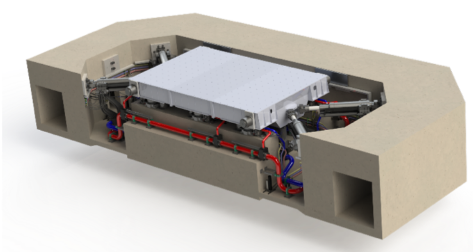
University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

National Science Foundation

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Highlights of Recent Projects: Contributions to Understanding Cold-Formed Steel-Framed Systems Response

Tara Hutchinson, UC San Diego



Joint Academia-Industry NHERI Workshop
NHERI@UC San Diego

September 21-22, 2020
University of California, San Diego

Outline

Two complementary projects@LHPOST

1) System-Level Building Testing: CFS-HUD
2) Component-Level Testing: CFS-NHERI (Wall-Line Test Phase)

My Hopeful Outcome (in this 12 min discussion):
Demonstrate the success of industry-academe collaborations

1) CFS-HUD: *Earthquake and Post-Earthquake Fire Testing of a Mid-Rise CFS-Framed Building*

PIs: **Tara Hutchinson**, Gil Hegemeir, Brian Meacham
Drs. Xiang Wang & Praveen Kamath

CFS-HUD: Building Conceptua

- 6-story (64′ tall) CFS building, representative of m
- Structural system:
  1) CFS-panelized shearwalls (gyp-bonded steel sheath
    - Long interior corridor SWs with door openings
    - Short/low aspect ratio exterior SWs with windows; tran
    - Zone 4 tie-tension rod system; end wall compression stu

eathing o

sec (est)

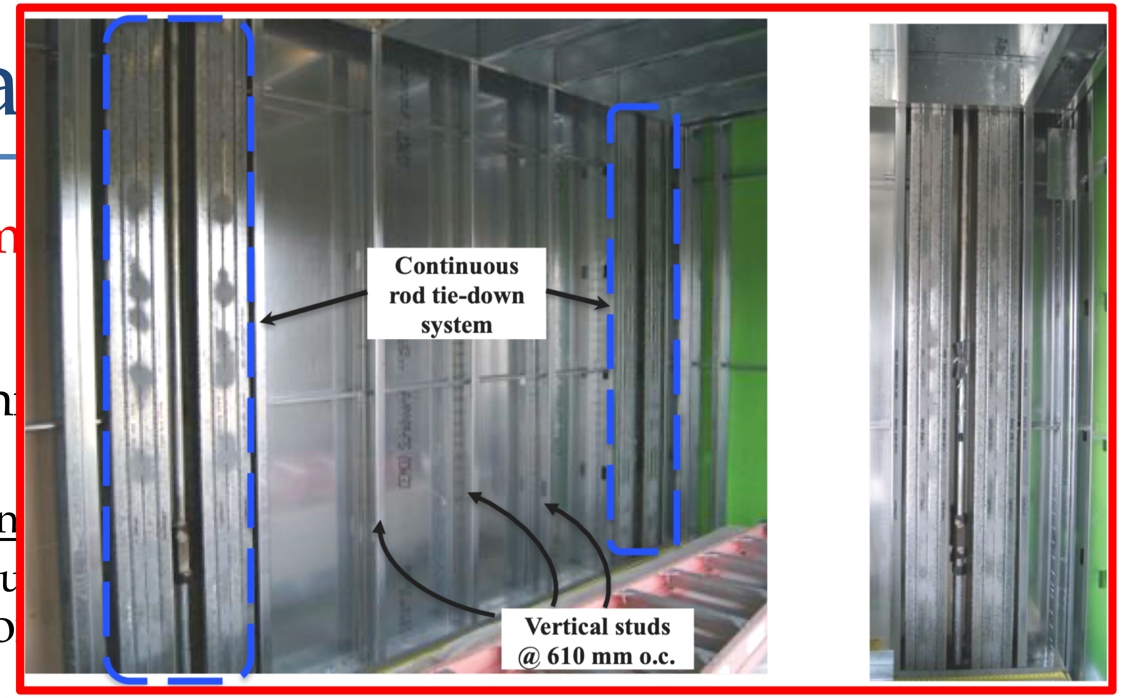
y D, site class D, S_{DS} = 1.5g, S_{D1} = 0.8g, seismic base

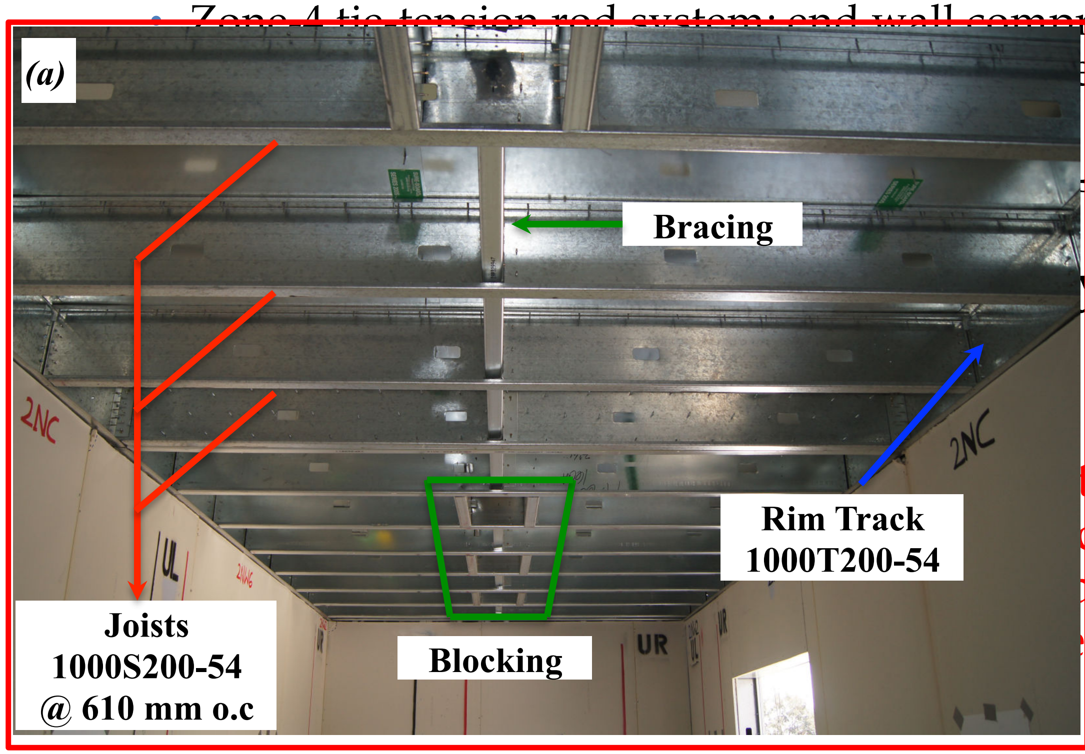
teral load (exterior walls short)

cted) torsional loads

bonded shearwalls; tie-down roads and

l forces





Extreme Events (test) Protocol

Phases of testing:

1) White noise & tire shock tests

2) Base shaking (pre-fire)

- White noise intermittent with increasing suite of scaled earthquake motions
- Three active earthquake test days, one day between each for physical inspection, test data analysis, preparation for next day

3) Live fire tests

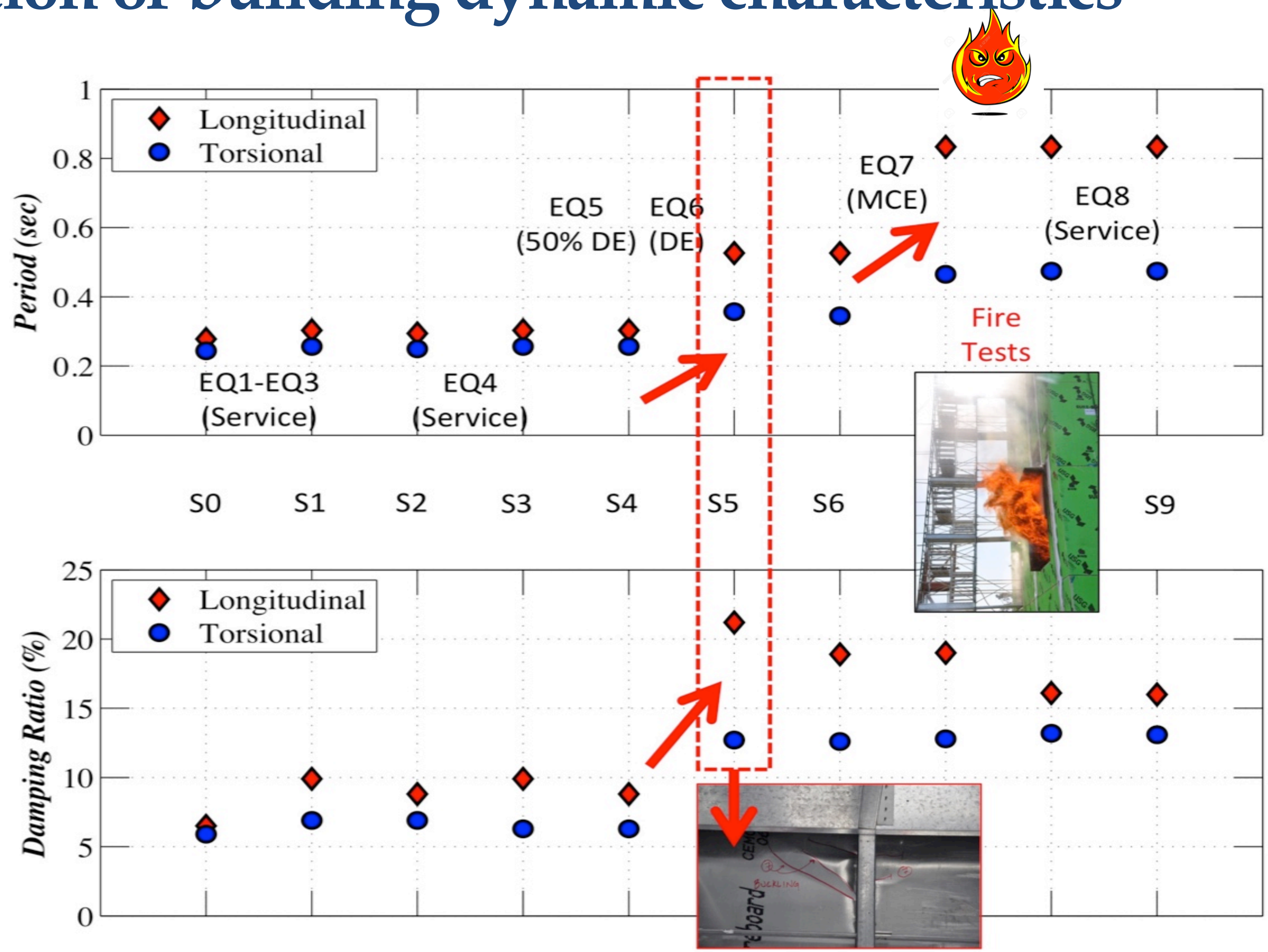
- 2 floors of live fire tests

4) *Aftershock+extreme earthquake* tests (post-fire)

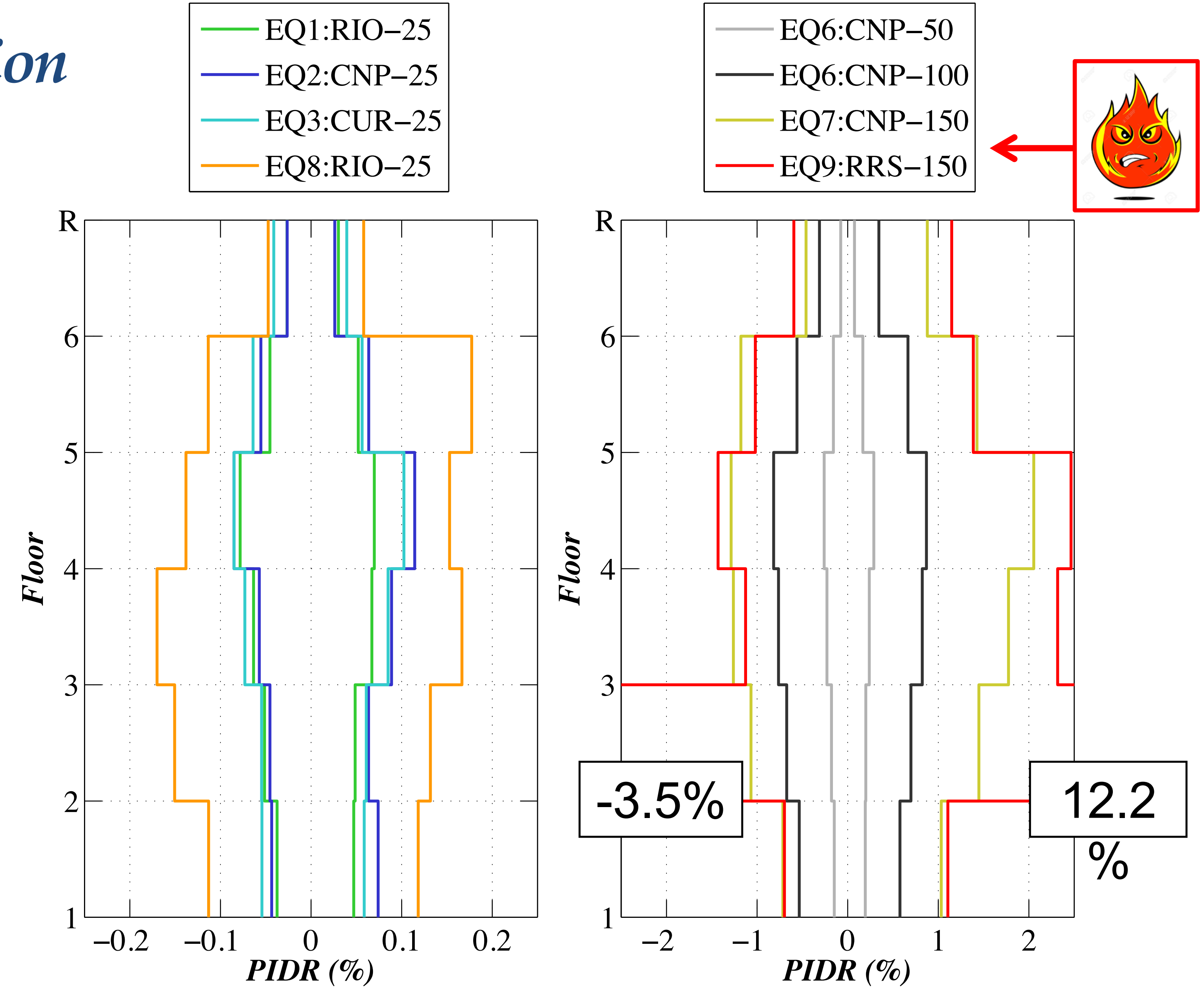
- Post-thermal base shaking earthquake sequence

CFS-HUD: Highlights of Physical Damage & Measured Response

Evolution of building dynamic characteristics



PIDR Distribution



Service-Level **Above Service-Level**

Global SW View – EQ9 (post-fire NF)

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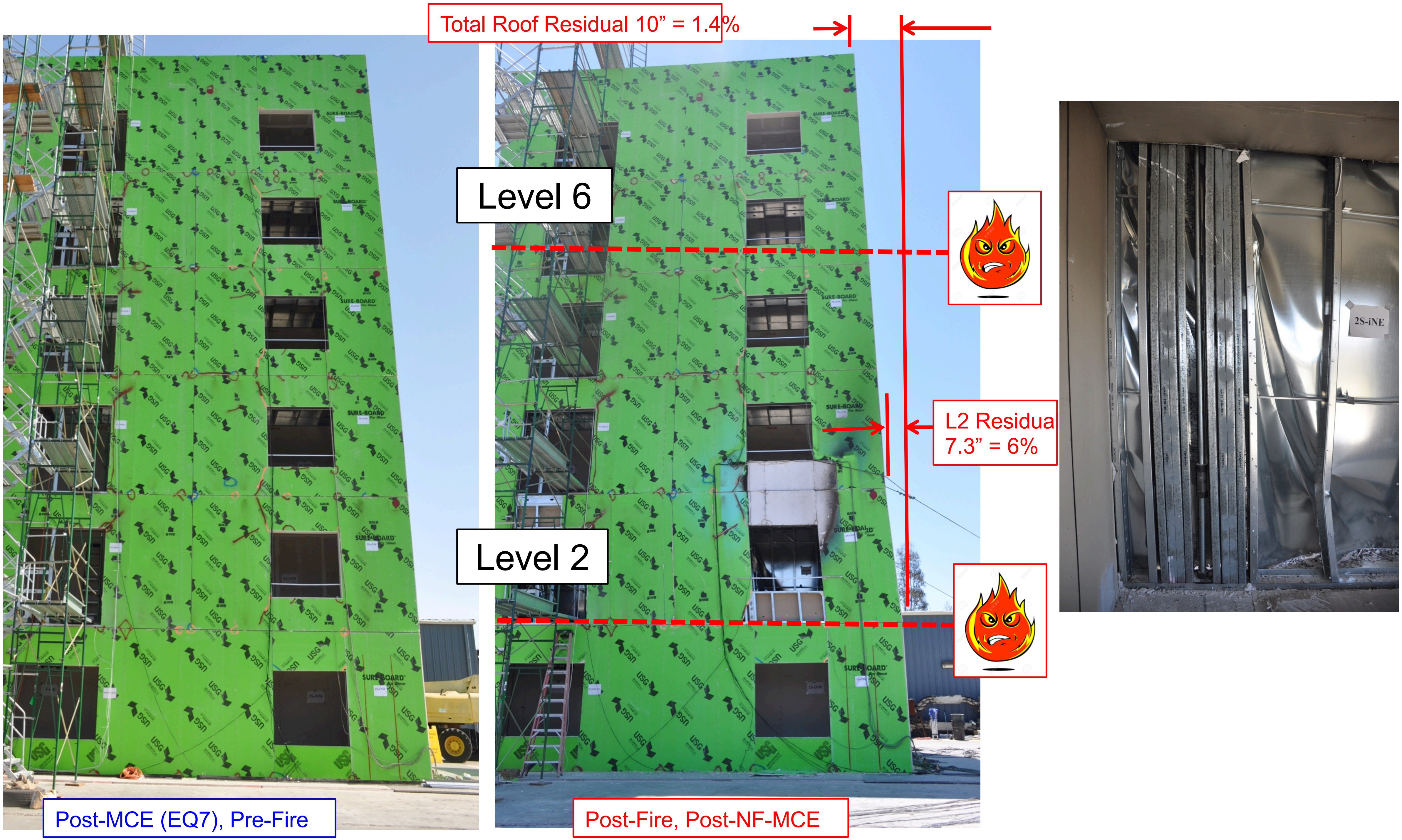
Earthquake & Post-Earthquake Fire Performance of Mid-Rise Light-Gauge Cold-Formed Steel Framed Buildings

Compilation of 2nd Floor Level (Interior Views)
During Final Near-Fault Earthquake Simulation
Post-Fire Tests

UCSD WPI


Total Roof Residual 10” = 1.4%
Level 6
Level 2
L2 Residual
7.3” = 6%
2S-iNE
Post-MCE (EQ7), Pre-Fire
Post-Fire, Post-NF-MCE

What did we NOT learn? What questions remain?

- How would this building have performed with *exterior finishes*?
  - It was already much stiffer than anticipated, at what demand level would the finishes sufficiently disengage and lack contribution to stiffness and seismic inertial load?
- How does this (gyp-bonded steel sheathed CFS-framed wall system) compare with a *generic structural shearwall*, in a system setting?
  - The stiffness and strength contribution of gyp-bonded steel sheathing is (potentially) a positive aspect; though not yet mainstream in practice
- How would the performance of the building compare if the *diaphragm had been flexible*?
  - Physical modeling necessitated the augmentation of mass loading with steel plates – this, combined with the drop-in prefabricated CFS-steel sheathed floor segments resulted in a very stiff floor diaphragm

What did we NOT learn? What questions remain?

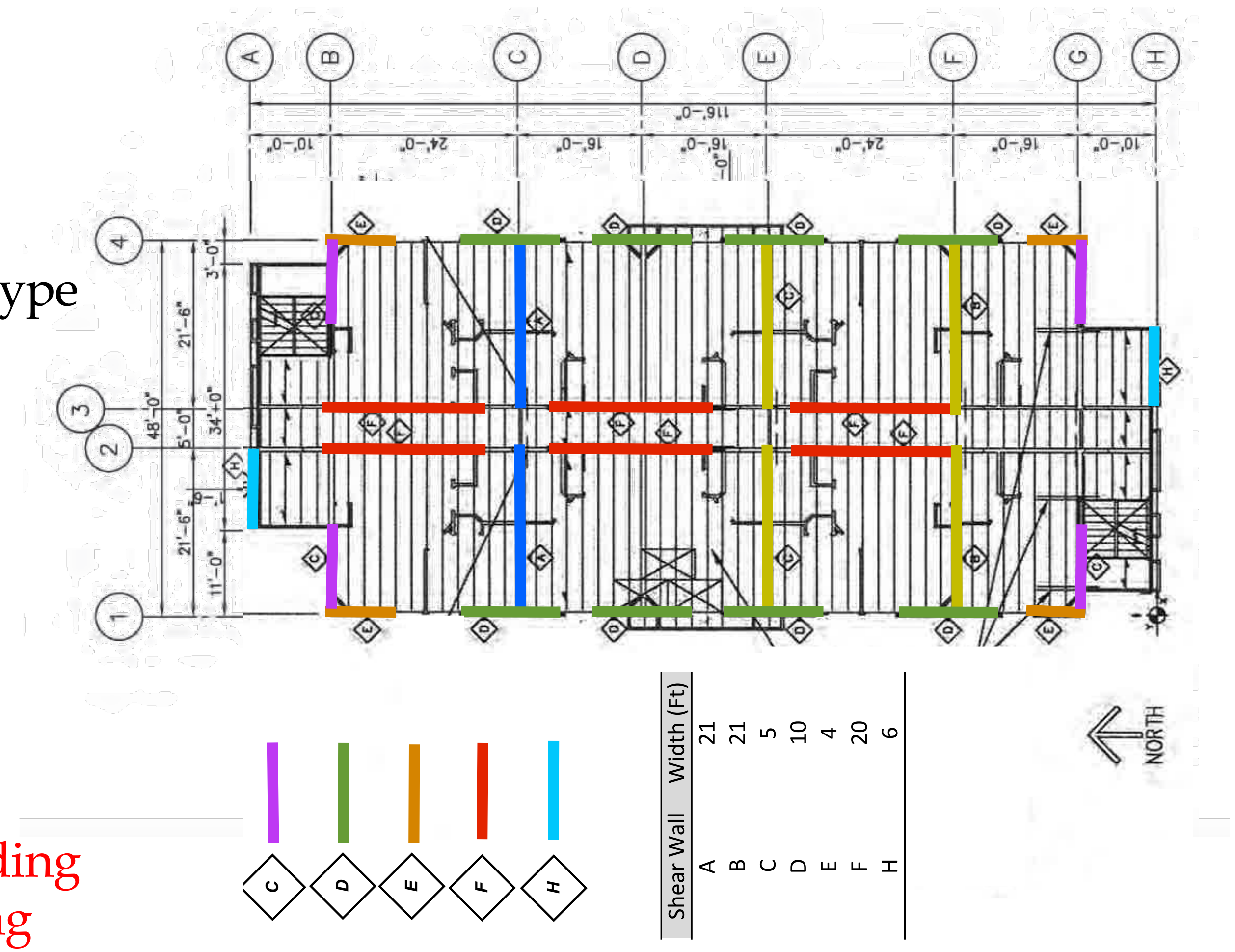
- What is the contribution of the **non-designated** load bearing systems?

2) CFS-NHERI: *Shake table and Quasi-static Wall-line Tests*

PIs: **Tara Hutchinson**, Ben Schafer & Kara Peterman
Amanpreet Singh & Dr. Xiang Wang (UCSD Researchers)

CFS-NHERI Archetype Buildings

- Complete CFS system walls
  (gravity and steel sheet shear walls)
- Designed <u>4 and 10</u> story buildings
  - Selected shear wall details based on building archetype
    - ➢ 4′ long x 9′ tall
    - ➢ Single side steel sheet: 30 mil
    - ➢ Chord Stud pack: 600S250-97
    - ➢ Gravity Stud: 600S250-68
    - ➢ Tie Rod: $\phi 1\,{}^{1}/_{8}$ "
    - ➢ Edge spacing: 2″/12″ o.c., #12 screws
    - ➢ Fully blocked
  - Reflect typical shear wall at <u>base</u> of the 4-story building or approximately <u>mid-height</u> in the 10-story building



Reference: Torabian, S., Nia, Z. S., & Schafer, B. W. (2016). An Archetype Mid-Rise Building for Novel Complete Cold-Formed Steel Buildings. In *Wei-Wen Yu International Specialty Conference on Cold-Formed Steel Structures, Baltimore, MD*.

Wall-Line Tests: *Experiment Objectives*

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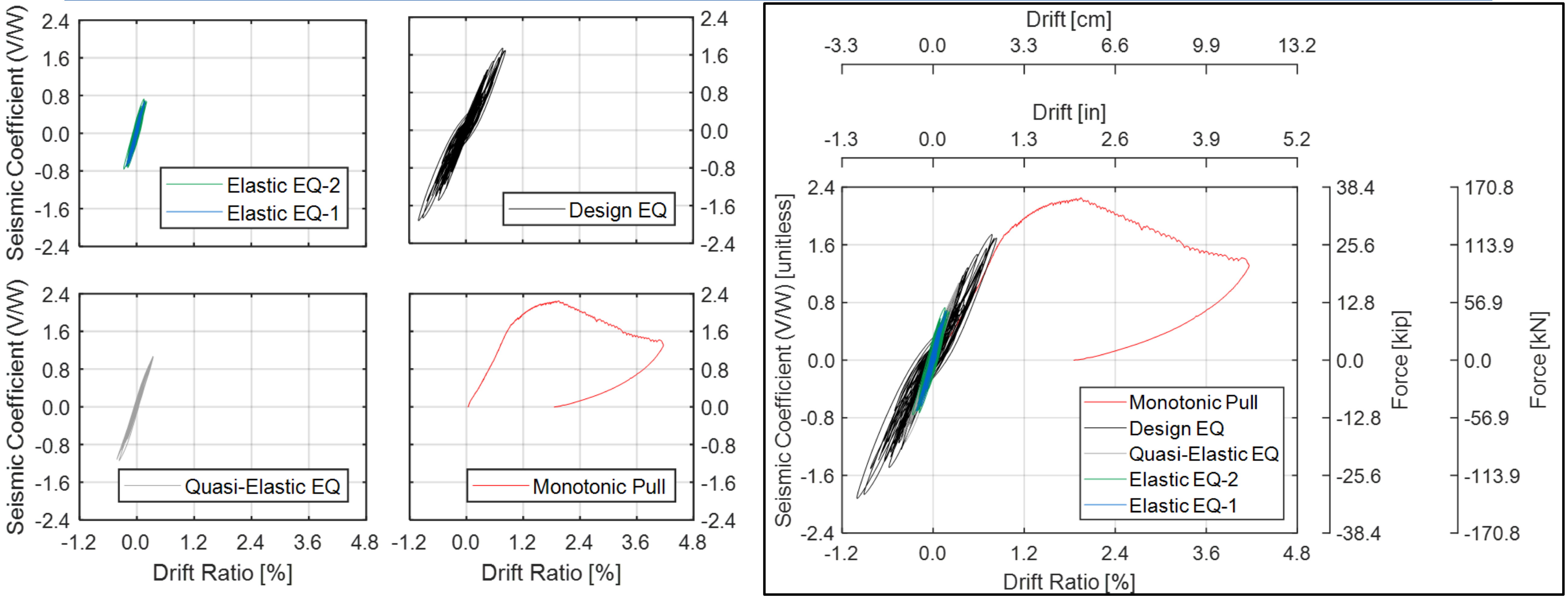
- Characterize dynamic performance of Cold-Formed Steel framed walls subjected to in-line earthquake motions of increasing intensity
- Understand the *effect of finishes* and *effects of openings* on wall behavior
- Compare the behavior of *Type I and Type II* walls
- Compare performance of walls with *steel tension tie-rods* assembly versus *hold-down* systems
- Compare the behavior of *symmetrical and unsymmetrical* walls
- Examine lateral load sharing between shear walls placed in-line with gravity walls

Test Setup: Shake Table Tests

CFS-NHERI: Highlights of Physical Damage & Measured Response of Select Wall-Line Components

SGGS-1 (Baseline Specimen) – Design EQ

Force-Displacement Response: *SGGS-1 (Baseline specimen)*



Specimen	Peak Strength, V_{max} [kip]	Drift, $\delta_{V_{max}}$ [in] (%)	Initial Stiffness*, k_e [kip/in]	Secant Stiffness, k_{sec} [kip/in]
SGGS-1	36.0	2.11 (1.95%)	66.2	17.1

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CFS-NHERI
In-line Wall Shake Table Tests

SGGG-1 Asymmetric Specimen

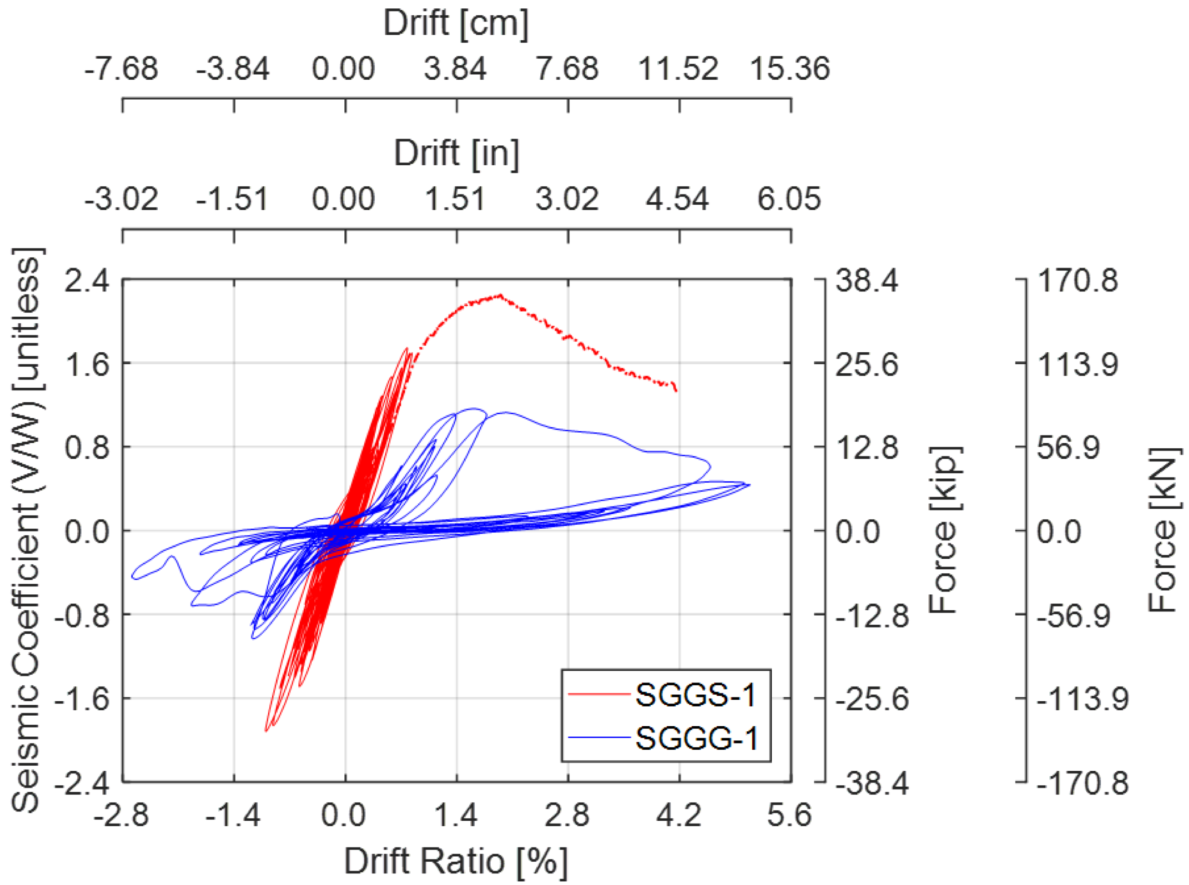
1994 Northridge (Canoga Park)

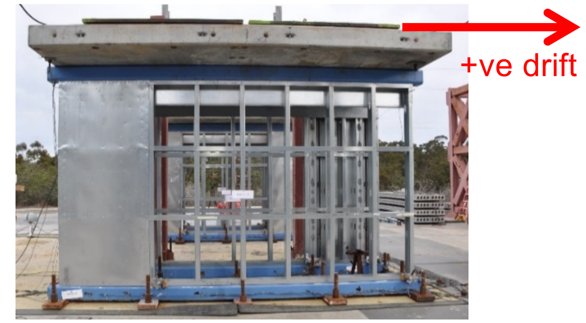
Scaled to Above Design Performance Level

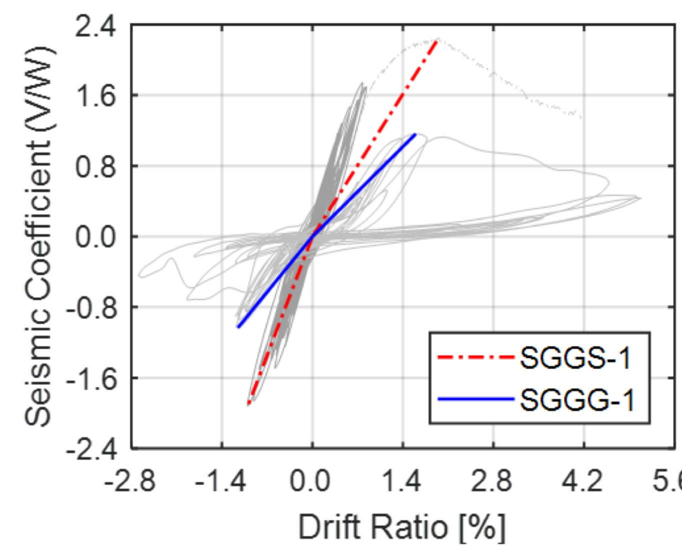
December 10, 2018

Johns Hopkins University UC San Diego UMass Amherst

Symmetric vs Unsymmetric Wall Systems

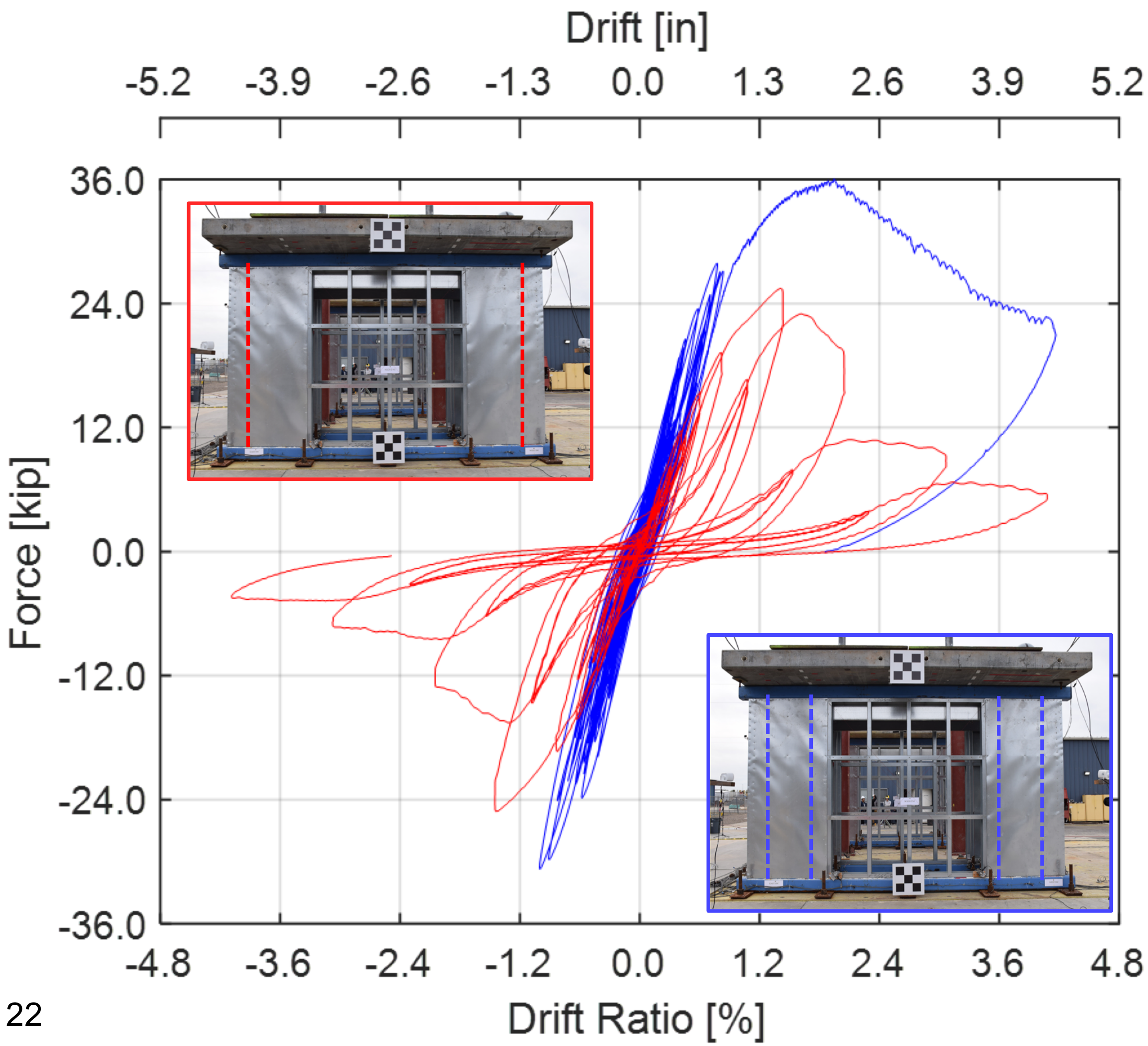




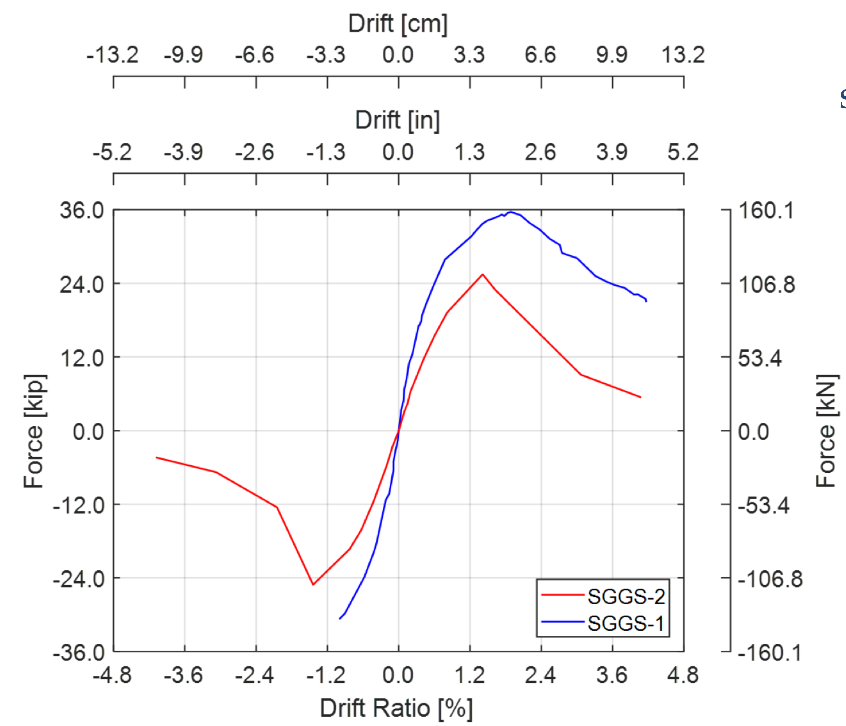


Specimen	Peak Strength, V_{max} [kip]	Drift, $\delta_{V_{max}}$ [in] (%)	Initial Stiffness*, k_e [kip/in]	Secant Stiffness, [kip/in]	
				k^+_{sec}	k^-_{sec}
SGGS-1	36.0	2.11 (1.95%)	66.2	17.1	28.4
SGGG-1	18.6 *(↓48.3%)*	1.73 (1.60%)	30.2 *(↓54.4%)*	10.8 *(↓36.9%)*	13.3

Type I vs Type II Wall Systems



Specimen	Peak Strength, V_{max} [kip]	Drift, $\delta_{V_{max}}$ [in] (%)	Initial Stiffness (kip/in)
SGGS-2	25.5	1.53 (1.41%)	25.87
SGGS-1	36.0 (↑41.3%)	2.11 (1.95%)	47.39



Initial Stiffness: secant at 40% of peak strength

Concluding Remarks

- Academic researchers sometimes come up with wild ideas, industry can help bring us back to the realities of construction practice
  - Industry collaborations are essential in these large-scale testing endeavors
- Together industry-academic research teams promise to make real change in understanding & improving the performance of structural (& non-structural) systems during earthquake events