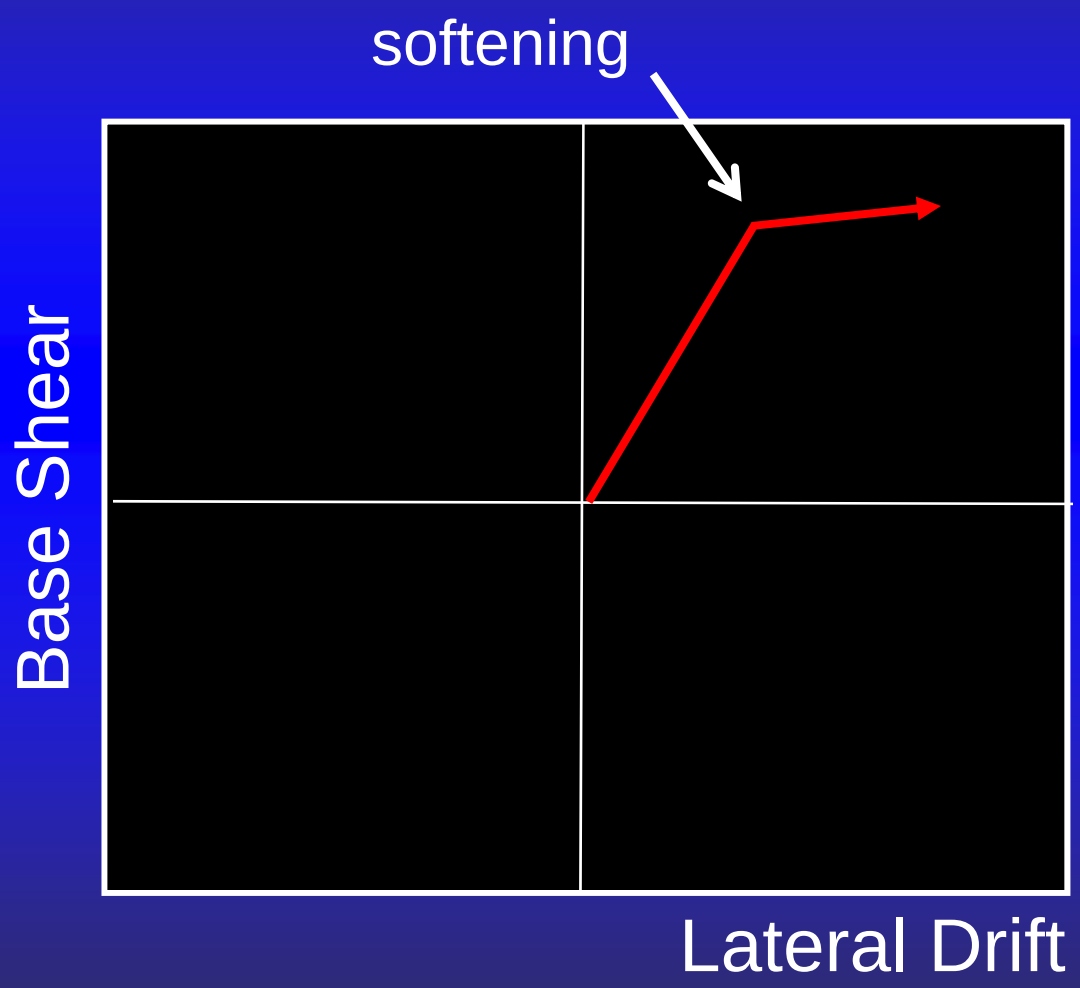


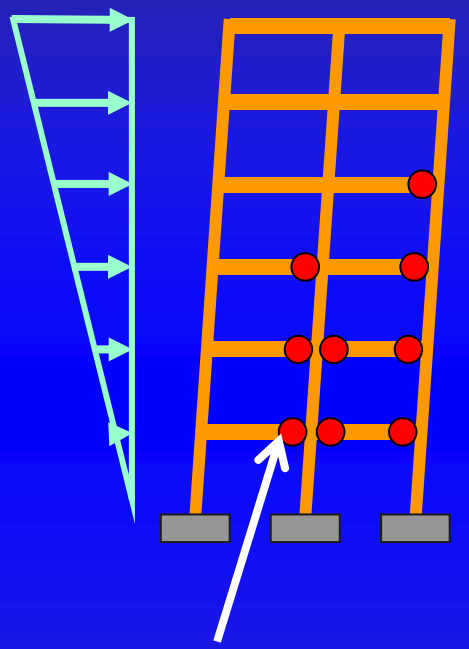
Design objective is life safety (prevent collapse).

Softening achieved through damage (yield in the reinforcing bars, and cracking and nonlinearity in the concrete).

Ductility and energy dissipation achieved through detailing.

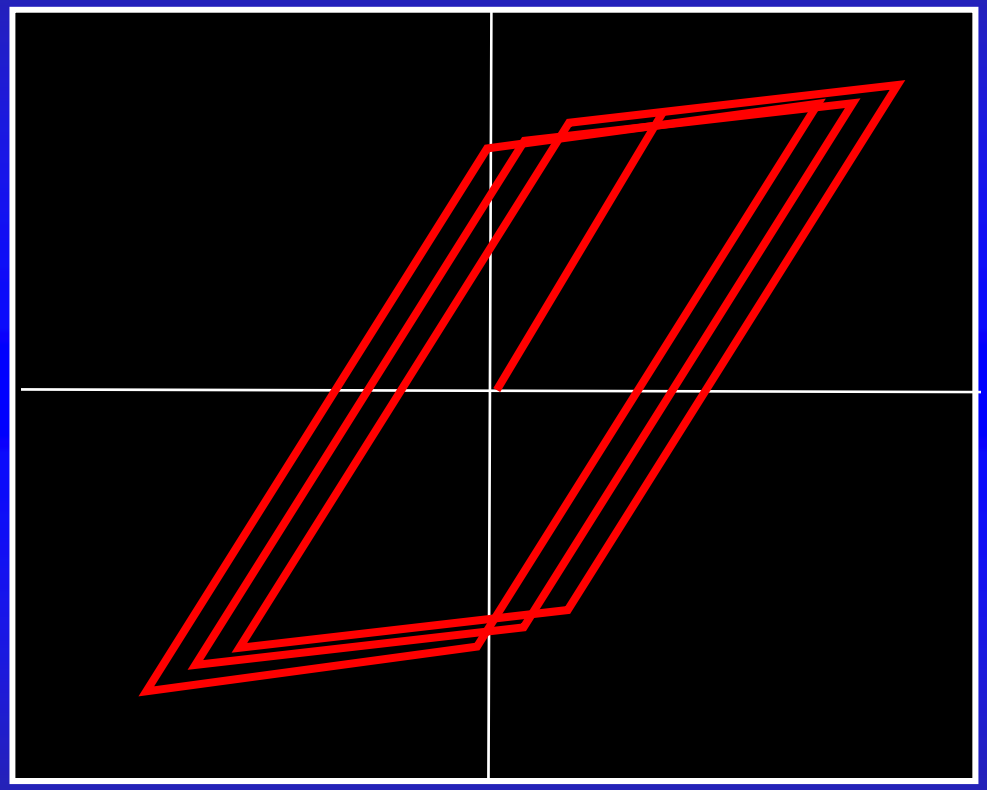
Traditional Systems – Steel Moment Frames

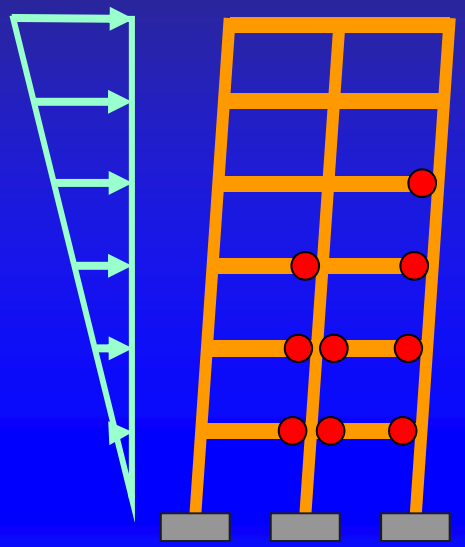




plastic hinges in steel beams

Traditional Systems – Steel Moment Frames

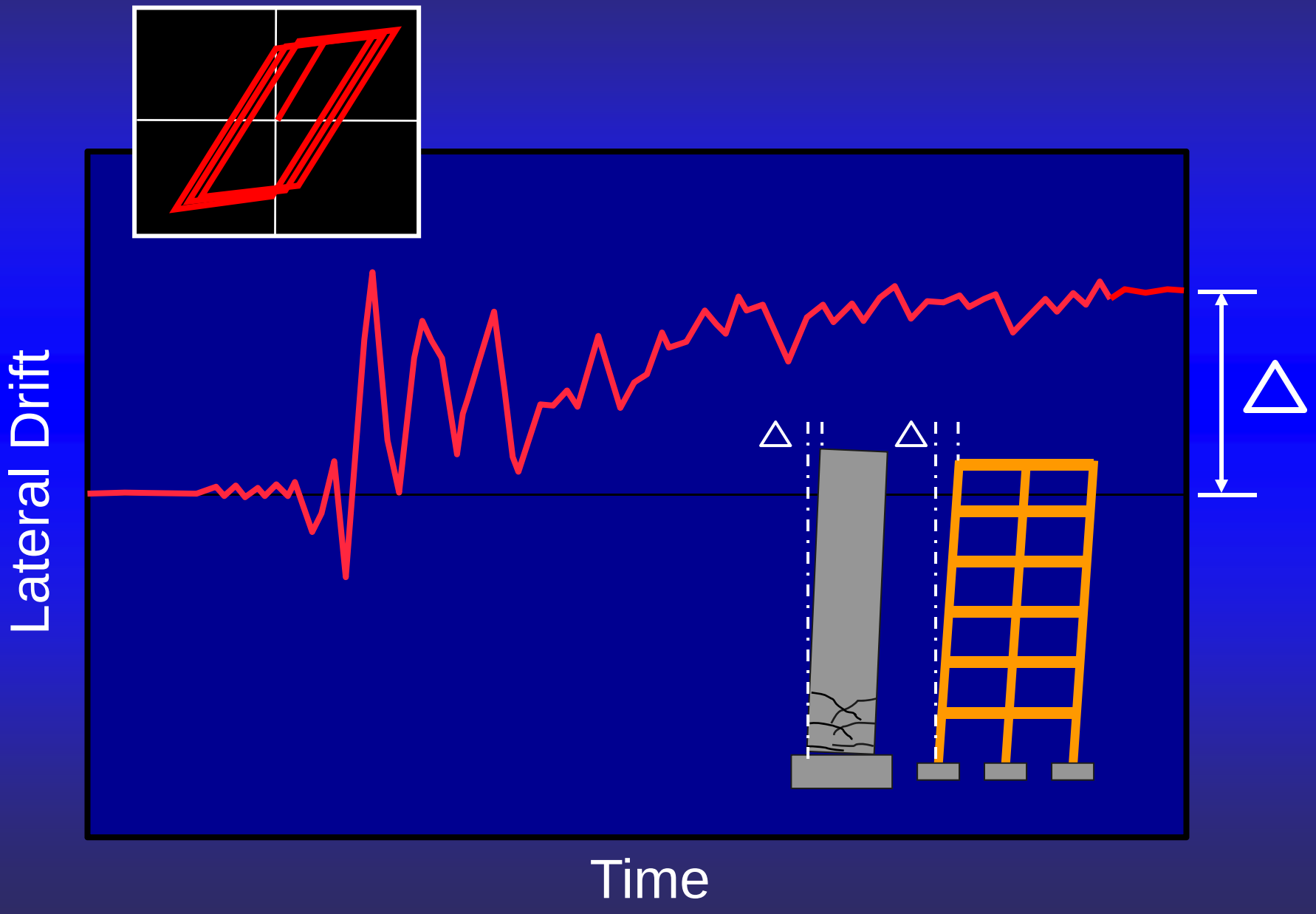




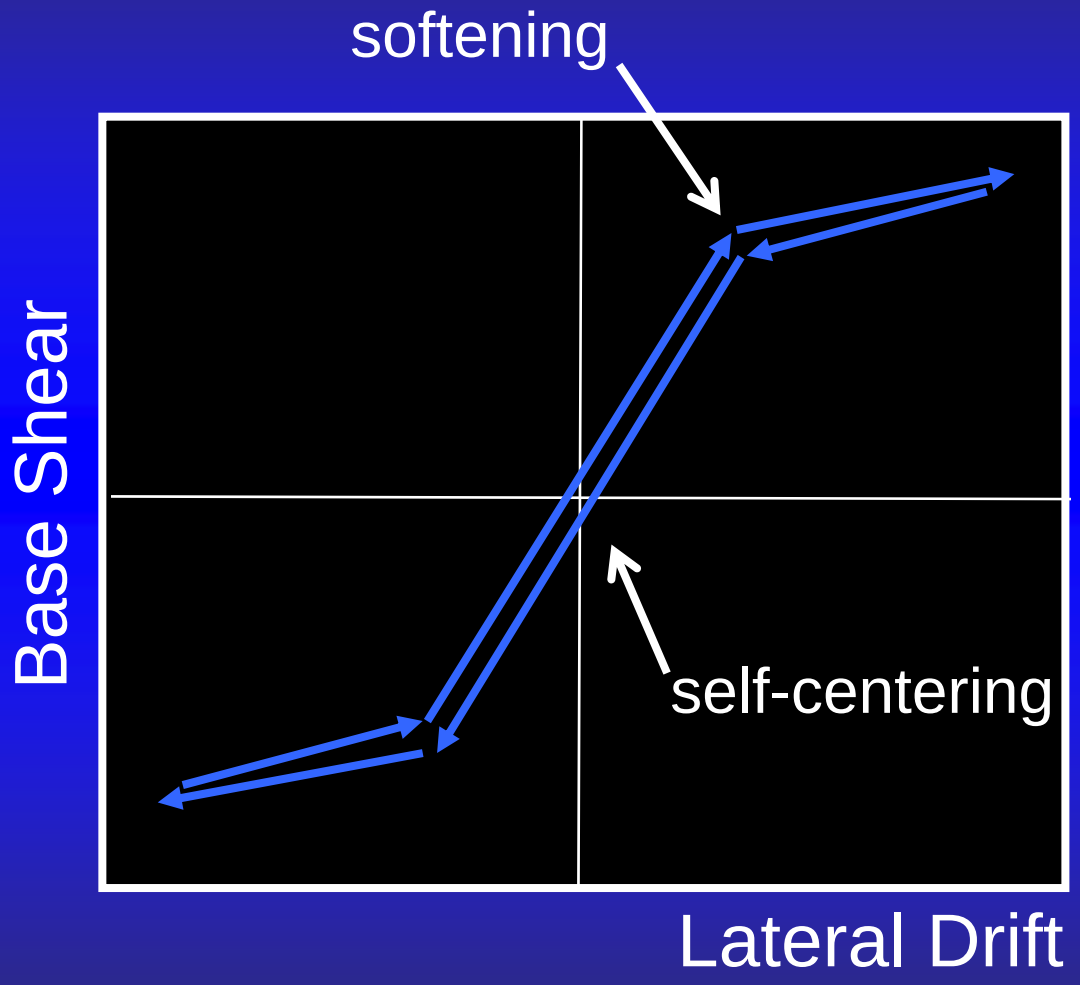
Softening achieved through damage (plastic hinges).

Ductility and energy dissipation achieved through detailing.

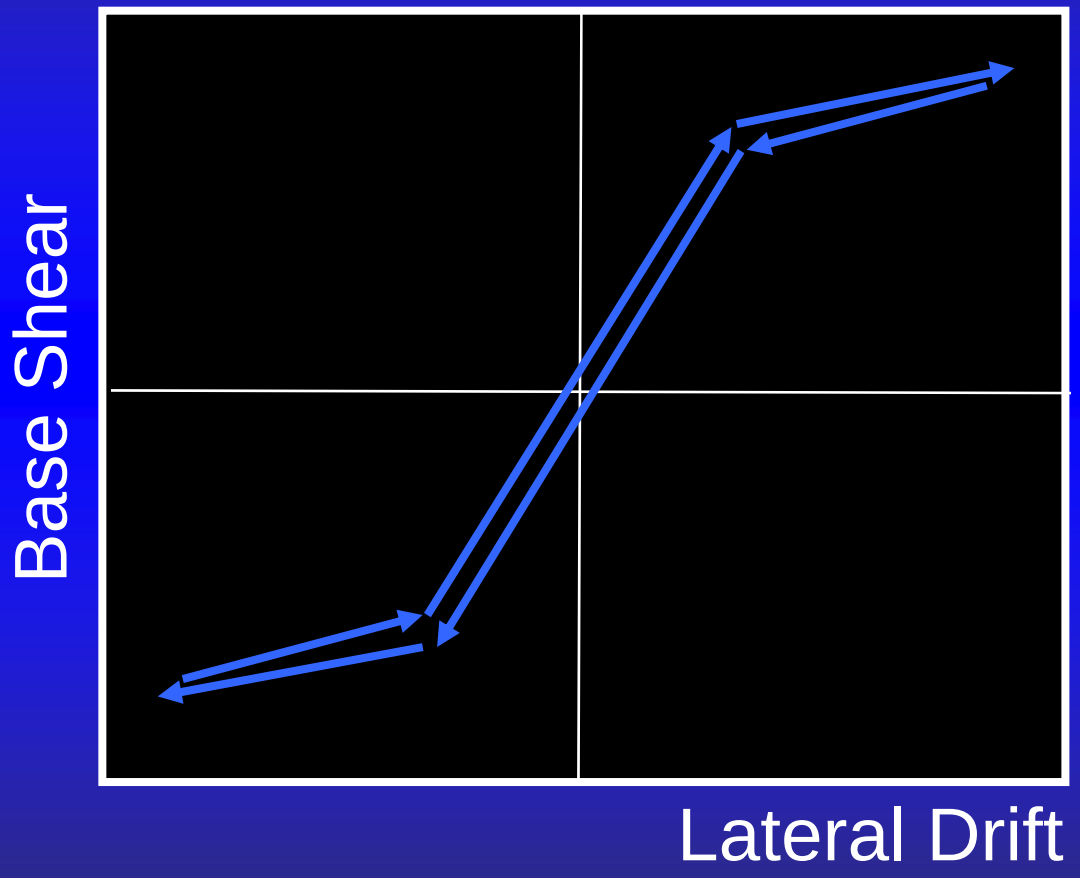
Overall Response of Traditional Systems



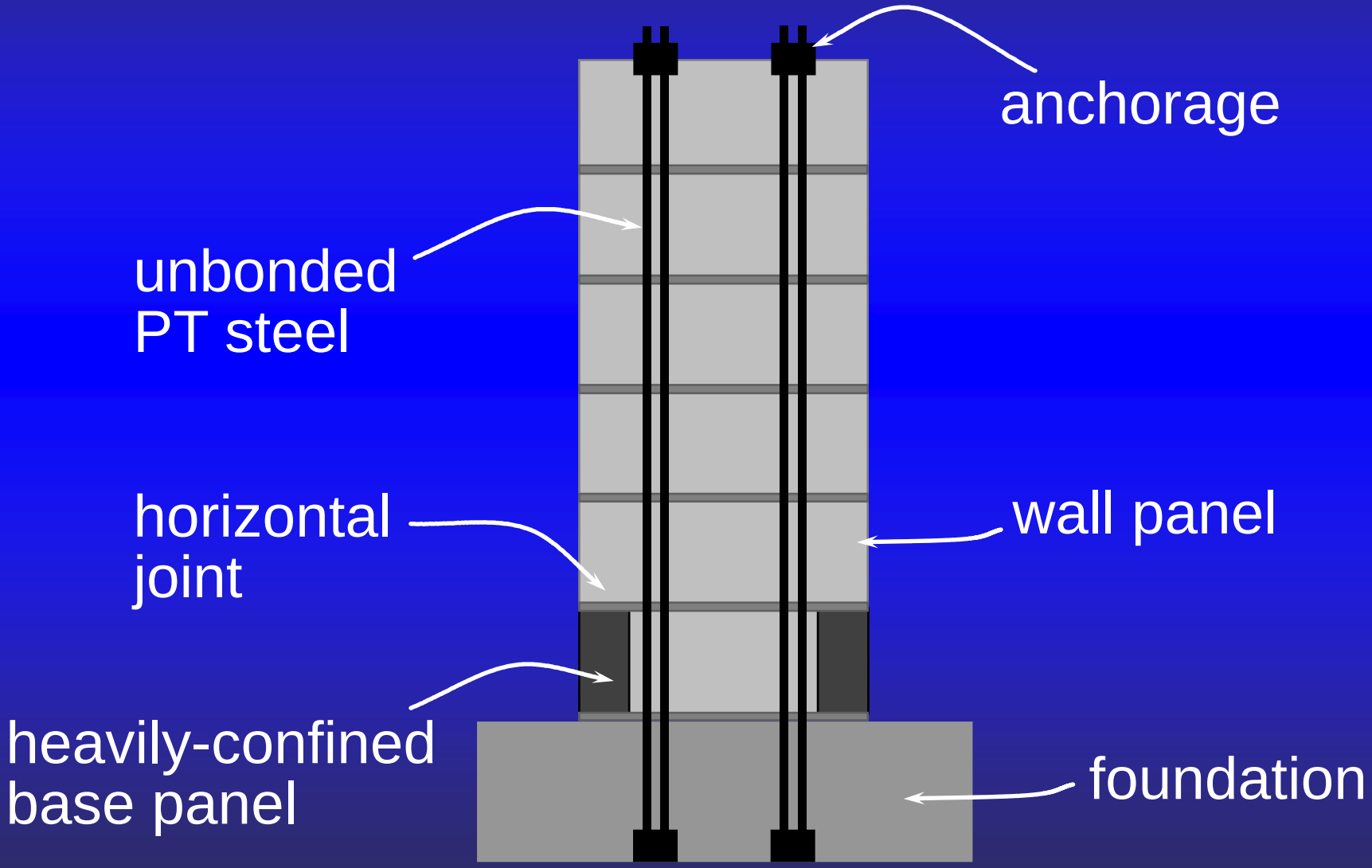
1990’s - Nonlinear Elastic Systems



How do you create a nonlinear elastic system?



Example - Unbonded Post-tensioned Precast Concrete Wall



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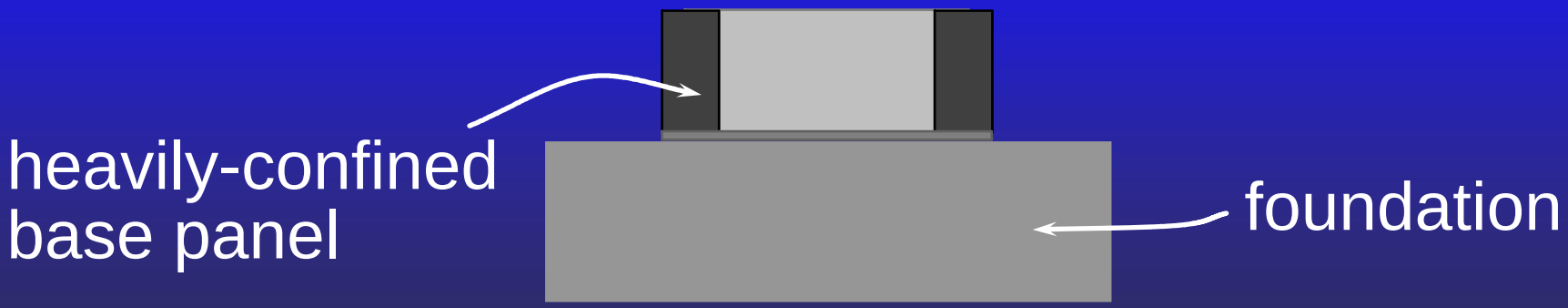

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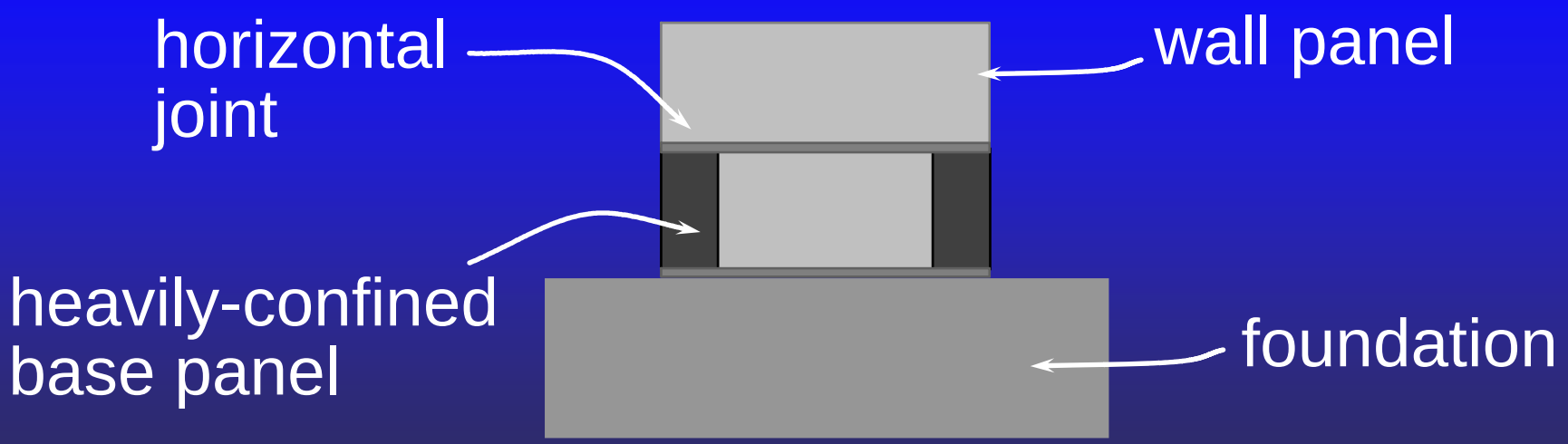

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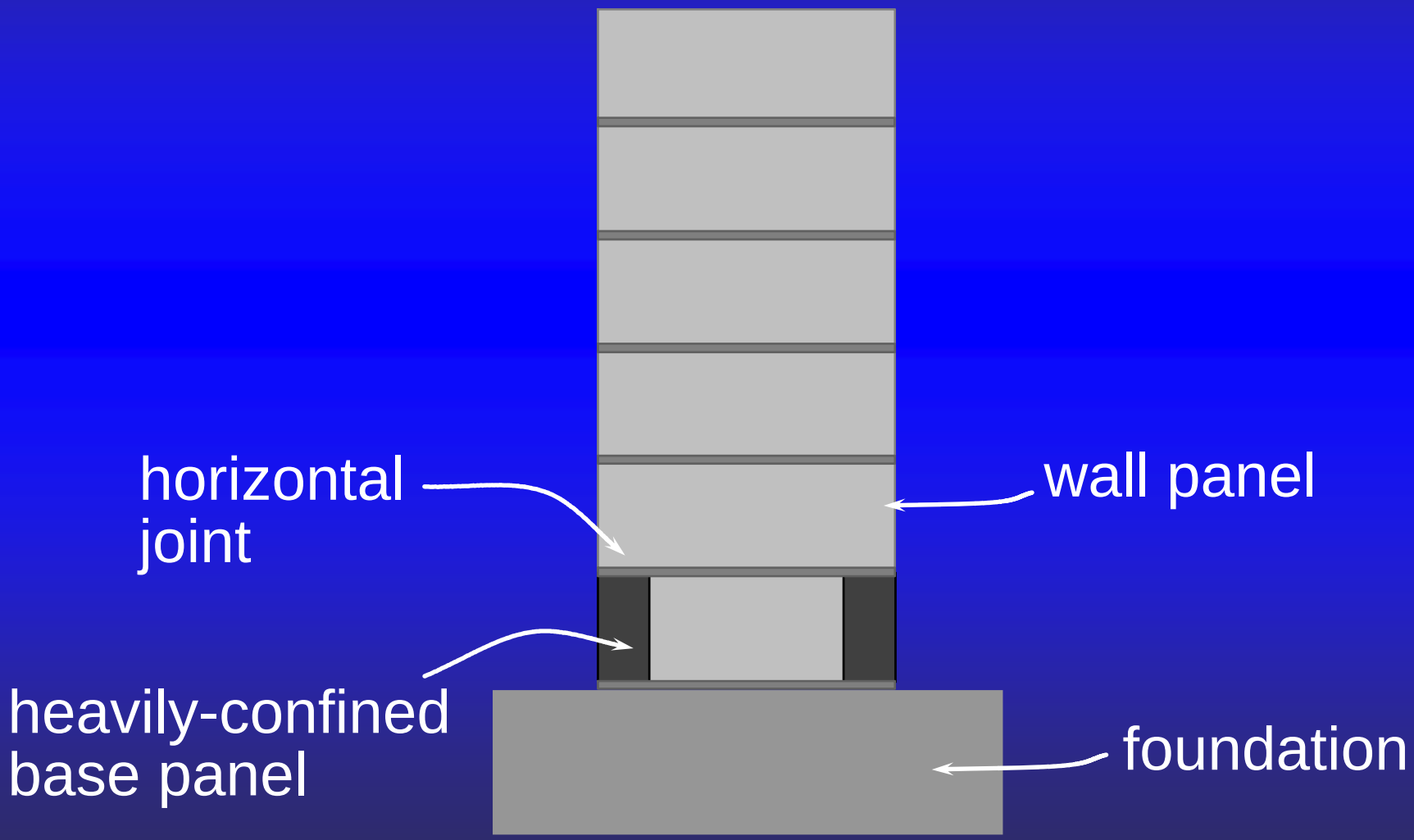
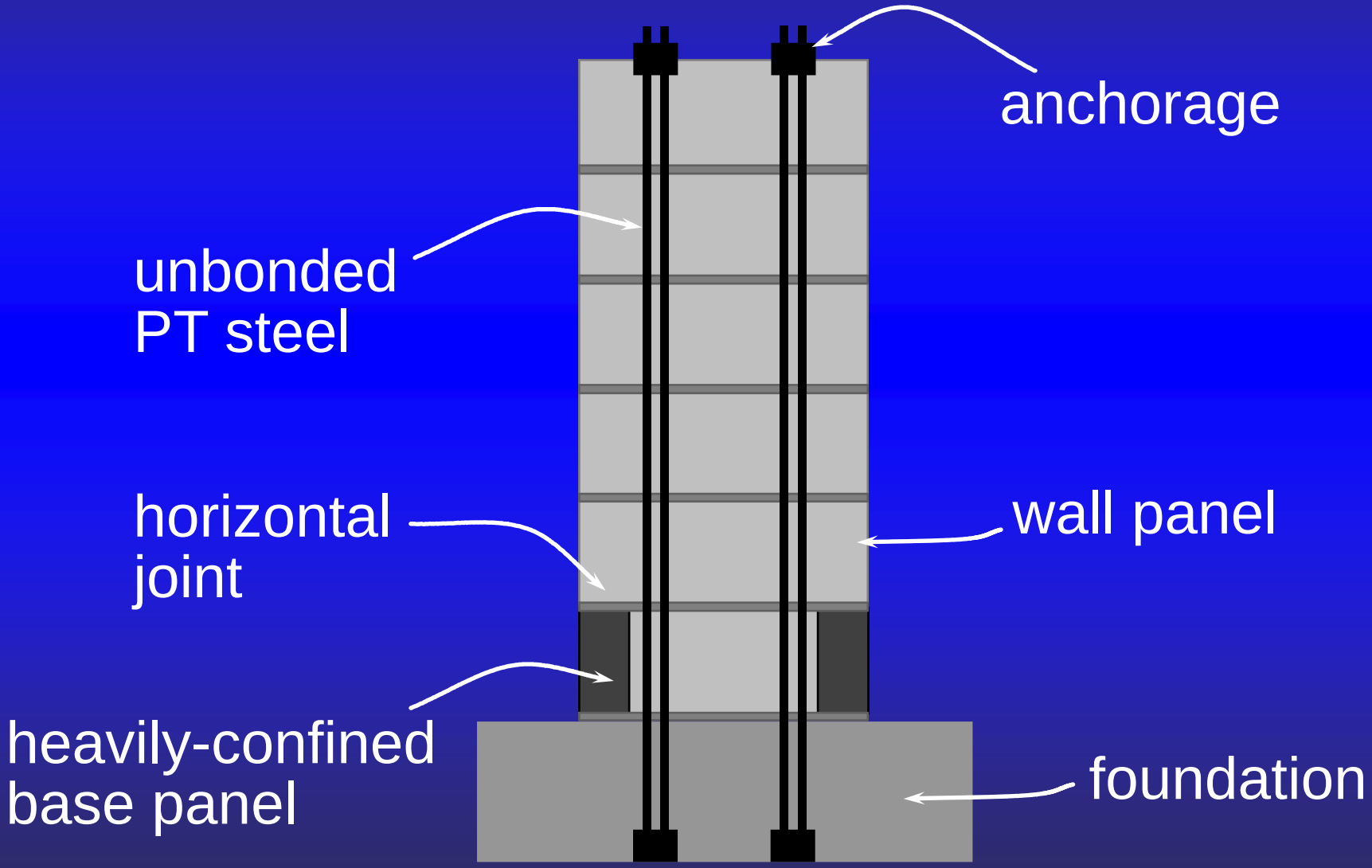


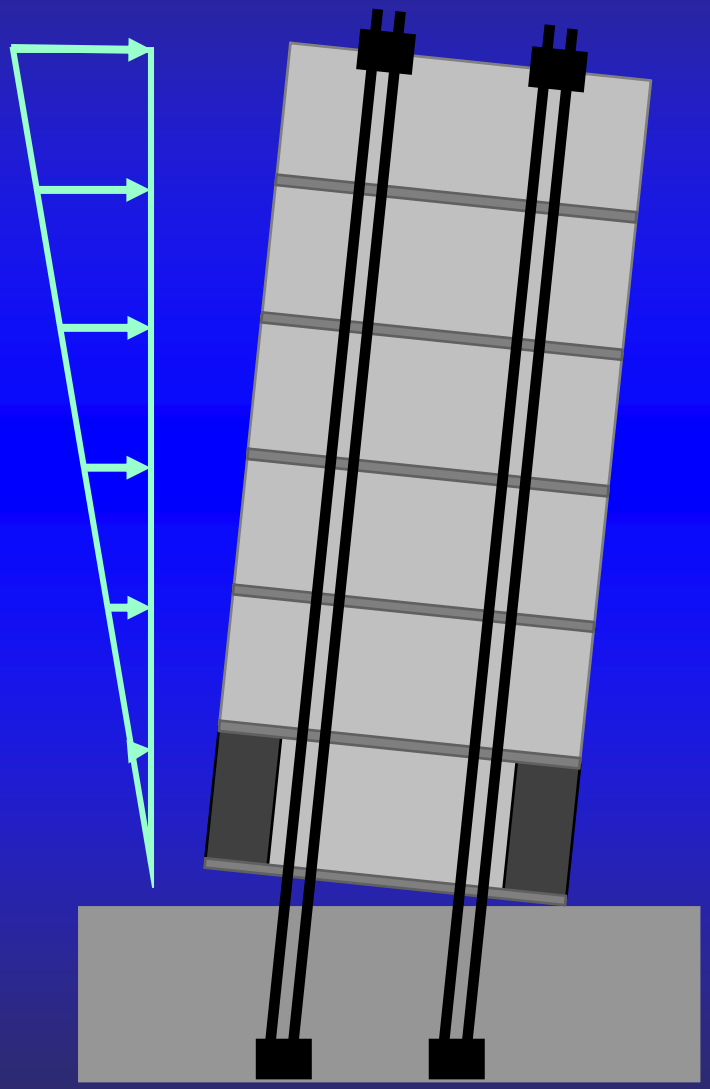
Example - Unbonded Post-tensioned Precast Concrete Wall



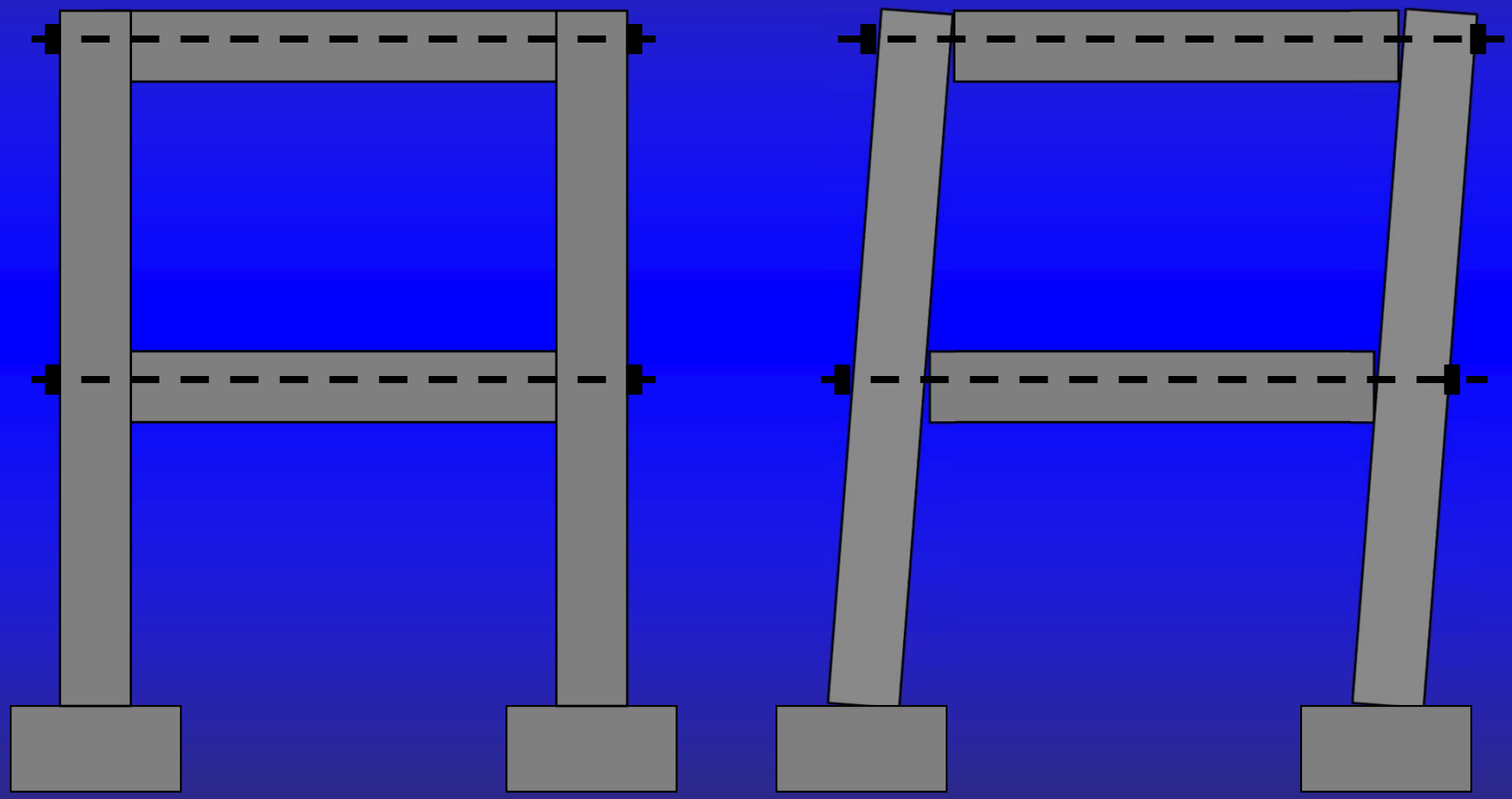
Example - Unbonded Post-tensioned Precast Concrete Wall

Softening achieved through gap opening, and not through damage.

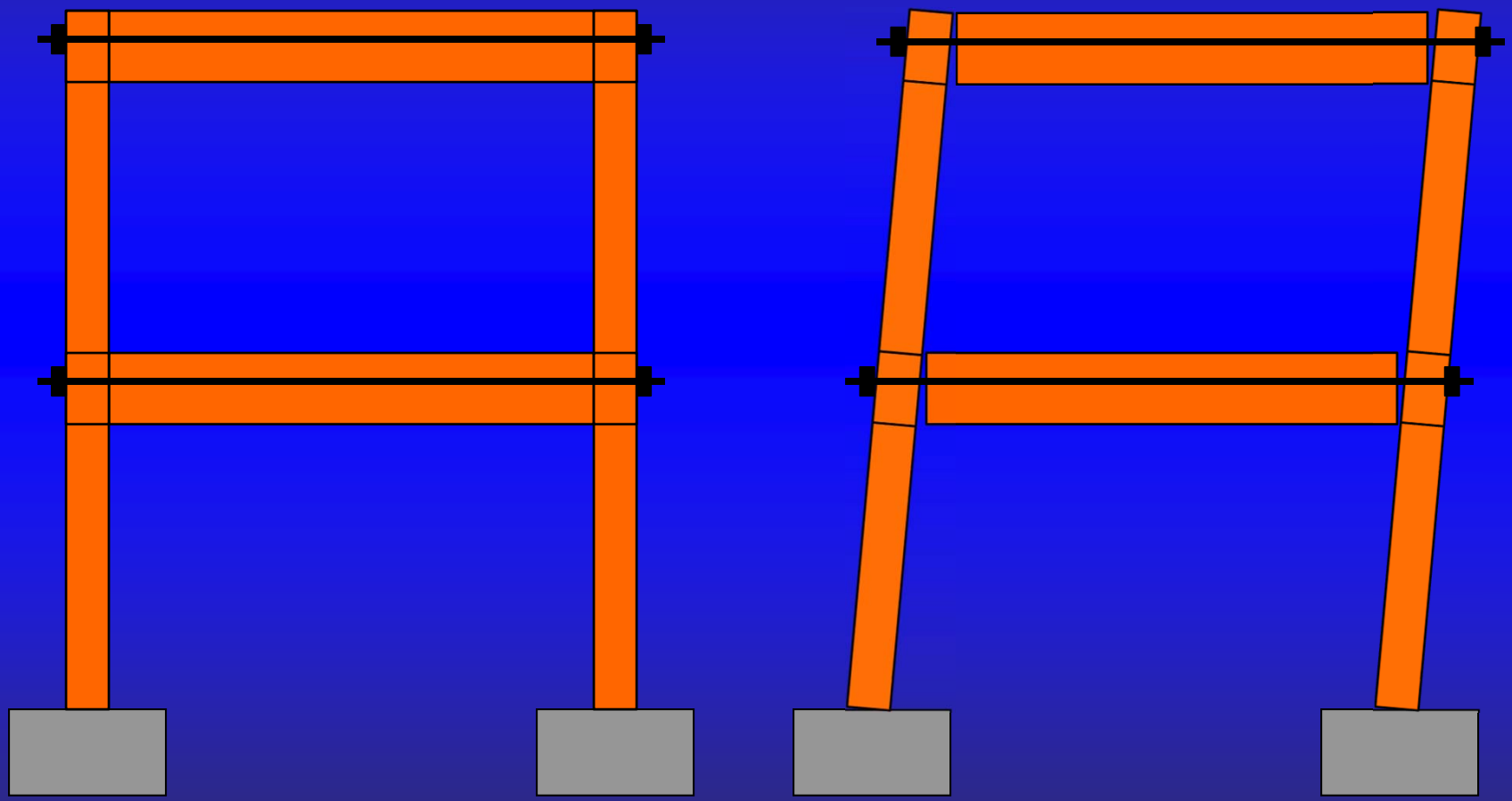
Post-tensioning protected from yielding because of debonding.



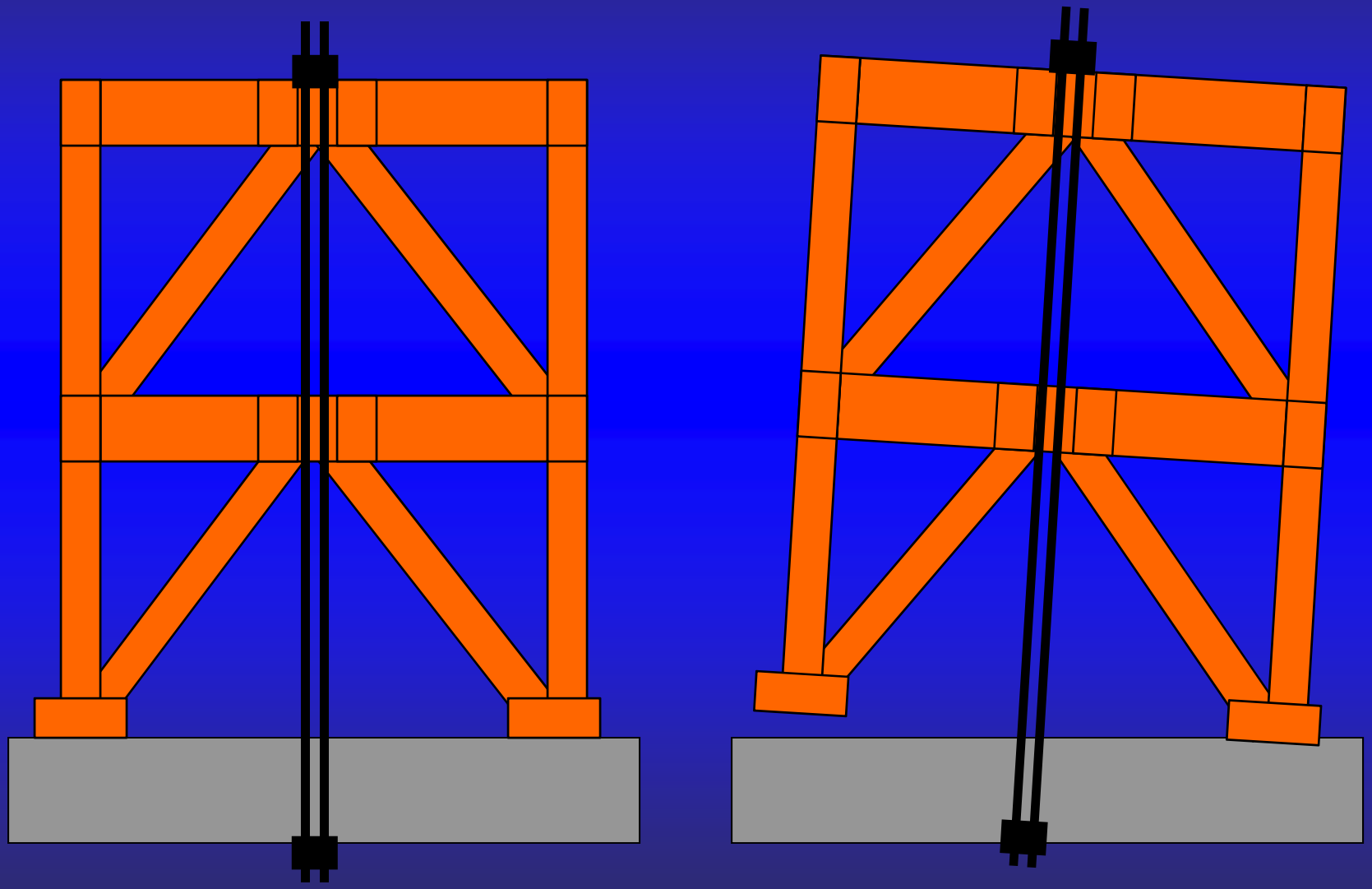
Example - Unbonded Post-tensioned Precast Concrete Frame

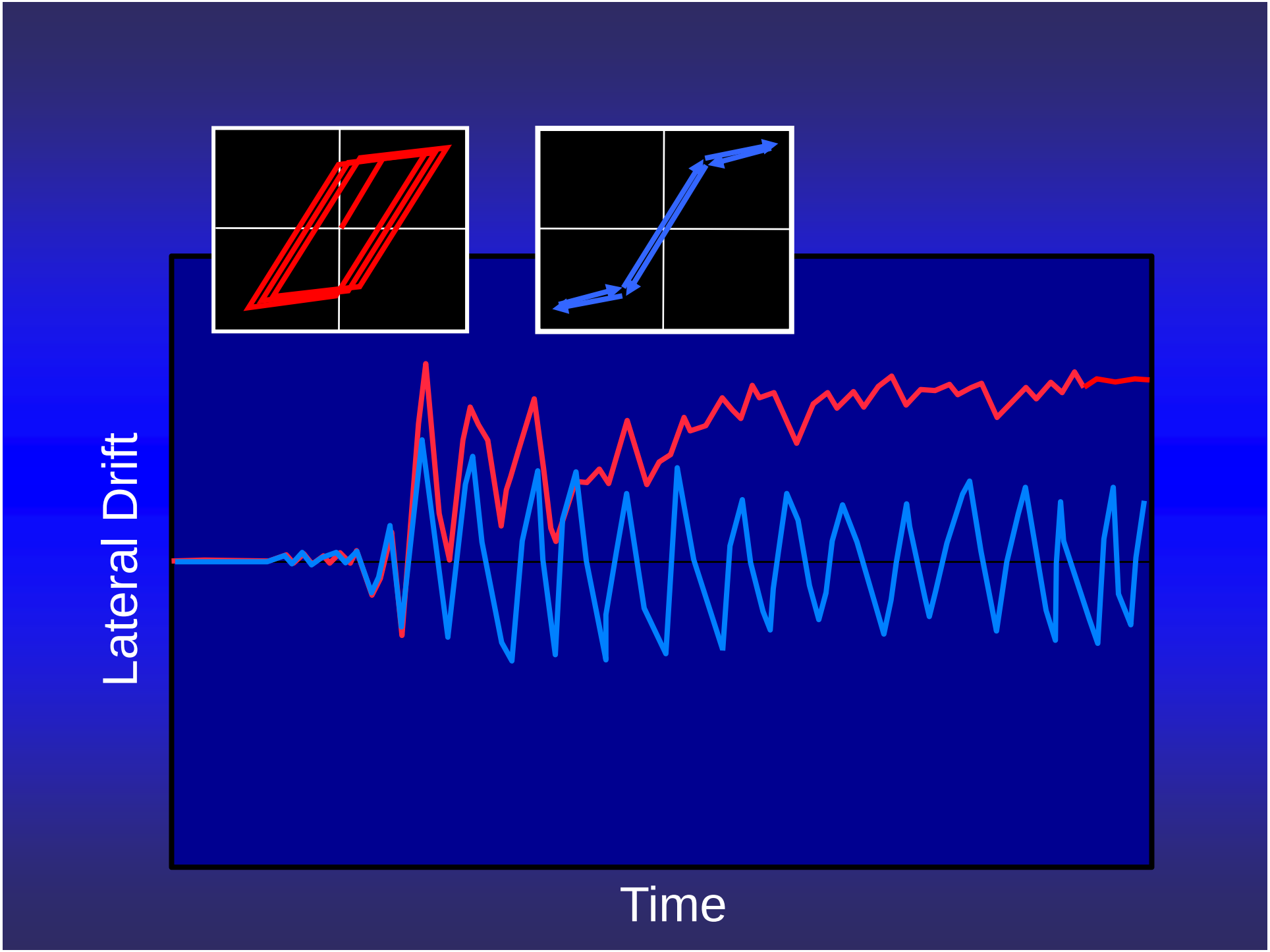


Example - Unbonded Post-tensioned Steel Frame

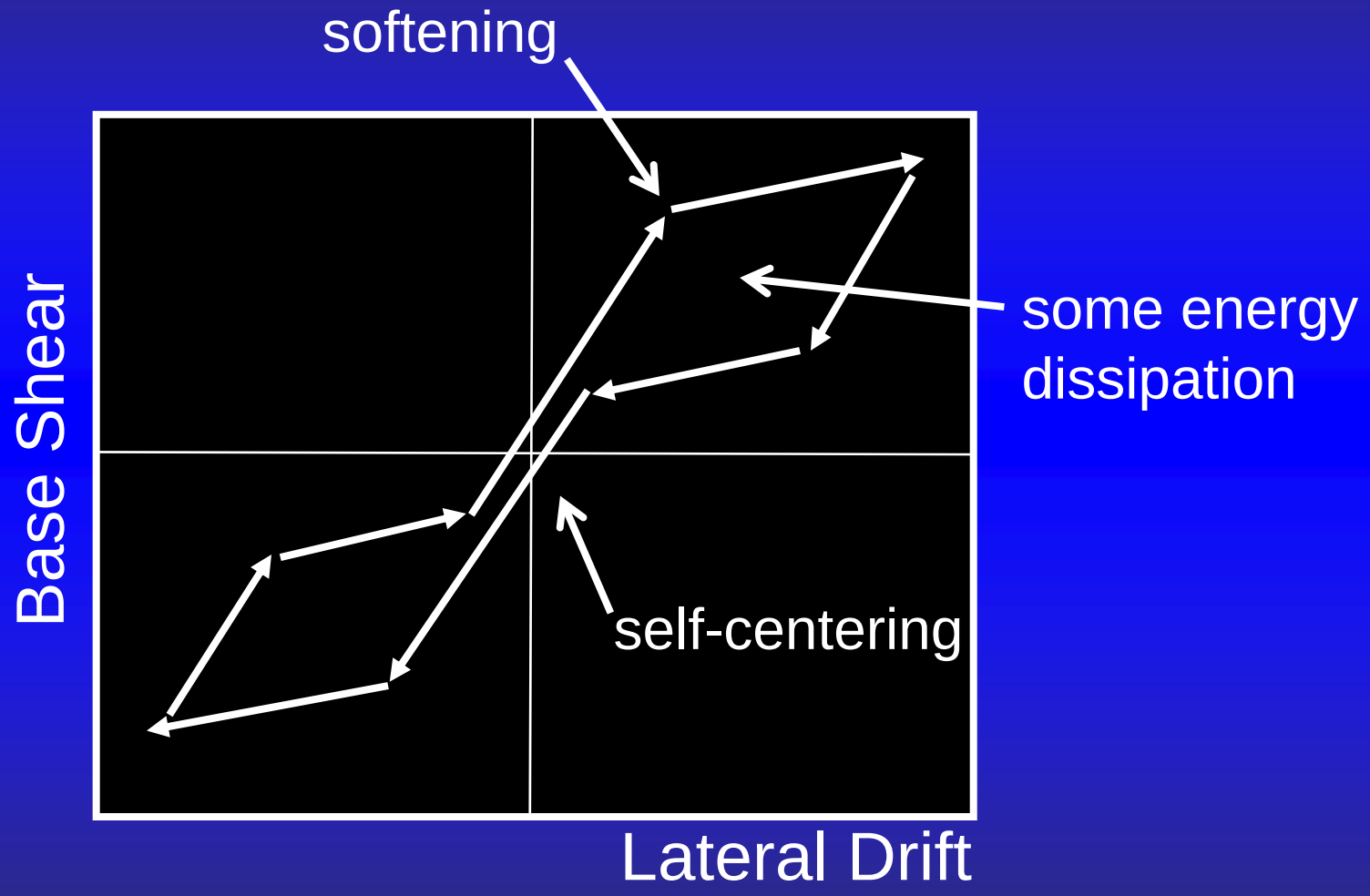


Example – Steel Rocking Frame

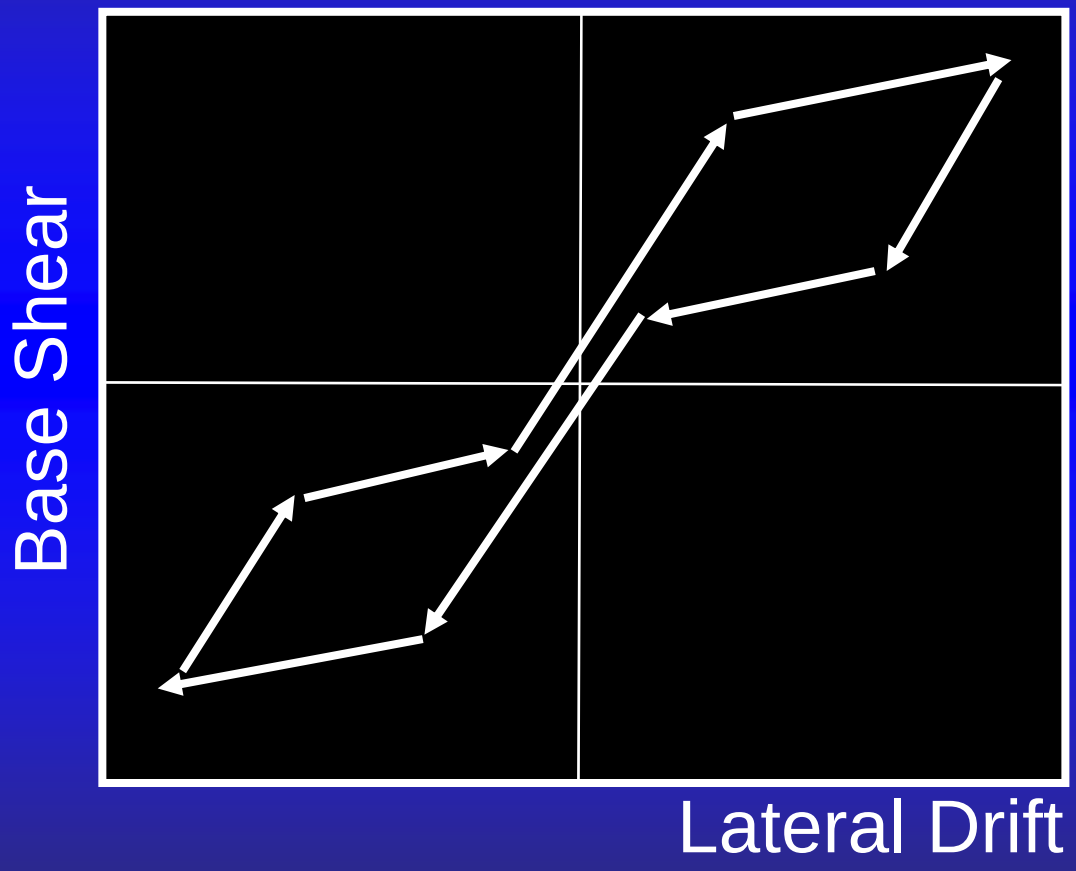



Lateral Drift
Time

2000’s - Hybrid Systems

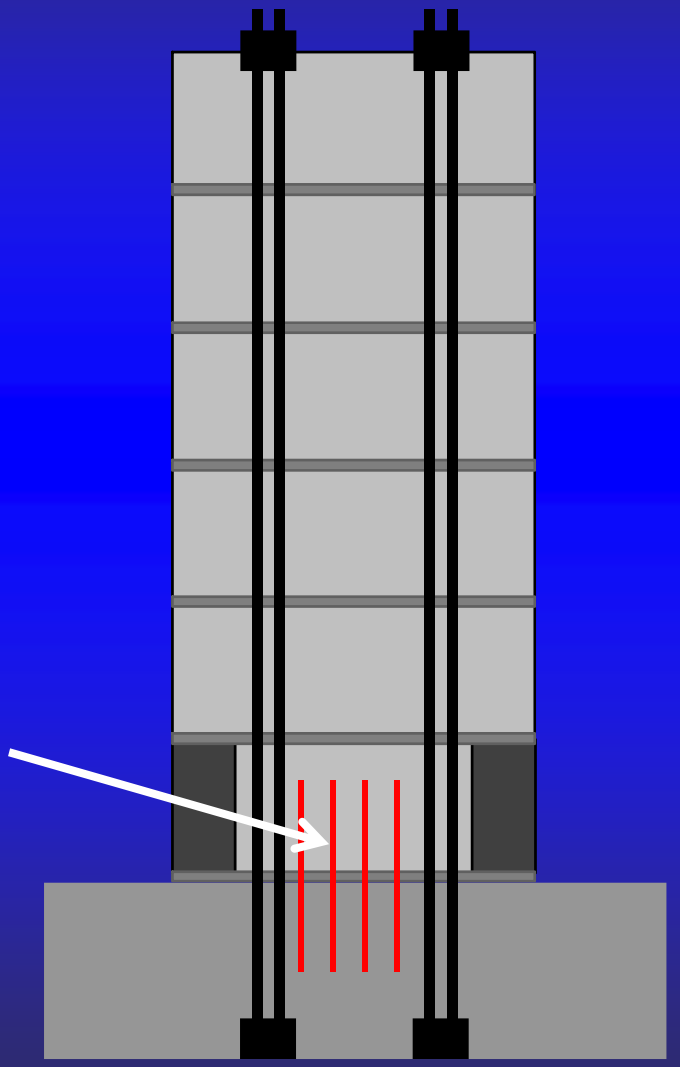


How do you create an hybrid system?



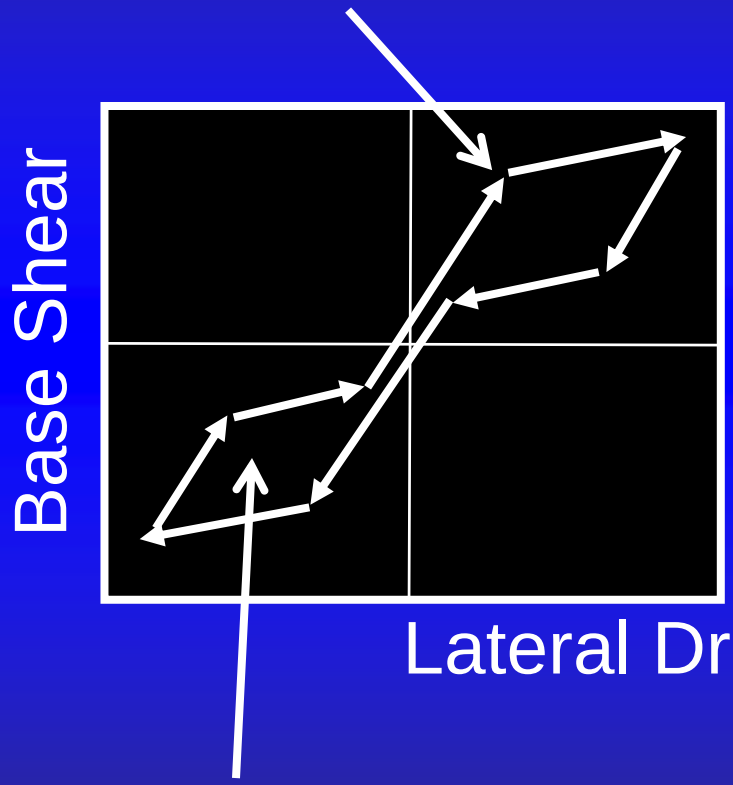
Example – Hybrid Precast Concrete Wall

add mild steel reinforcing bars at base of wall

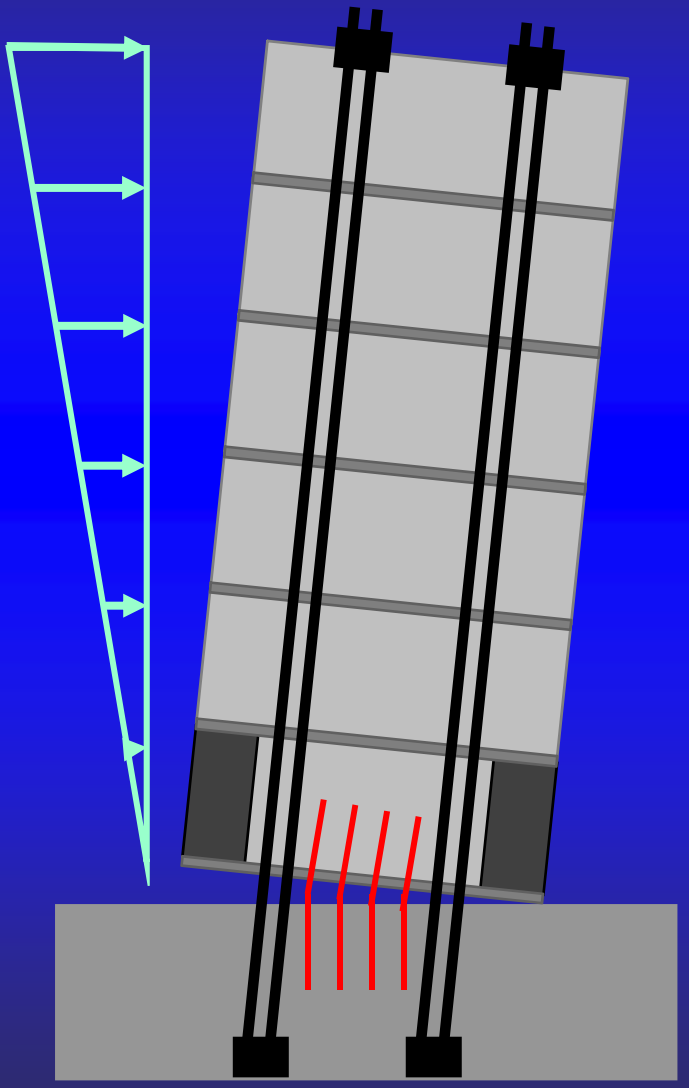


Example – Hybrid Precast Concrete Wall

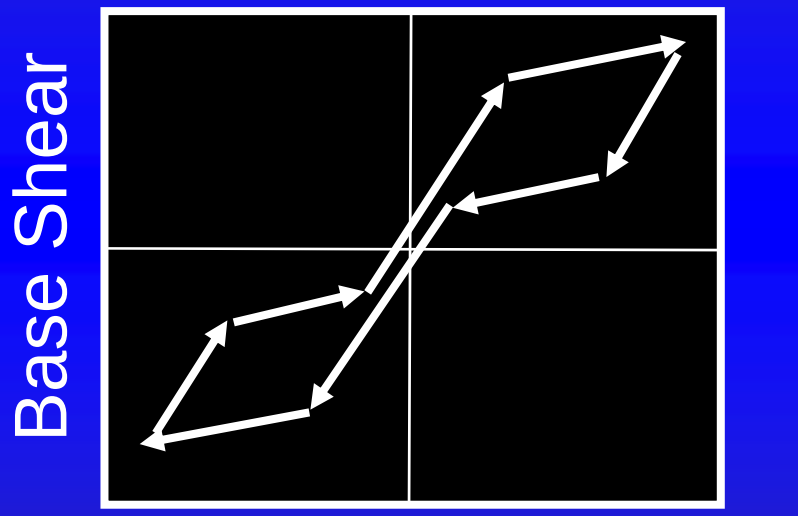
softening due to gap opening

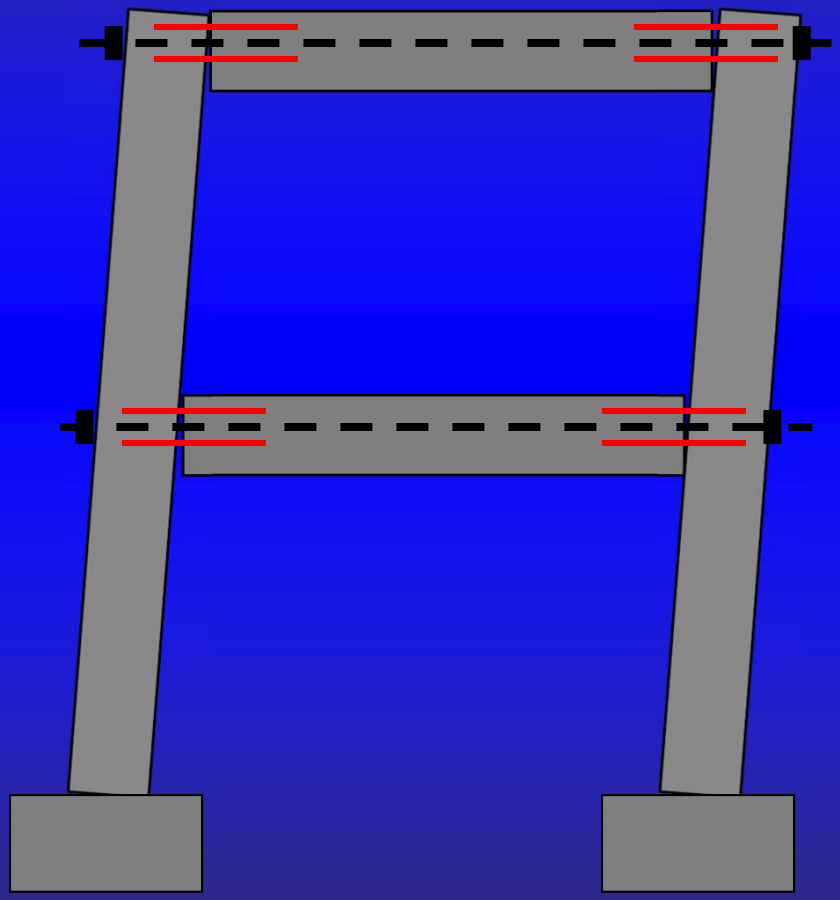


energy dissipation due to yield of mild steel reinforcing

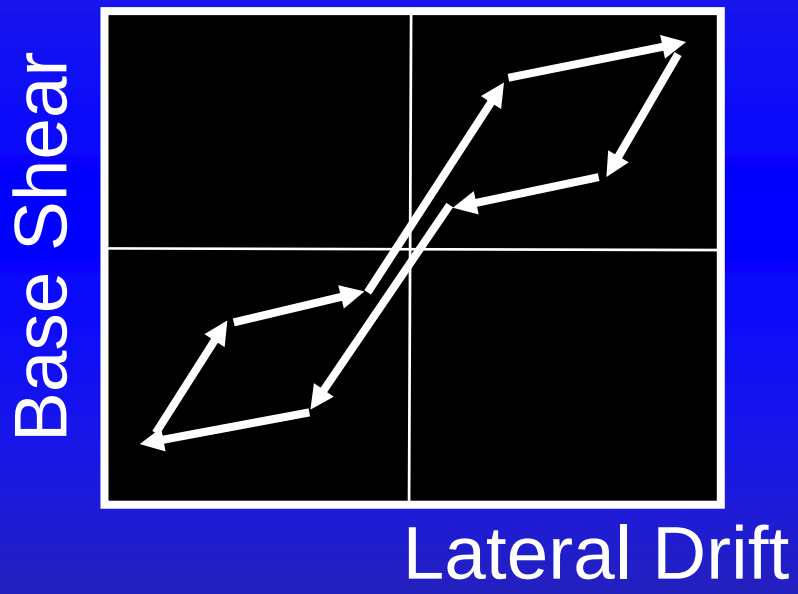


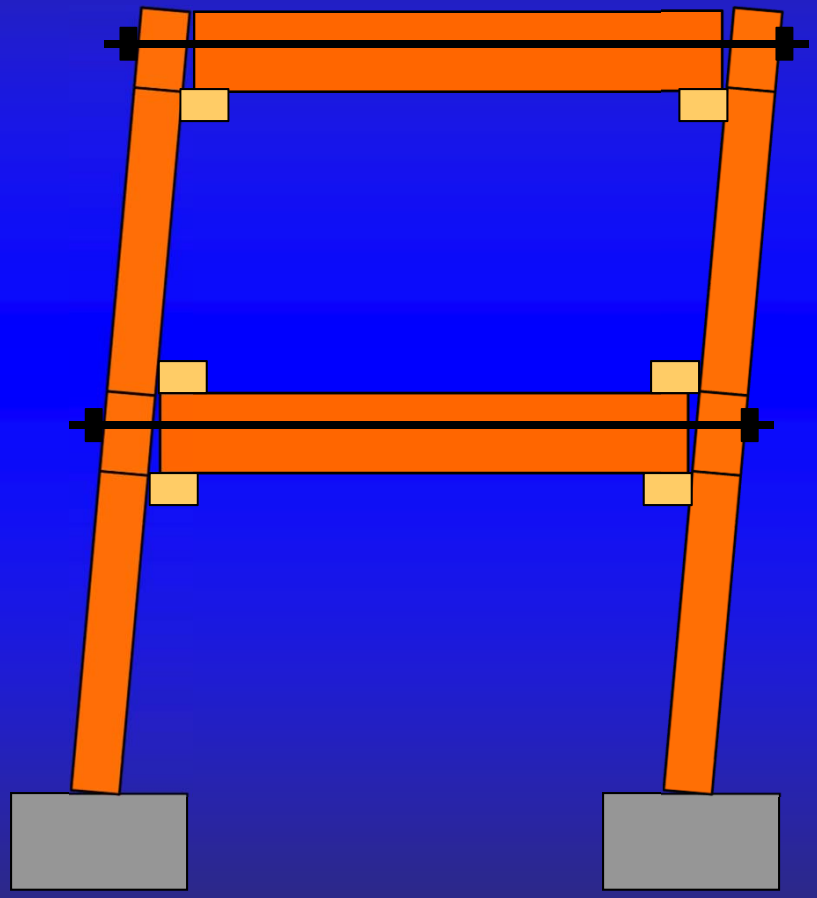
Example – Hybrid Precast Concrete Frame

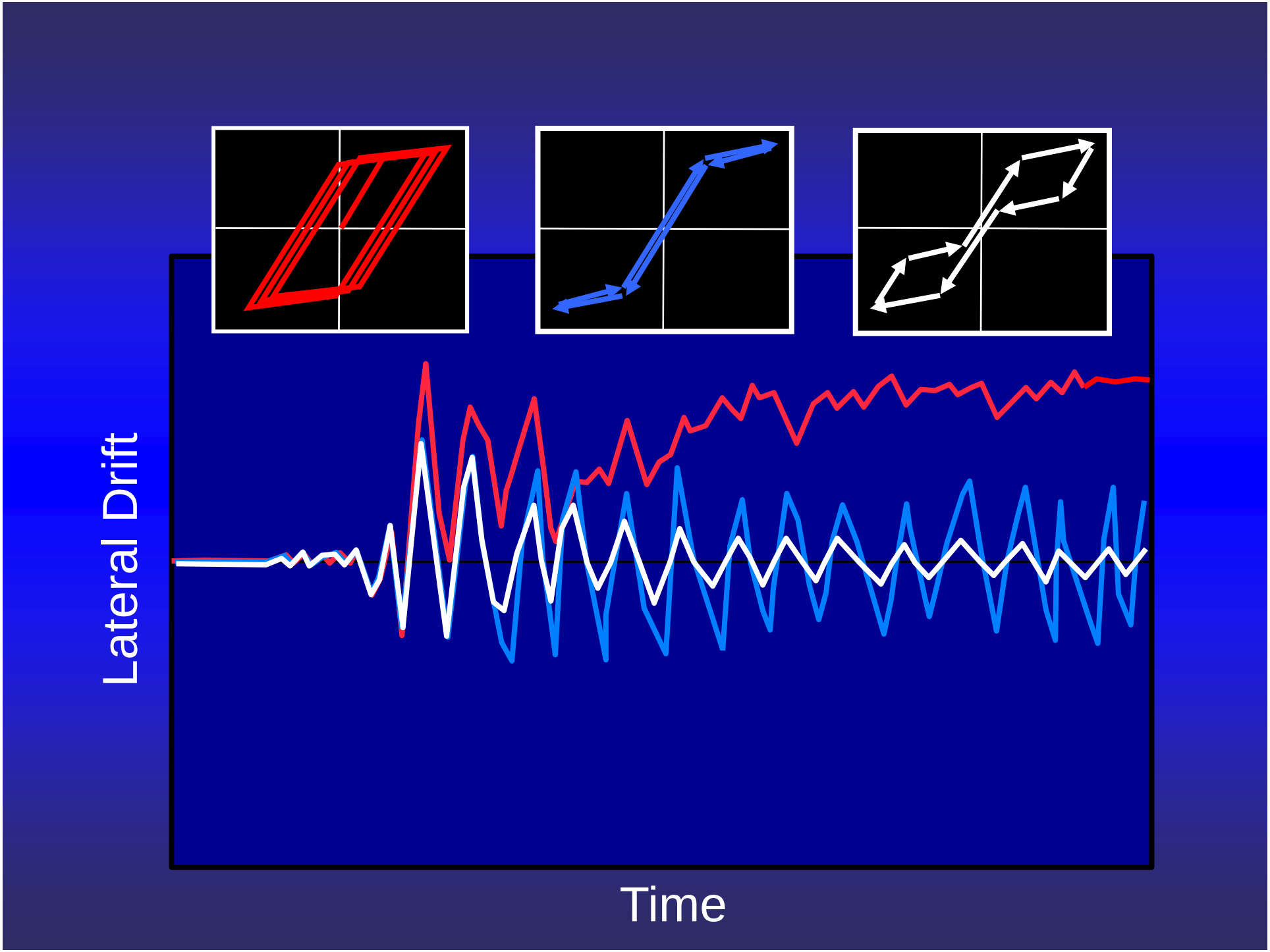




Example – Hybrid Steel Frame

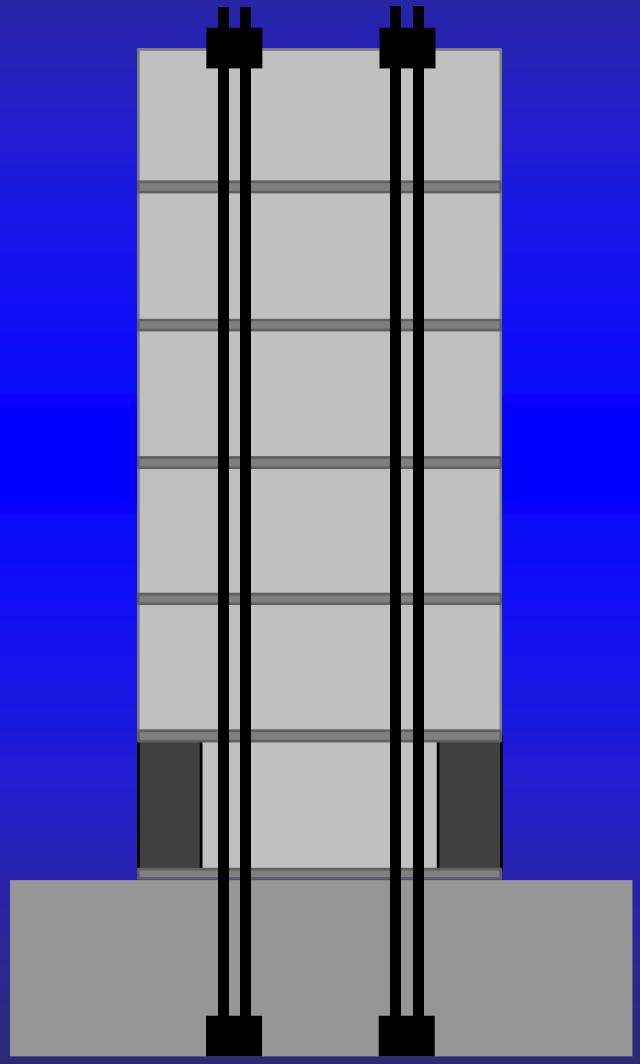


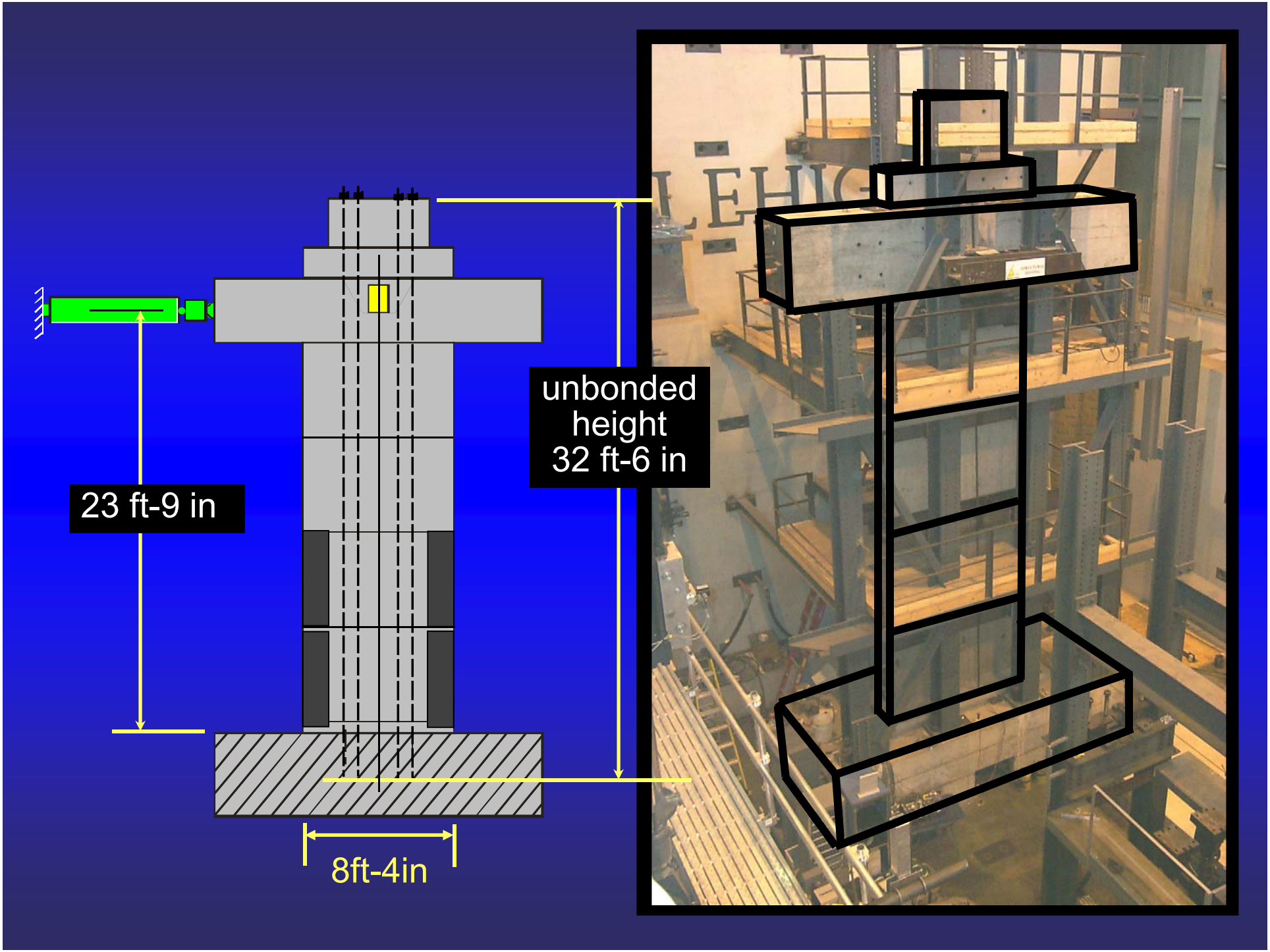



Lateral Drift
Time

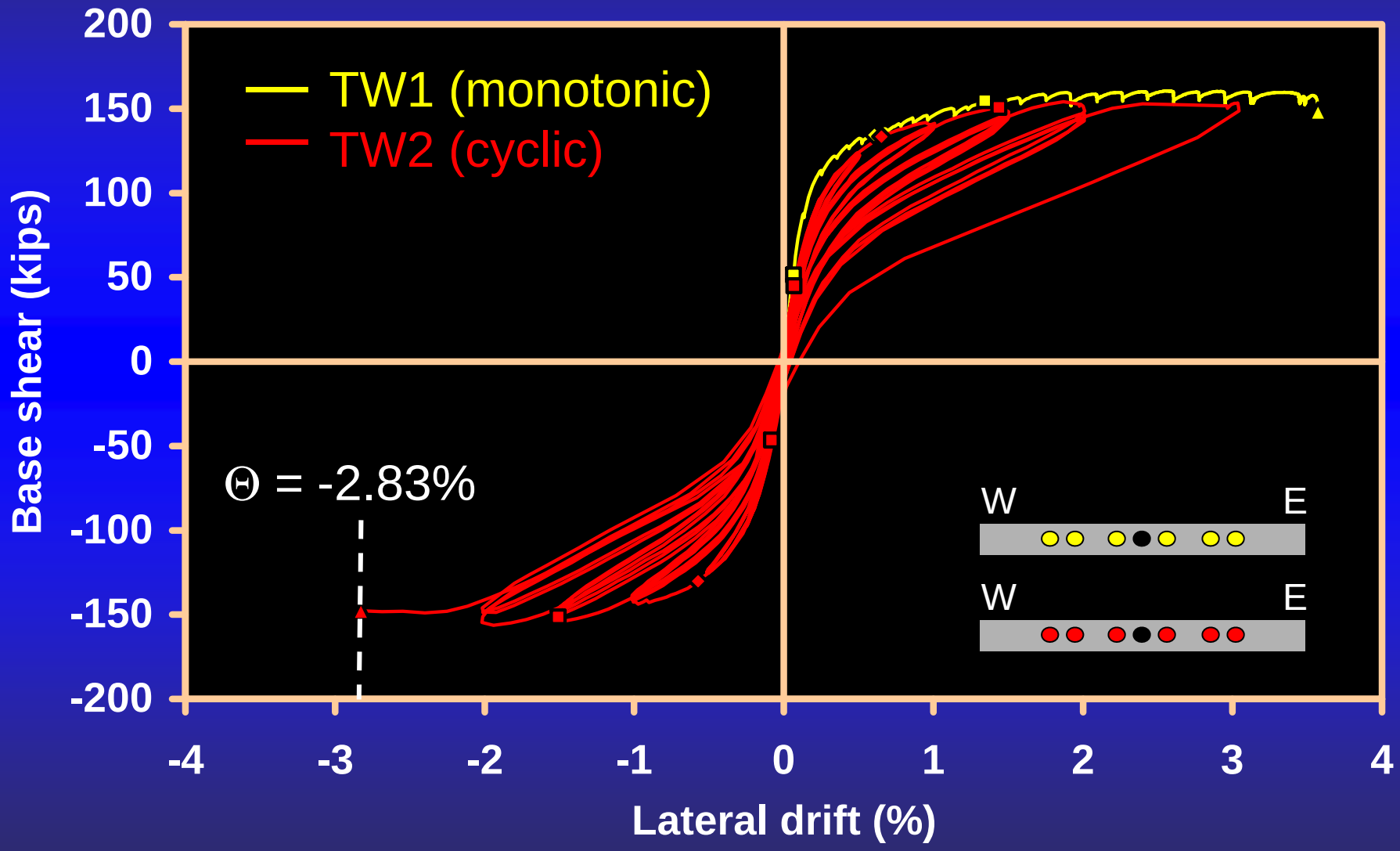

Concept
Research
Practice

Unbonded Post-tensioned Precast Concrete Wall



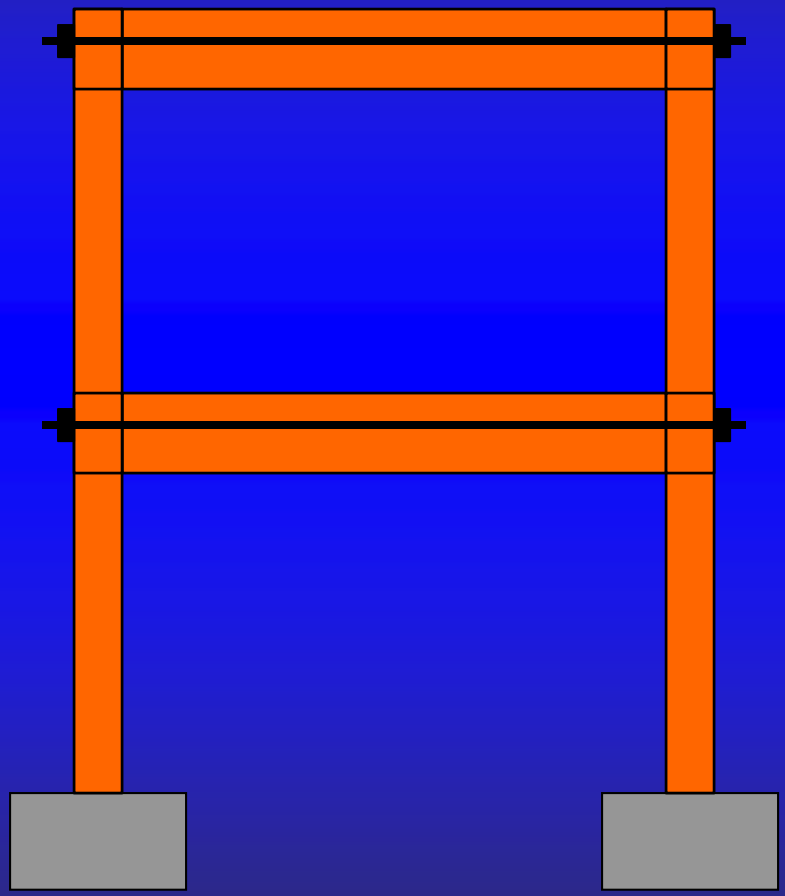

unbonded
height
32 ft-6 in
23 ft-9 in
8ft-4in

Results - TW1 and TW2



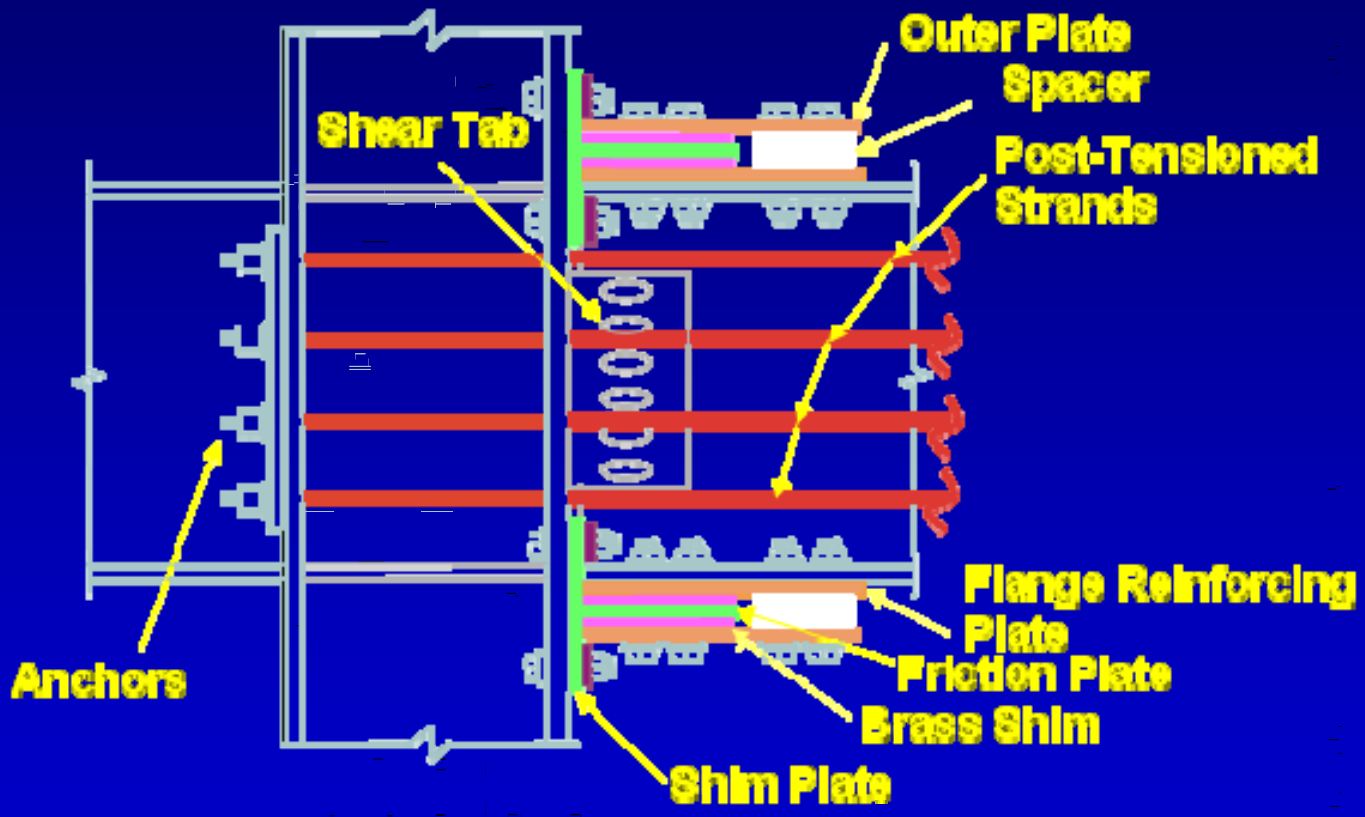
TW1 $\Theta = 3.48\%$

Hybrid Steel Frame

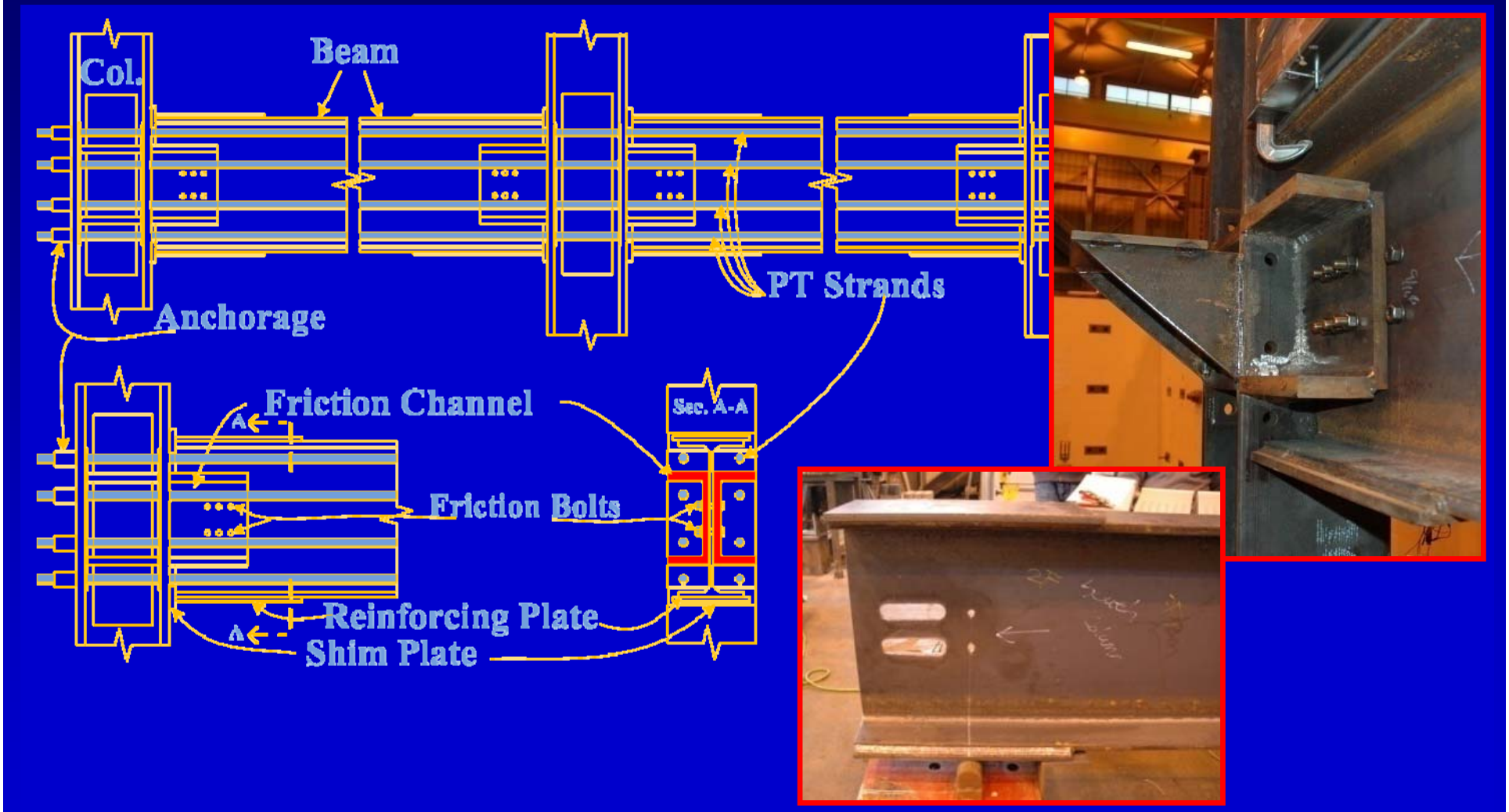


Hybrid Steel Frame

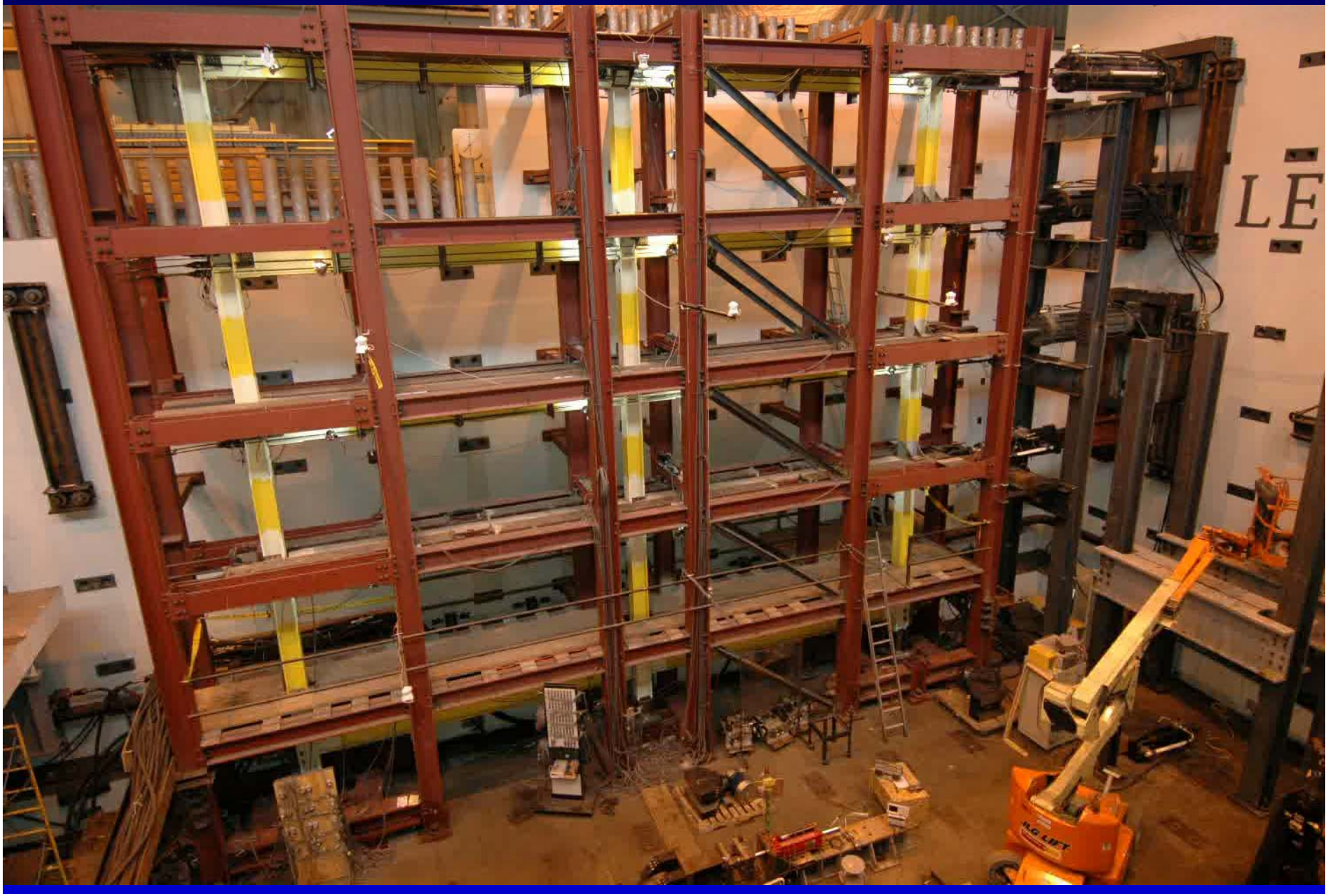
Hybrid Steel Frame with Flange Friction Devices



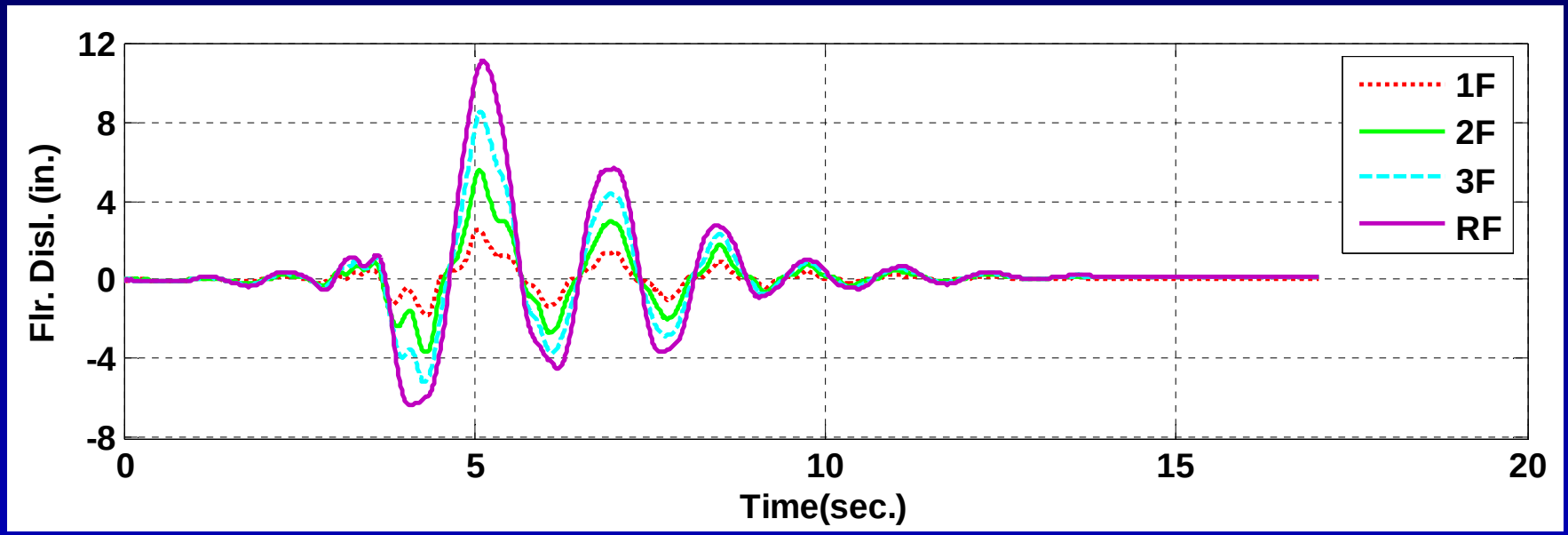
Hybrid Steel Frame with Web Friction Devices



1994 Northridge - 1.18 Scale Factor

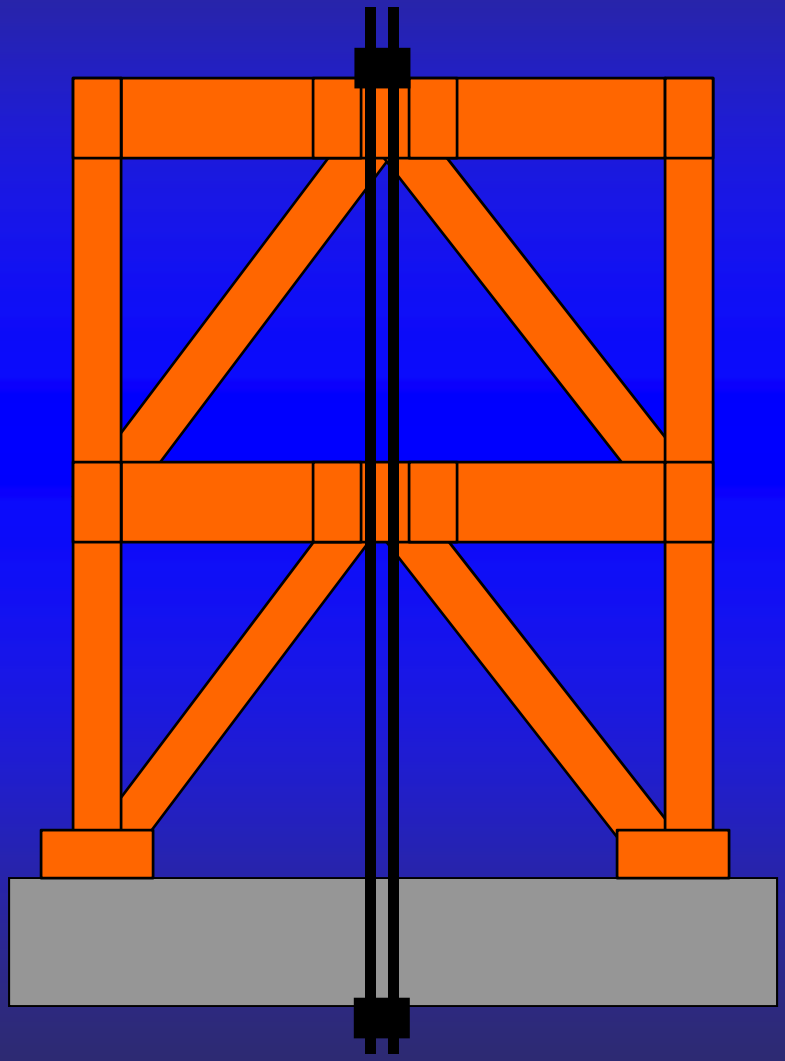


1994 Northridge - 1.18 Scale Factor

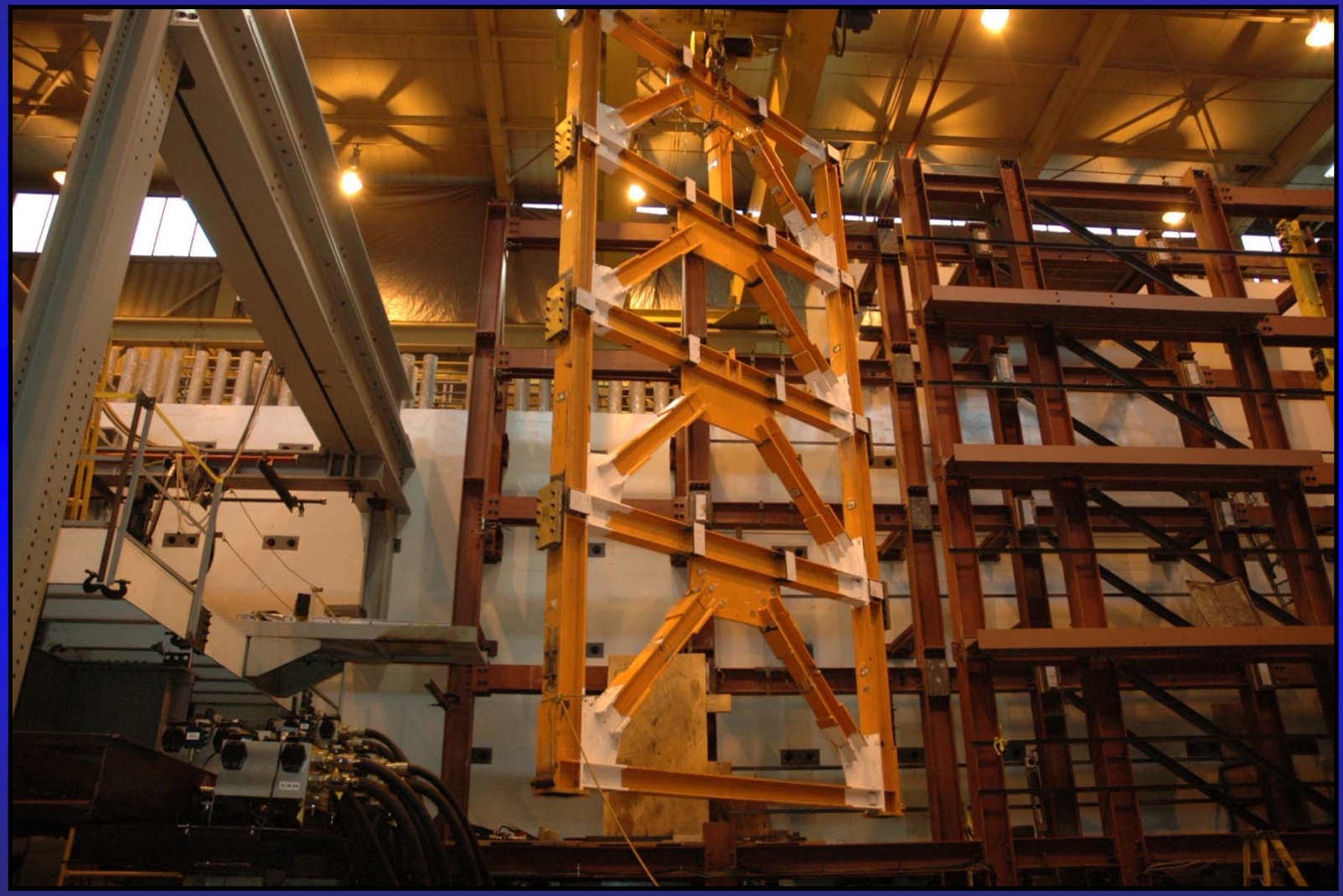


Level	Max. Interstory Drift (% rad.)	Residual Drift (% rad.)
RF	3.9	0.008
3F	3.5	0.023
2F	3.5	0.063
1F	2.1	0.074

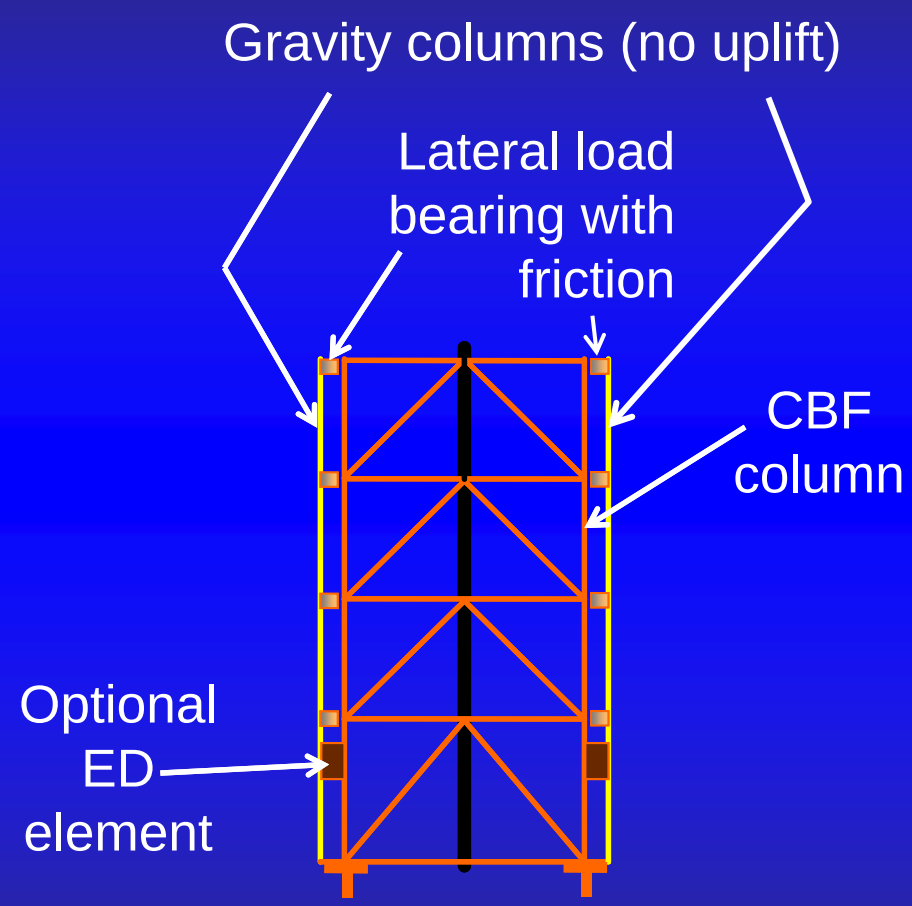
Steel Rocking Frame



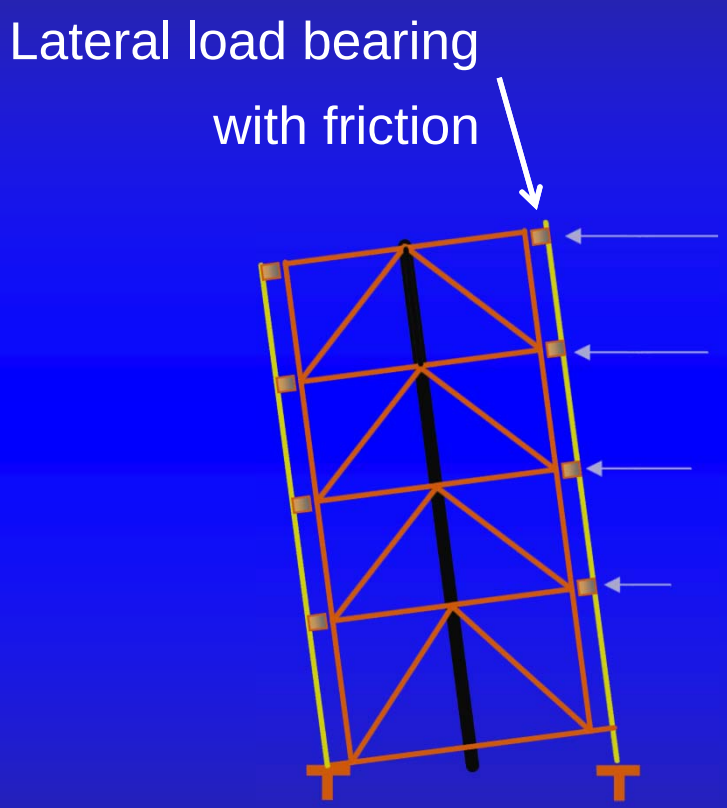
Steel Rocking Frame



Steel Rocking Frame

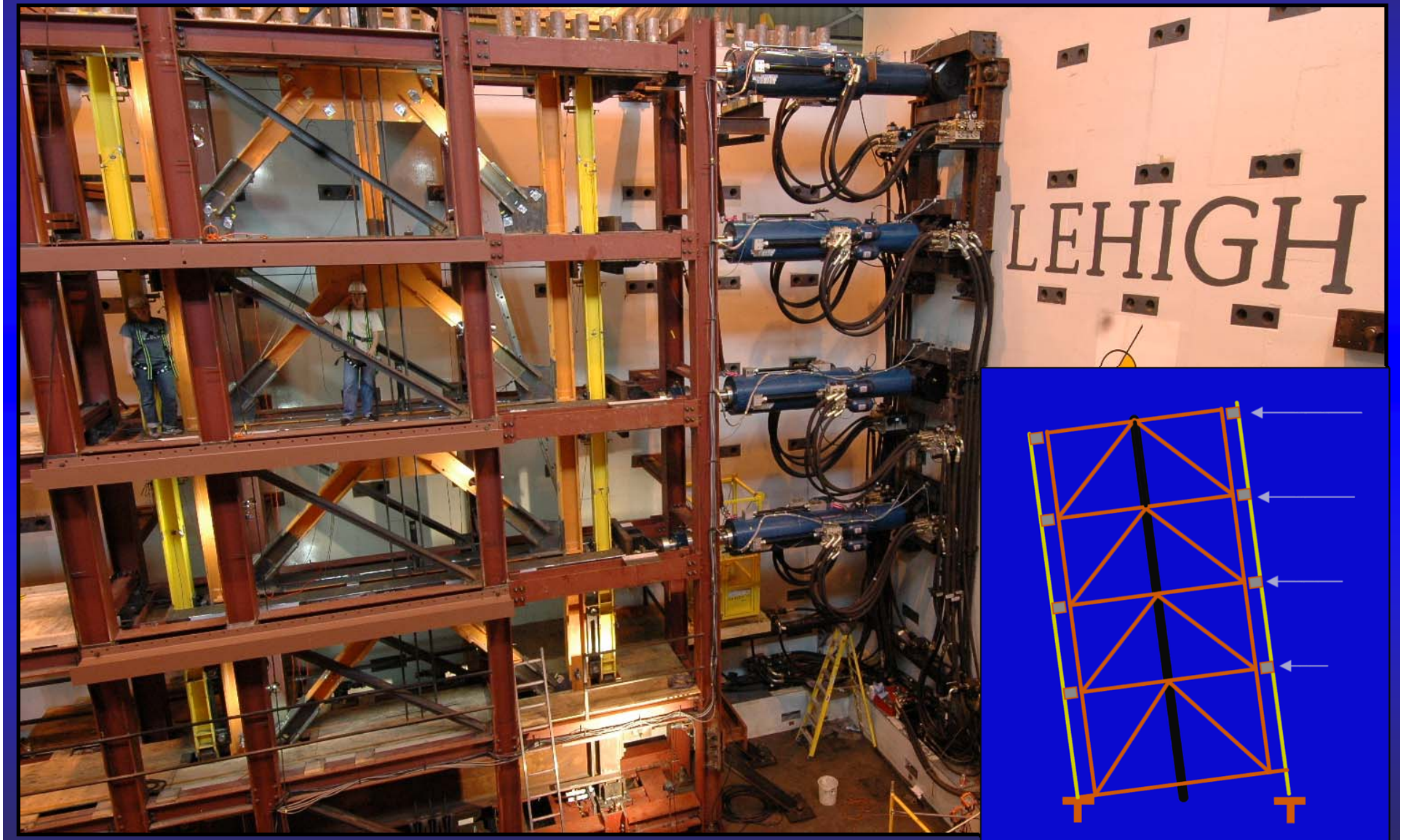


Frame D

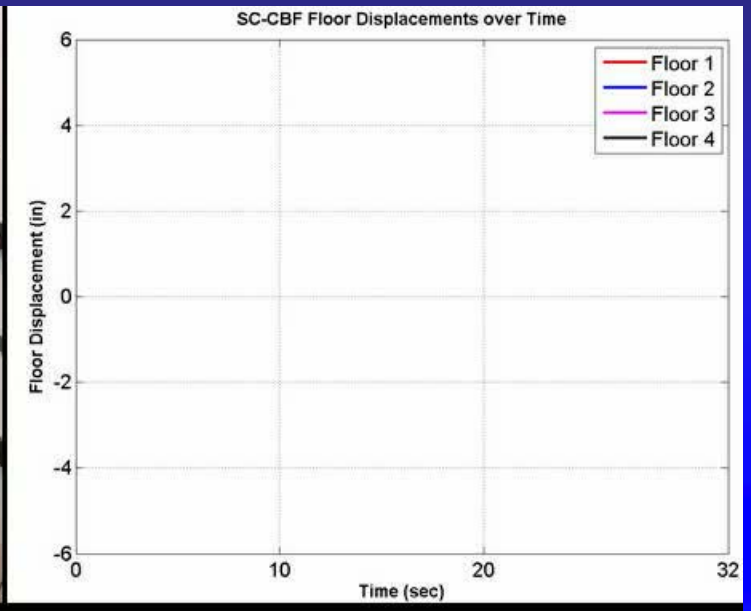


Frame D Selected for Experimental Study

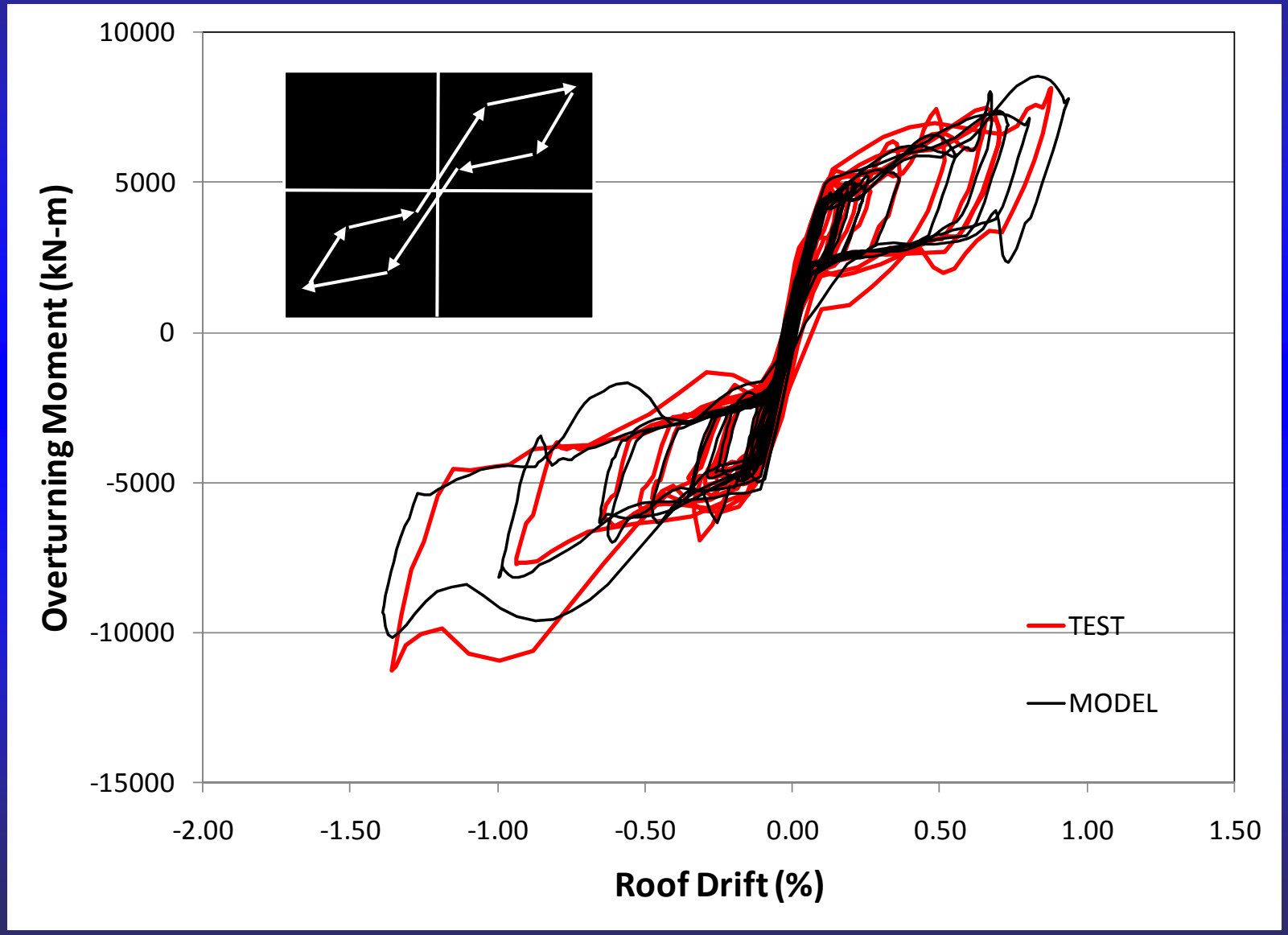
Steel Rocking Frame



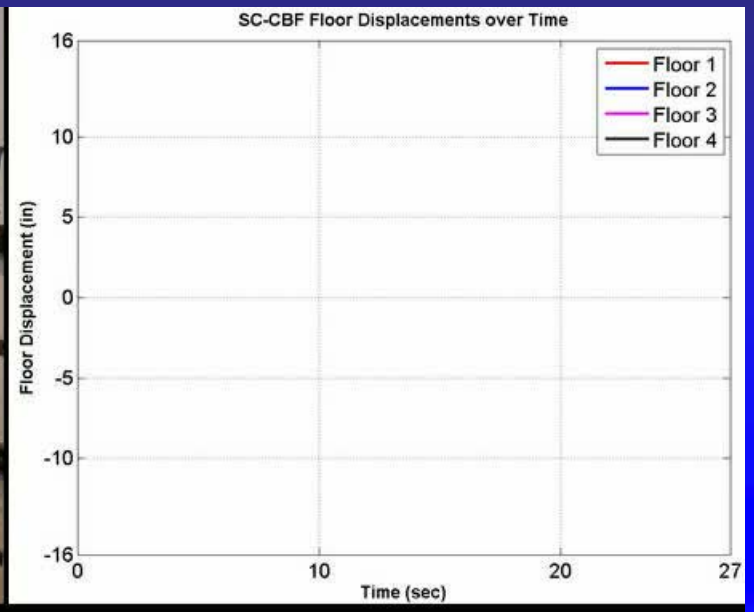
Design Basis Earthquake



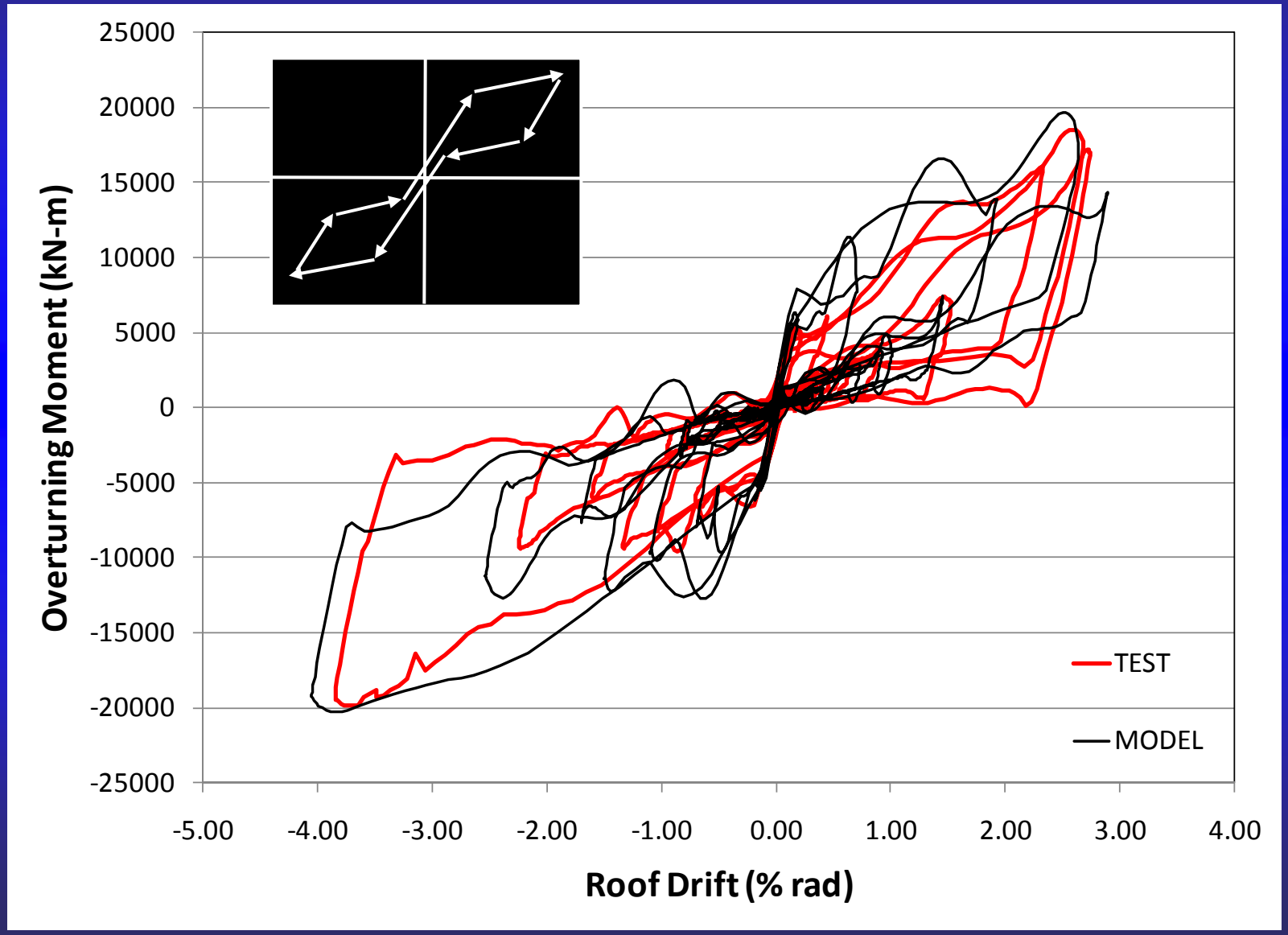
Design Basis Earthquake – Moment vs. Roof Drift



Maximum Considered Earthquake

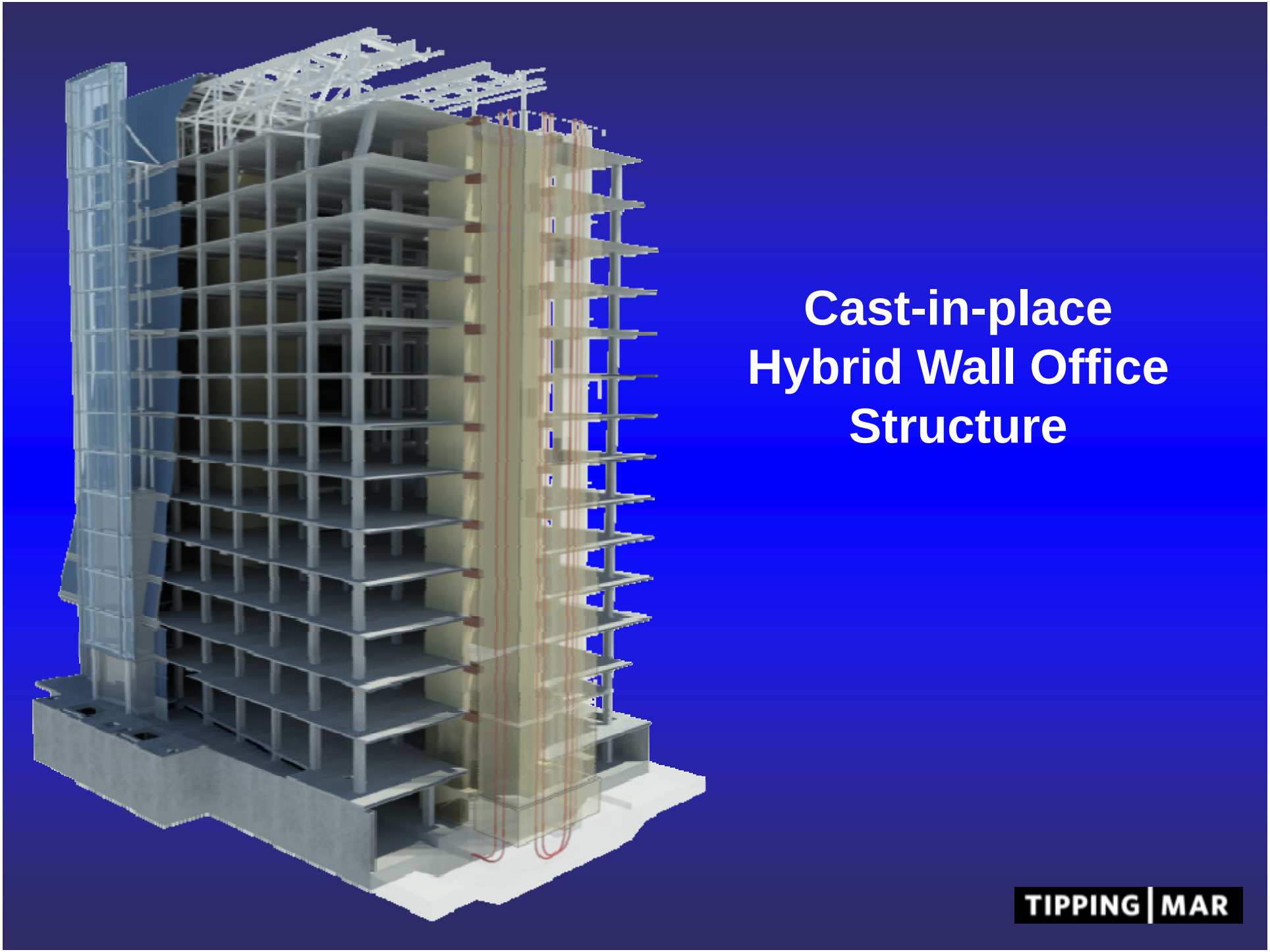


Maximum Considered Earthquake – Moment vs. Roof Drift




Concept
Research
Practice

Cast-in-place Hybrid Wall Office Structure


Cast-in-place
Hybrid Wall Office
Structure
TIPPING | MAR

TIPPING | MAR

TIPPING | MAR

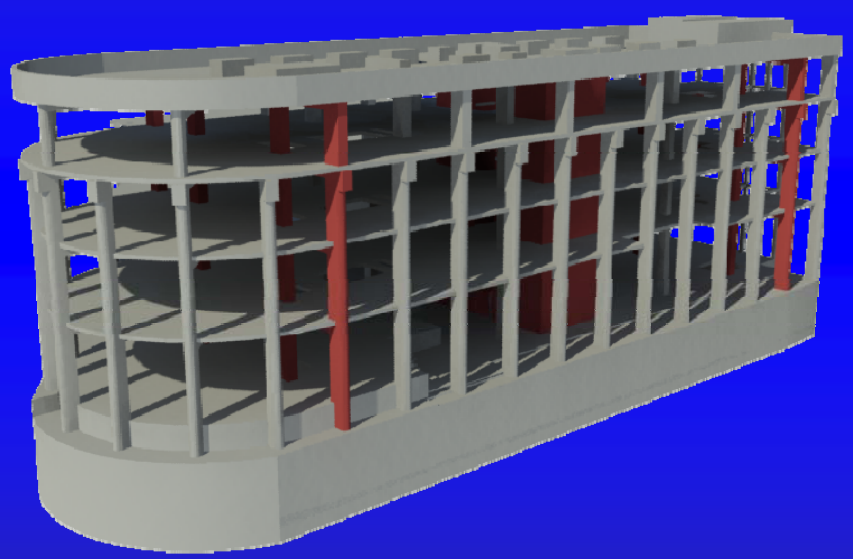
Cast-in-place Hybrid Wall / Hybrid Frame Mixed-use Structure

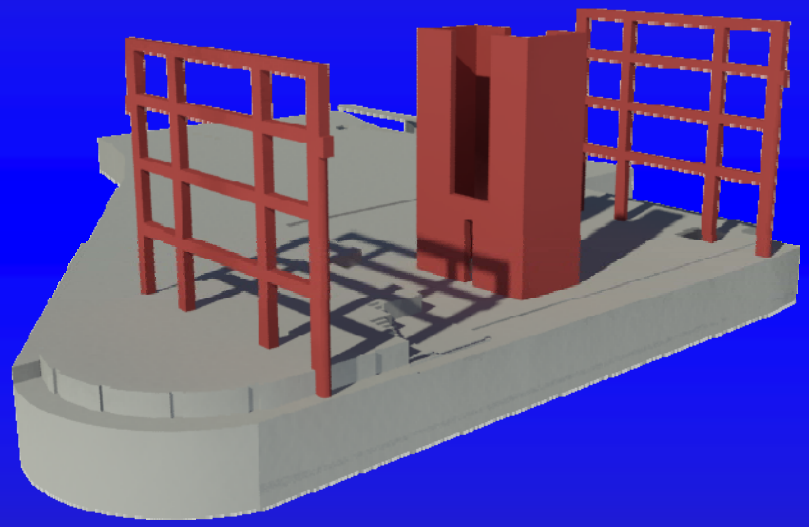
TIPPING | MAR

Cast-in-place Hybrid Wall / Hybrid Frame Mixed-use Structure

TIPPING | MAR

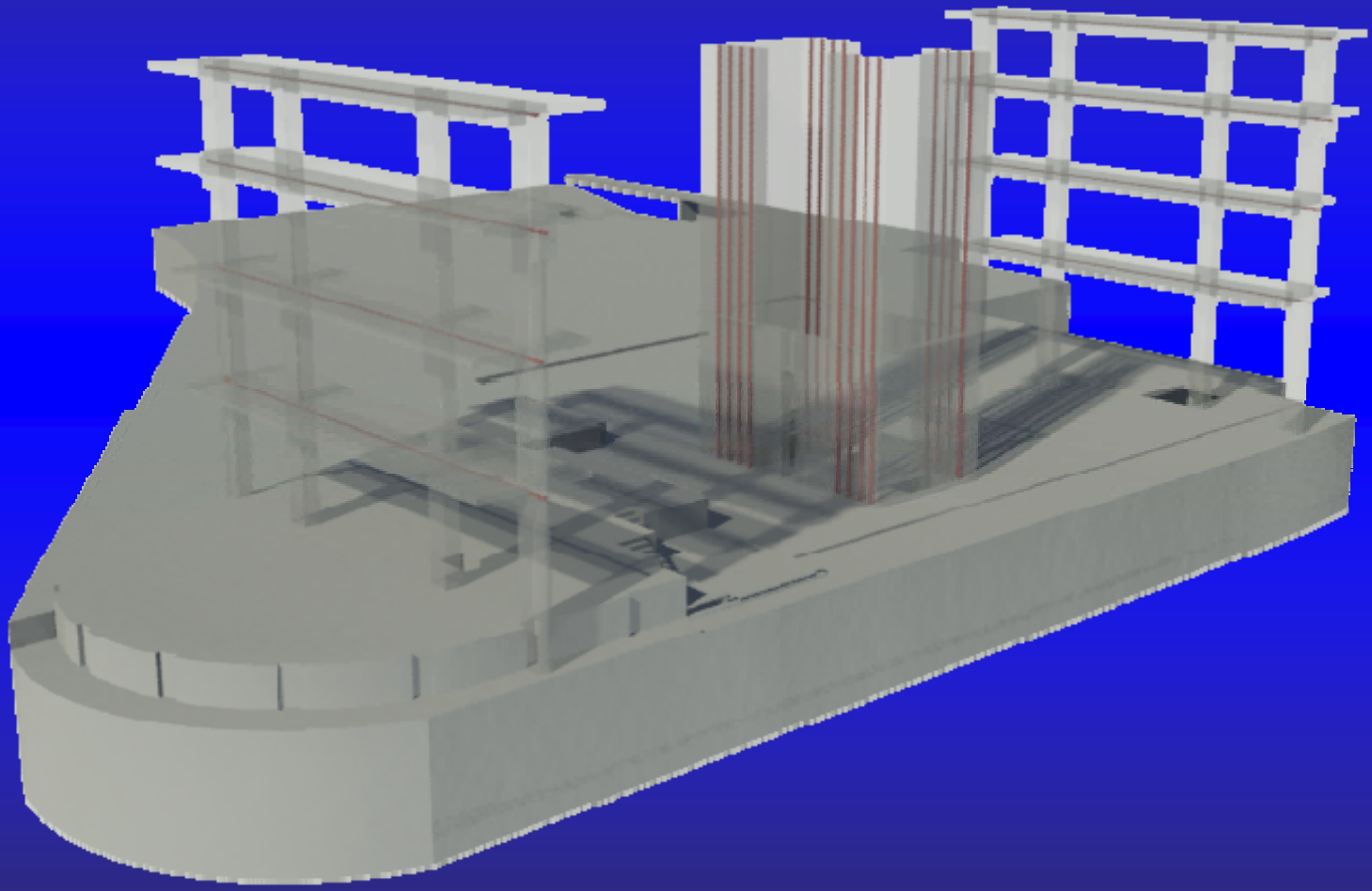
Cast-in-place Hybrid Wall / Hybrid Frame Mixed-use Structure





TIPPING | MAR

Cast-in-place Hybrid Wall / Hybrid Frame Mixed-use Structure



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Cast-in-place Hybrid Wall Seismic Retrofit

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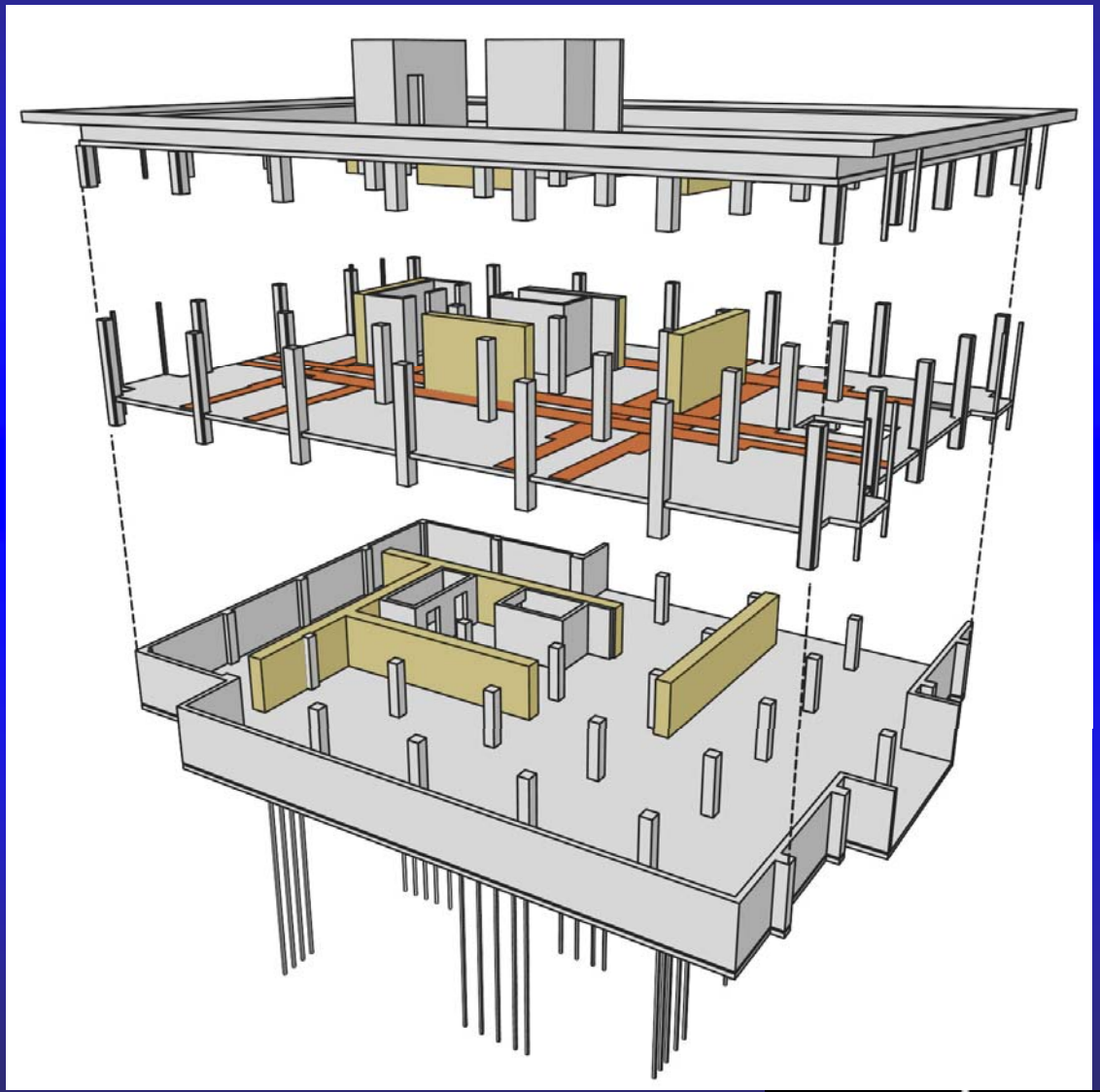
Cast-in-place Hybrid Wall Seismic Retrofit

6-story non-ductile concrete frame, built 1970

Reinforced masonry in-fill

1.4 km from Hayward fault



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Precast Hybrid Frame Office Structure

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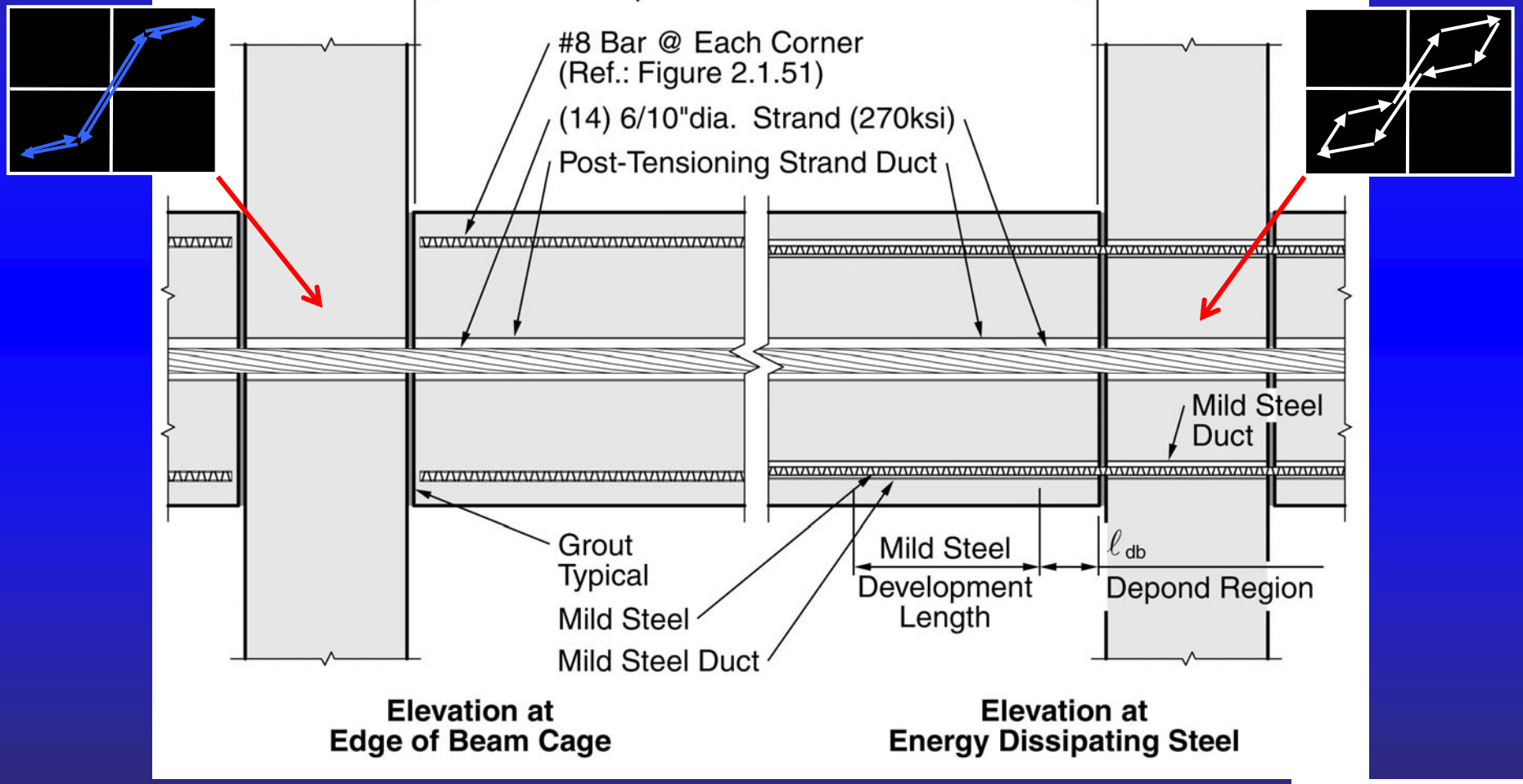
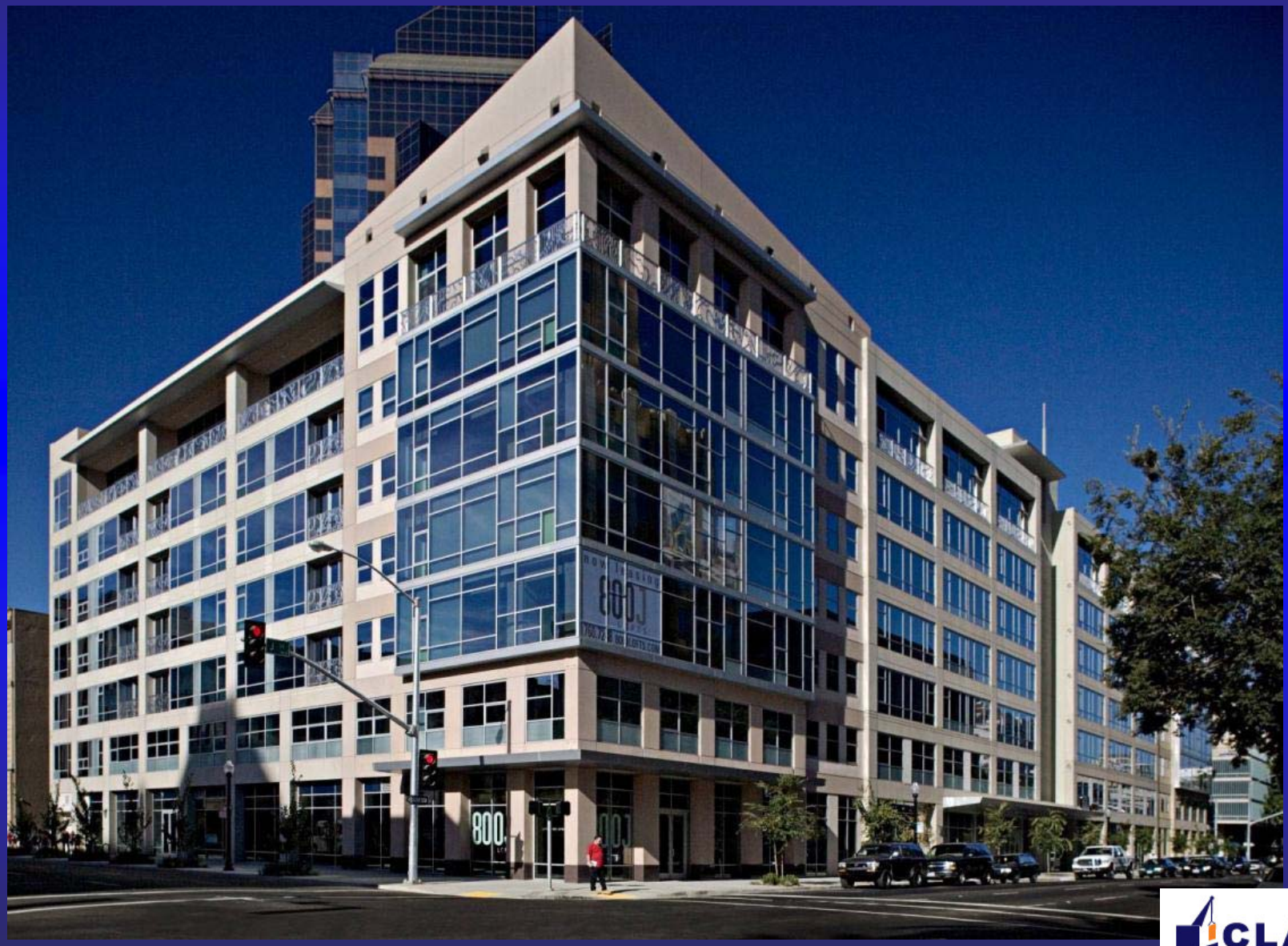
Precast Hybrid Frame Office Structure



Precast Hybrid Frame Office Structure

Mid-state Precast

Precast Hybrid Frame Mixed-Use Residential



CLARK PACIFIC

Precast Hybrid Frame Mixed-Use Residential

CLARK PACIFIC

Precast Hybrid Frame Parking Structure

Steel Rocking Frame

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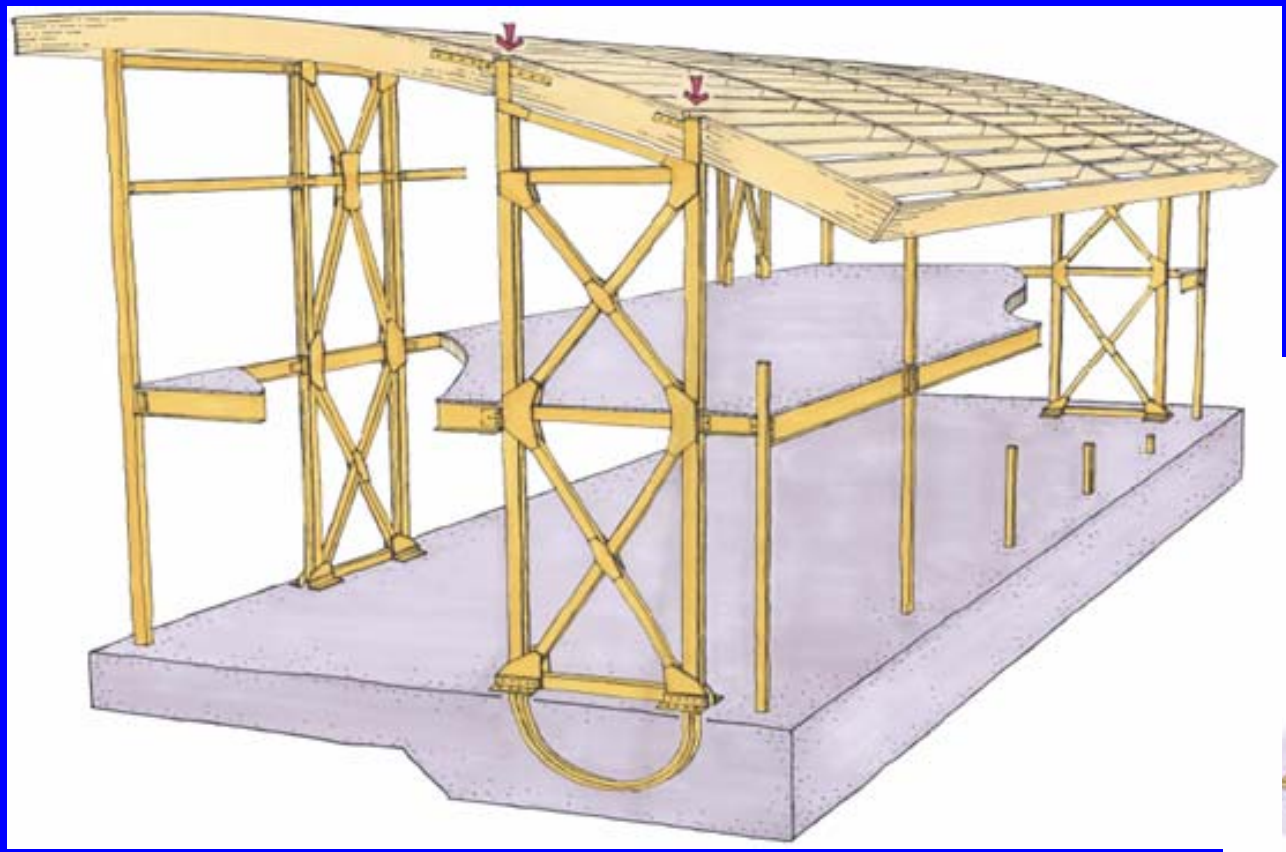
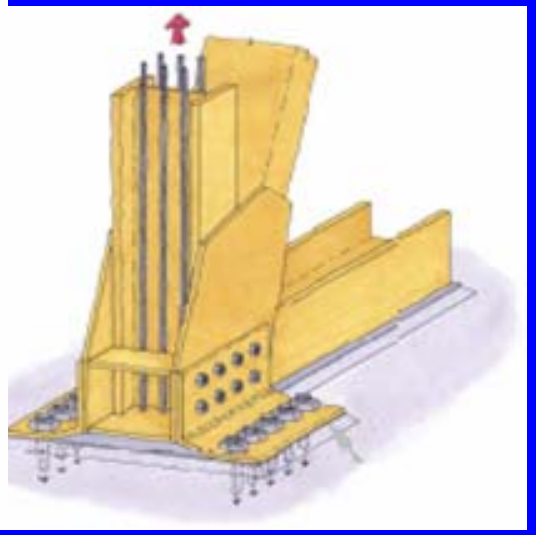
Steel Rocking Frame





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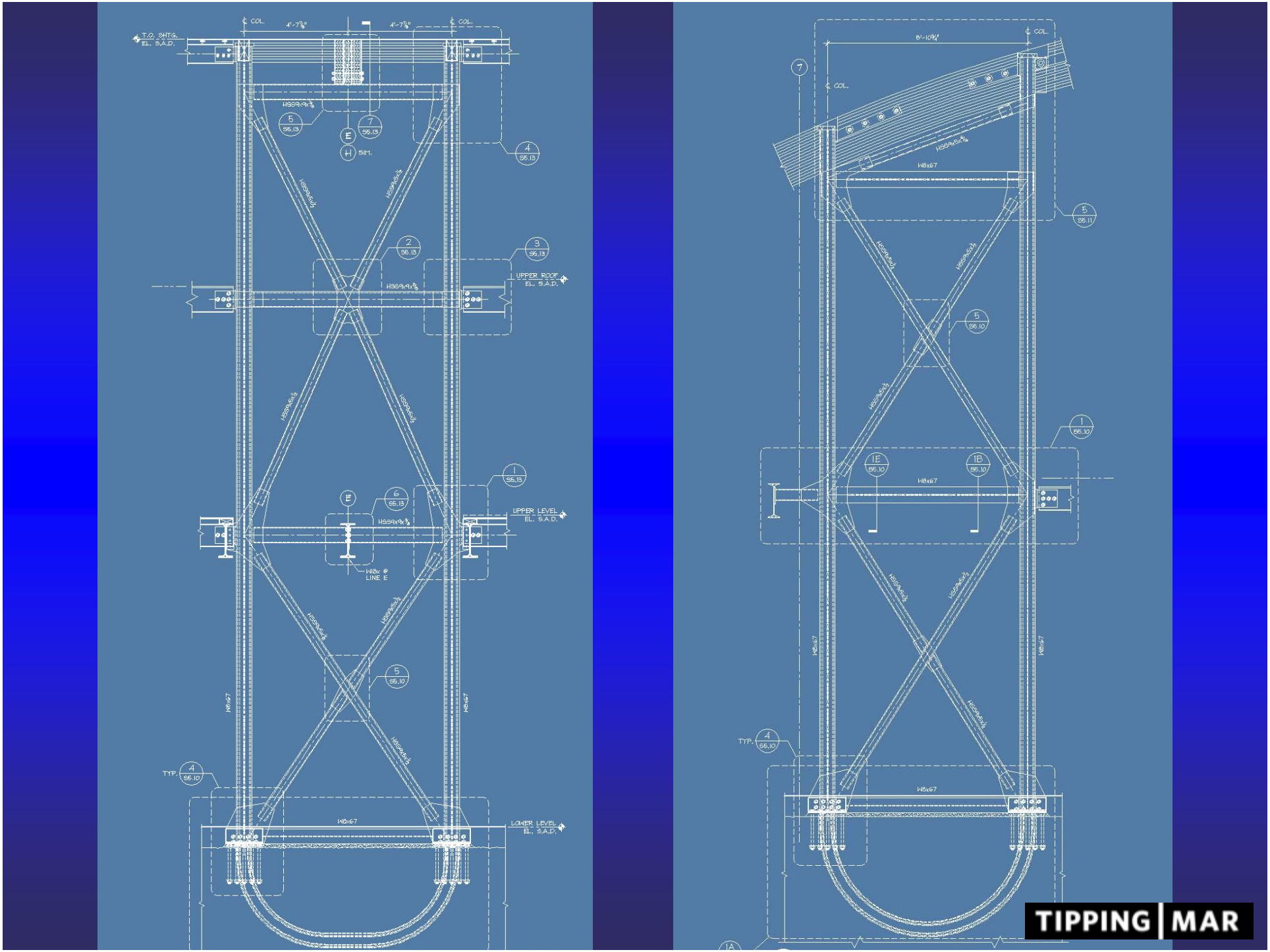
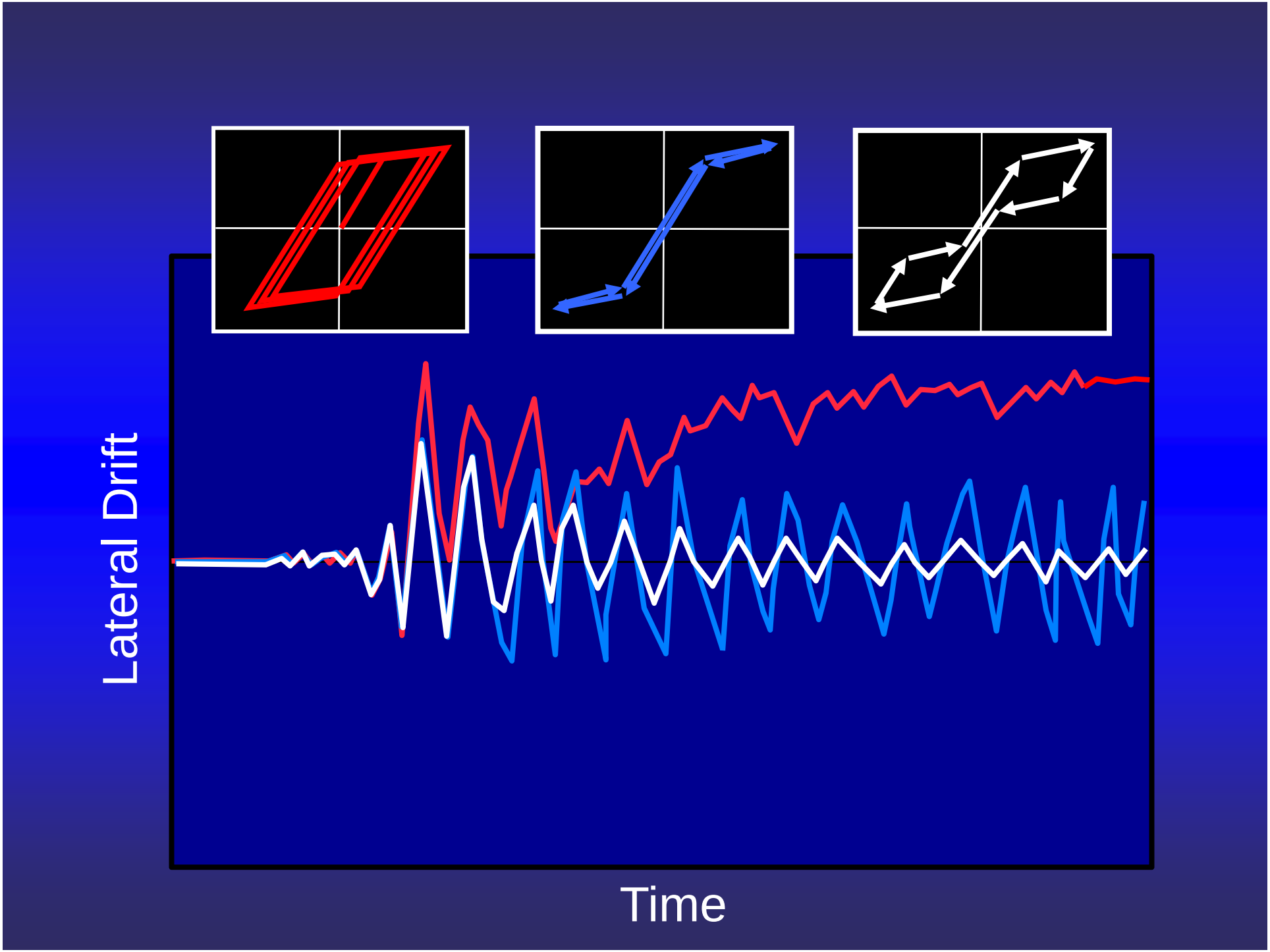

T.O. SHTG.
EL. S.A.D.
℄ COL.
4'-7⅞"
4'-7⅞"
℄ COL.
HSS8x4x⅜
HSS8x4x¼
HSS8x4x⅜
UPPER ROOF
EL. S.A.D.
UPPER LEVEL
EL. S.A.D.
W18x
LINE E
W18x67
W18x67
W18x67
LOWER LEVEL
EL. S.A.D.
TYP.
SIM.
8'-10¾"
℄ COL.
HSS8x4x⅜
W18x67
W18x67
W18x67
TYP.
TIPPING | MAR

Steel Rocking Frame

Steel Rocking Frame


Lateral Drift
Time

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Innovative Seismic Lateral Force-Resisting Systems

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Presentation at PTI Convention
Norfolk VA, 6 May 2014