

CFS-NHERI 10-STORY BUILDING SHAKE TABLE TEST SPECIMEN: DESIGN UPDATES



University of California at San Diego



Session: EXP2
July 5, 2024

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cfsrc.org/projects/cfs-nheri
cfs10.ucsd.edu



Alfred E. Alquist
**SEISMIC SAFETY
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**American
Iron and Steel
Institute**



JOHNS HOPKINS
UNIVERSITY

UMass**Amherst**

UC San Diego



CAL POLY

Why Light-Gauge Cold-Formed Steel (CFS)?

- Thin, rapidly produced in large quantities, **consistent quality with high precision**
- Compared with other light-weight materials:
 - **Highest strength-weight ratio** [25 times greater than wood] (increased prevalence in seismic zones)
 - Ease of fabrication & erection
 - Durable, moisture and mold-resistance, **recyclable**
 - **Non-combustible**
- **Prefabrication** – putting members together in a controlled shop environment as subsystems/components is a significant advancement
- **Green material solution¹**
 - Reduced waste; accurate design and manufacturing, <1% waste from frame & truss manufacture
 - **Steel 100% recyclable** (overall recycling rate of steel = 66%, highest industry in the world)



¹Framecad (manufacturing) stats (2020); Steel framing Industry Association (2019)

CFS-NHERI Inspiration

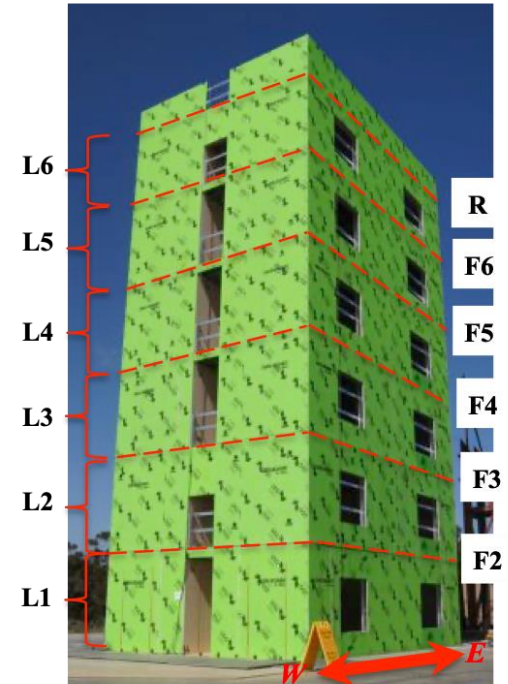
Previous system level (full-scale building) CFS-framed shake table experiments (CFS-NEES, CFS-HUD):

- Demonstrated robust structural performance can be achieved
- Highlighted importance of overstrength that manifest courtesy of non-seismic designated and/or finish elements

CFS-NEES¹
(2-stories)



CFS-
HUD²



¹K. D. Peterman, M. J. Stehman, R. L. Madsen, S. G. Buonopane, N. Nakata, and B. W. Schafer. "Experimental seismic response of a full-scale cold-formed steel-framed building. I: System-level response," ASCE J. Struct. Eng., vol. 142, no. 12, pp. 04016127, Dec. 2016, DOI:10.1061/(ASCE)ST.1943-541X.0001577.

²T. C. Hutchinson, X. Wang, G. Hegemier, P. Kamath, and B. Meacham. "Earthquake and post-earthquake fire testing of a midrise cold-formed steel-framed building. I: Building response and physical damage," ASCE J. Struct. Eng., vol. 147, no. 9, pp. 04021125, Sep. 2021, DOI: 10.1061/(ASCE)ST.1943-541X.0003097.

CFS-NHERI 10-Story Building Test (CFS10): 2024-2025

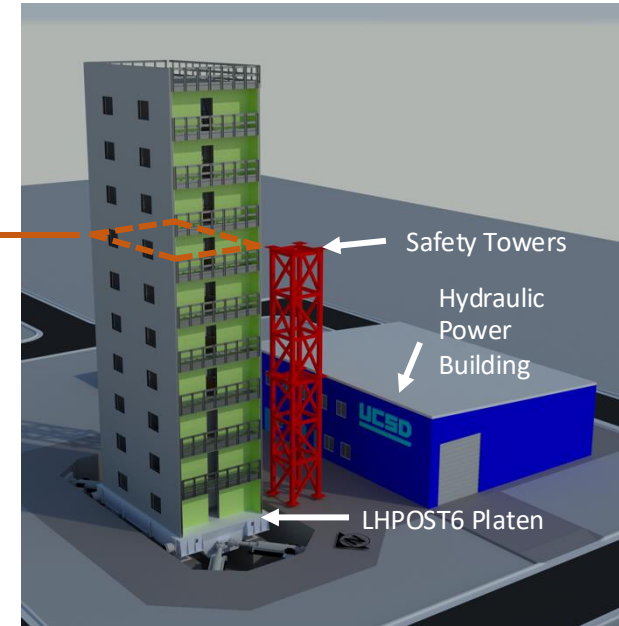
10-story Cold-Formed Steel (CFS)-framed building test at UC San Diego NHERI 6-DOF Large High Performance Outdoor Shake Table

CFS-NHERI **capstone** experimental effort:

- Proof of concept (100ft tall CFS building)
- Exceeds **ASCE 7 code 65ft height limitations**
- Multi-directional seismic response
- Post-earthquake fire performance evaluation

Generation of essential full-scale, system-level experimental data

→ **Support design code improvements, development of construction detailing and practices, validate numerical models**



Milestones & target date

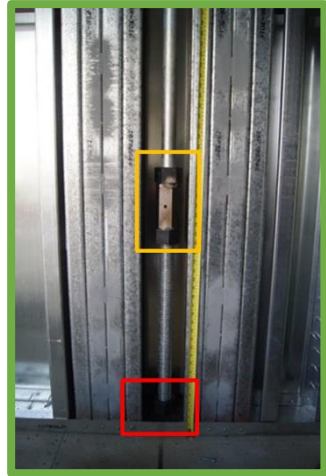
May-June 2024
July 2024
Sep 2024

Material Procurement
Fabrication (off-site)
Construction on Table

May-June 2025
July-Aug 2025

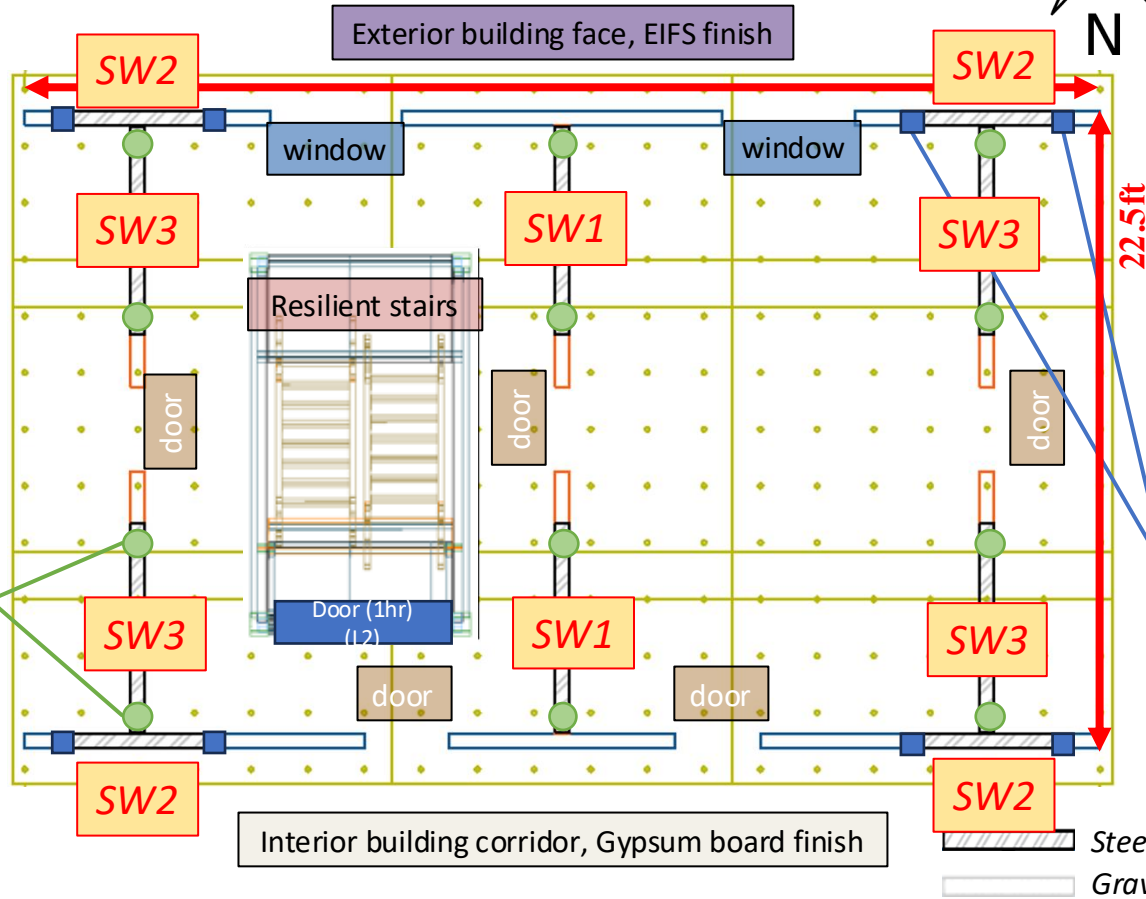
Seismic Test Program
Live Fire Test Program

Test Building: *Basic Layout of the Slice*



N-S Shear walls use continuous tie-rod sandwiched between end posts.

(West coast preference in construction)



E-W Shear walls use hold-downs and splice connected end posts

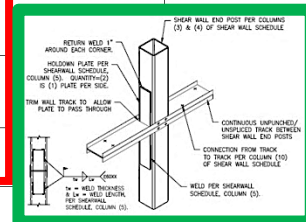
(East coast preference in construction)

Shear Wall Details: *Longitudinal (E-W) Direction*

SHEAR WALL SCHEDULE *										
SHEARWALL TYPE (DETAILS)	(1)	(2)	END POSTS		HOLD-DOWNS AT BOTTOM OF WALL (TOP OF LEVEL BELOW)		SHEATHING		BOTTOM CONNECTION	
	LEVEL	SHEAR WALL MINIMUM ON-CENTER STUD & TRACK MATERIAL	(3) END POSTS MEMBER	(4) PROFILE	(5) TYPE	(6) DE (BOTTOM)	(7) DE (TOP)	(8) FASTENER PATTERN	(9) FASTENER PATTERN	(10) WALL BOTTOM TO TOP TRACK FASTENERS
SW-2 TERIOR W1 & CORRIDOR W5 WALL GRIDLINES 1 & 2	10	43-MIL (33 KSI) MIN	(1) 600HDS300-43 (33 KSI)	MP1.1	(1) CD8-S (17) #14 SCREWS	5/LSF-5.0	7/8"Ø F1554 Gr36, (2) HVY HN's & FW	27 MIL STEEL SHEET (33Ksi)	6 / 12	#12 SCREW AT 16" ON-CENTER
	9	68-MIL (33 KSI) MIN	(1) 600HDS300-68 (50 KSI)	MP1.6	(1) CD15-S (32) #14 SCREWS	5/LSF-5.0	1"Ø F1554 Gr36, (2) HVY HN's & FW's	27 MIL STEEL SHEET (33Ksi)	4 / 12	#12 SCREW AT 9" ON-CENTER
	8	68-MIL (50 KSI) MIN	(2) 600HDS300-68 (50 KSI)	MP1.8	(2) CD15-S (32) #14 SCREWS	5/LSF-5.0	(2) 1"Ø F1554 Gr36 (2) HVY HN's & FW	33 MIL STEEL SHEET (33Ksi BLOCKED)	6 / 12	#12 SCREW AT 12" ON-CENTER
	7	97-MIL (50 KSI) MIN	(2) 600HDS300-97 (50 KSI)	MP1.8	(2) 300HDP050 (4) 3/4" Thread Rods	2 & 7/LSF-5.0	N/A	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	#12 SCREW AT 9" ON-CENTER
	6	118-MIL (50 KSI) MIN	HSS 6 x 6 x 3/16 (A500 GR.B)	MPC.1	(2) 500HDP038 tw=5/16" Lw=9"	7/LSF-5.0	N/A	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	5	118-MIL (50 KSI) MIN	HSS 6 x 6 x 1/4 (A500 GR.B)	MPC.1	(2) 500HDP050 tw=5/16" Lw=9"			33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	4	118-MIL (50 KSI) MIN	HSS 6 x 6 x 5/16 (A500 GR.B)	MPC.1	(2) 500HDP050 tw=5/16" Lw=9"			33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	3	118-MIL (50 KSI) MIN	HSS 6 x 6 x 3/8 (A500 GR.B)	MPC.1	(2) 500HDP050 tw=5/16" Lw=9"			33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	2	118-MIL (50 KSI) MIN	HSS 6 x 6 x 1/2 (A500 GR.B)	MPC.1	(2) 500HDP075 tw=1/2" Lw=9"			33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	1	118-MIL (50 KSI) MIN	HSS 6 x 6 x 1/2 (A500 GR.B)	MPC.1	(4) 7/16" x 5 1/8" Lw Weld HSS @ Transfer PL			33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	3/8" DIA x 1" Gr5 HEX HEAD CAP SCREW AT 6" OC OR 0.157"Ø HILTI X-U PAF AT 4" OC

Traditional hold-downs connected to CFS member

Plate hold-downs welded/bolted to HSS member



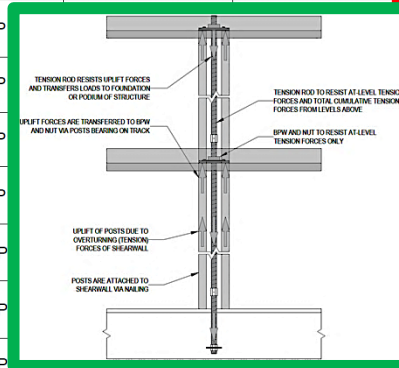
Thicker sheet and tighter spacing at lower levels

Heavier gauge CFS studs at lower levels

Shear Wall Details: *Transverse (N-S) Direction*

SHEAR WALL SCHEDULE *											
SHEARWALL TYPE (DETAILS)	(1)	(2)	END POSTS		HOLD-DOWNS AT BOTTOM OF WALL (TOP OF LEVEL BELOW)			SHEATHING		BOTTOM CONNECTION	
	LEVEL	SHEAR WALL ON-CENTER STUD & TRACK MATERIAL	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
			END POSTS MEMBER	FASTENERS	TAIL OF WALL	TAIL OF WALL	THREADED ROD ANCHOR	TYPE	FASTENER PATTERN	WALL BOTTOM TO TOP TRACK FASTENERS	
SW-1 INTERIOR WALL AT W3 GRIDLINE D	10	43-MIL (33 KSI) MIN	2x (2) 600S162-43 (33KSI)					3/4" Ø A36 THREADED ROD	27 MIL STEEL SHEET (33Ksi)	6 / 12	#12 SCREW AT 16" ON-CENTER
	9	43-MIL (33 KSI) MIN	2x (2) 600S162-43 (33KSI)	MP1.10	--	--	--	1"Ø A36 THREADED ROD	27 MIL STEEL SHEET (33Ksi)	4 / 12	#12 SCREW AT 9" ON-CENTER
	8	54-MIL (50 KSI) MIN	2x (2) 600S200-54 (50KSI)	MP1.10	--	--	--	1 1/4"Ø A36 THREADED ROD	27 MIL STEEL SHEET (33Ksi)	3 / 12	#12 SCREW AT 6" ON-CENTER
	7	68-MIL (50 KSI) MIN	2x (2) 600S250-68 (50KSI)	MP				1 1/2"Ø A36 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	6 / 12	#12 SCREW AT 12" ON-CENTER
	6	97-MIL (50 KSI) MIN	2x (2) 600S200-97 (50KSI)	MP				1 3/4"Ø Gr B7 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	4 / 12	#12 SCREW AT 9" ON-CENTER
	5	97-MIL (50 KSI) MIN	2x (2) 600S200-97 (50KSI)	MP				1 1/2"Ø Gr B7 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	#12 SCREW AT 9" ON-CENTER
	4	118-MIL (50 KSI) MIN	2x (2) 600S250-118 (50KSI)	MP				1 3/4"Ø Gr B7 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	#12 SCREW AT 6" ON-CENTER
	3	118-MIL (50 KSI) MIN	2x (3) 600S162-118 (50KSI)	MP				2"Ø Gr B7 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	2	118-MIL (50 KSI) MIN	2x (3) 600S200-118 (50KSI)	MP				2"Ø Gr B7 THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	1	118-MIL (50 KSI) MIN	2x (3) 600S250-118 (50KSI)	MP				2"Ø Fu = 150 Ksi THREADED ROD	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	3/8" DIA x 1" Gr5 HEX HEAD CAP SCREW AT 6" OC OR 0.157"Ø HILTI X-U PAF AT 4" OC

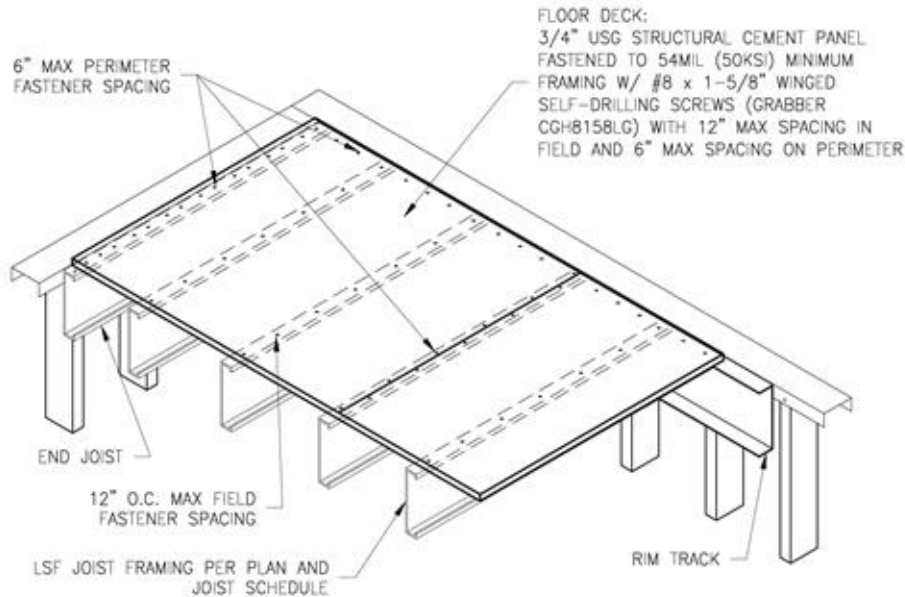
Tension tie-rod sandwiched between shear wall posts



Heavier gauge built-up CFS chord studs at lower levels as compression posts

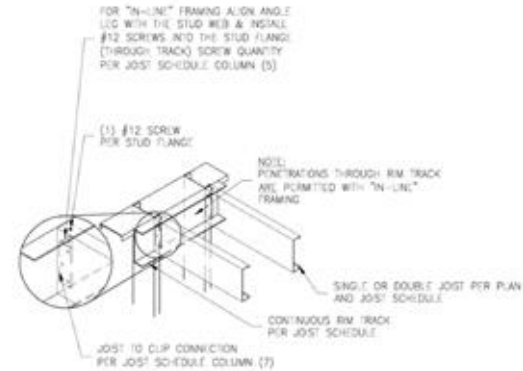
Thicker sheet and tighter spacing at lower levels

Test Building: *Floor and Diaphragm Details*

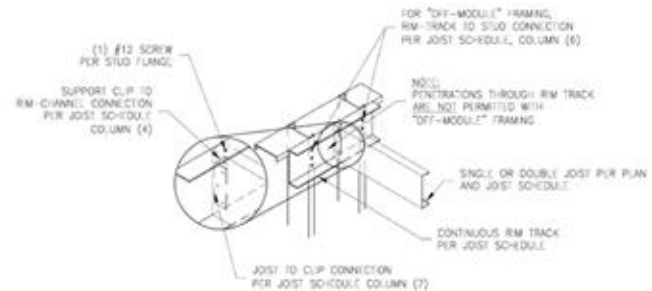


6 FLOOR DECK CONNECTION TO FRAMING

Ref. Plan Notes from Structural Plans



A TYPICAL "IN-LINE" JOIST-TO-RIM TRACK CONNECTION



B TYPICAL "OFF-MODULE" JOIST-TO-RIM TRACK CONNECTION

4 JOIST AND END-JOIST CONNECTIONS

TYPICAL UNLESS NOTED OTHERWISE

Balloon framing – THE approach to use for taller CFS buildings

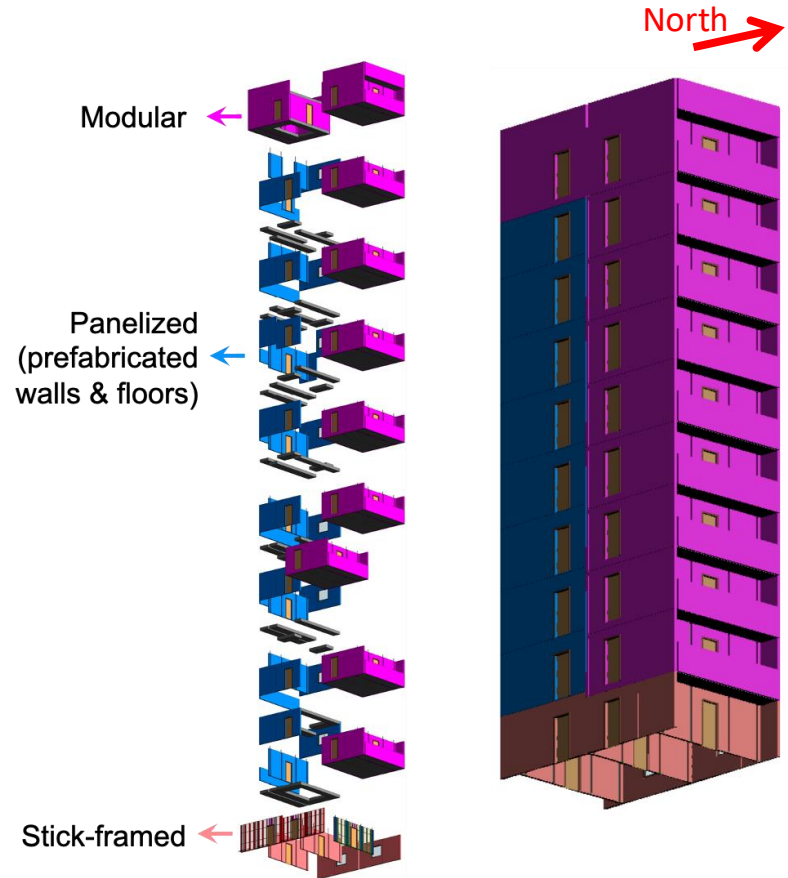
CFS10: Design Updates

Design of the building specimen has been enhanced in scope to integrate three types of construction:

- 1) Stick-framing (1D)
- 2) Prefabricated wall and floor panels (2D)
- 3) Volumetric modular units (3D)

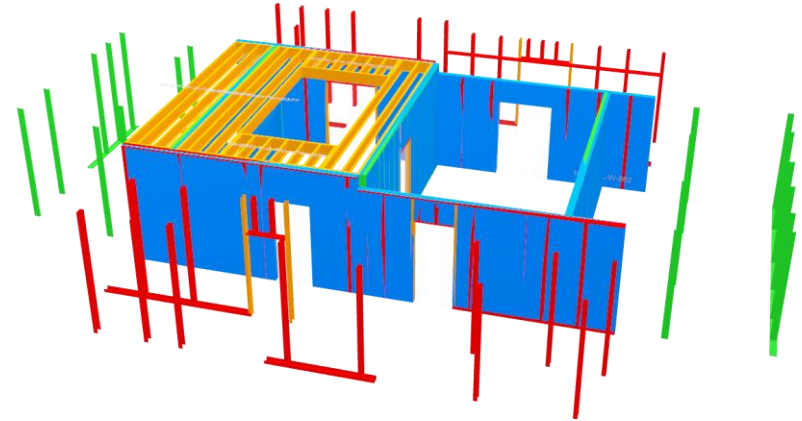
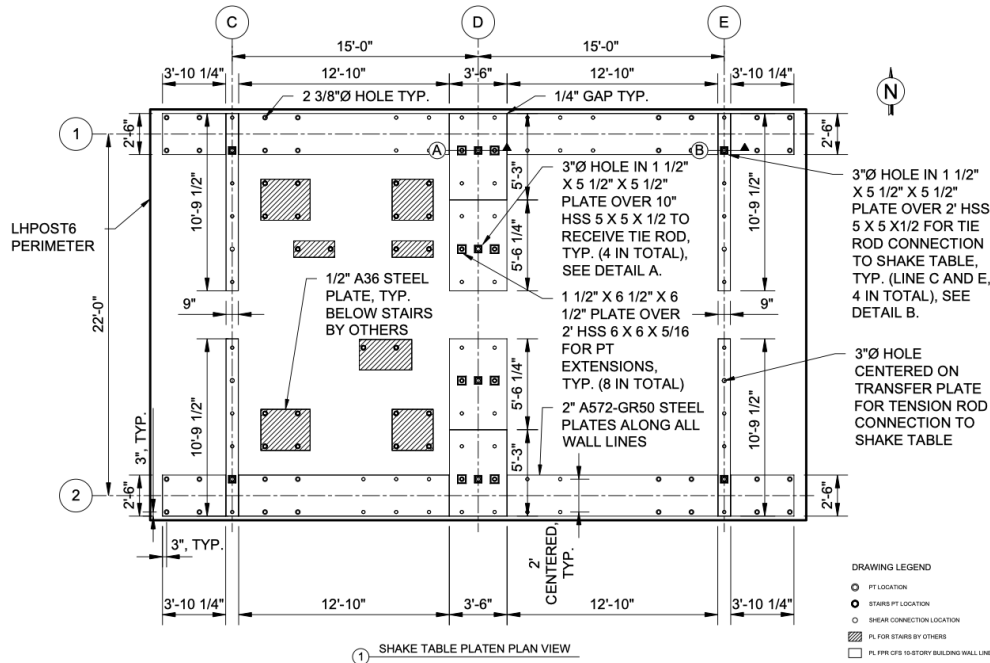


HUD Research-Industry Partnership Program



CFS10: Design Updates

Stick-framing (L1): to facilitate attachment to shake table: captures the most common construction method

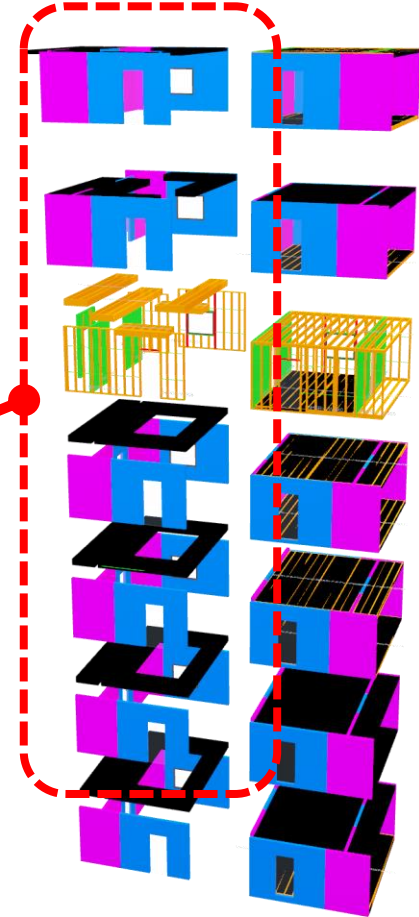
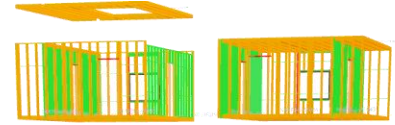
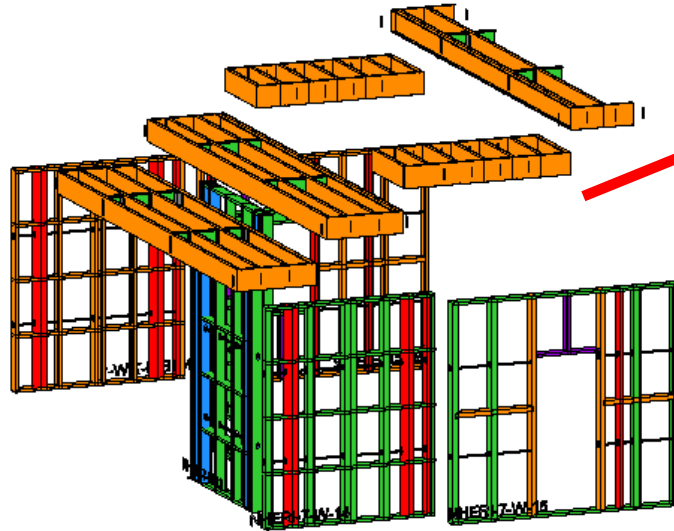


CFS10: Design Updates

Pre-fabricated wall and floor panels (2D) [L2-9 East rooms]: to facilitate ease of construction surrounding full-height stair tower, more modern, cost-effective construction method



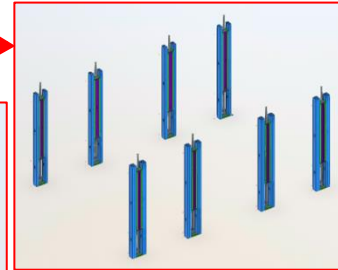
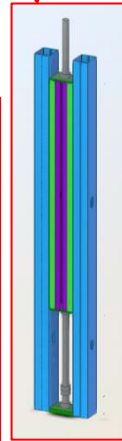
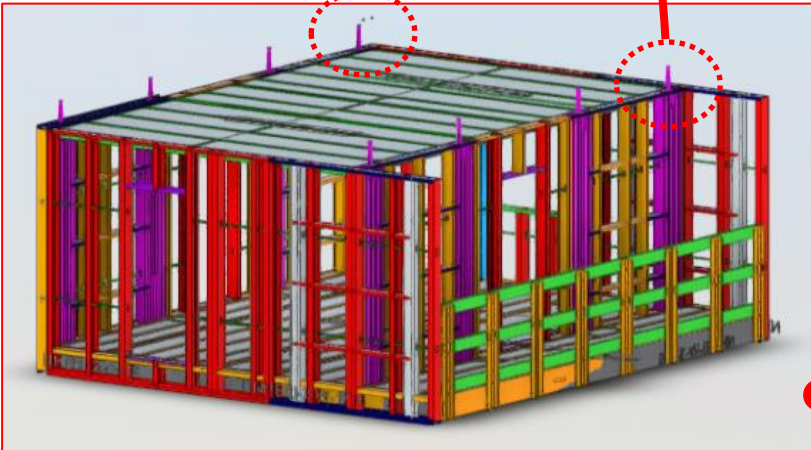
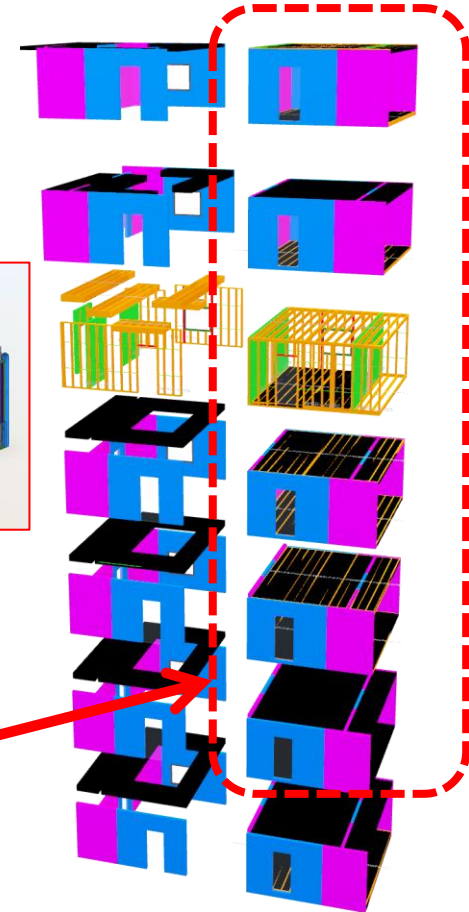
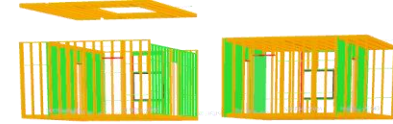
CFS-HUD pre-fabricated wall/floor panel (L2-L6) construction to LHPOST



CFS10: Design Updates

Volumetric modular units (3D) [L2-9 West rooms & L10]:

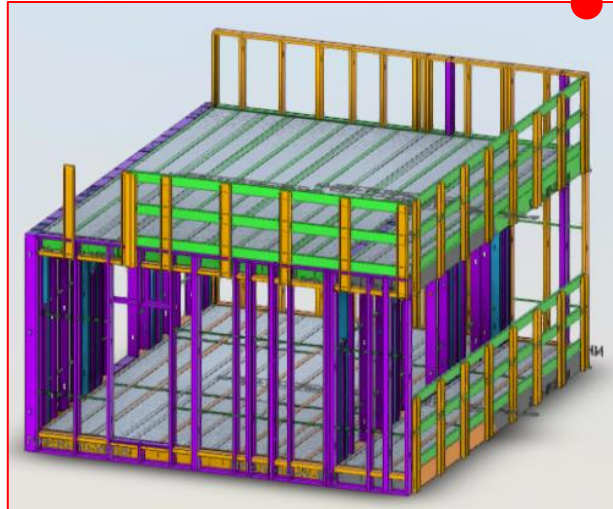
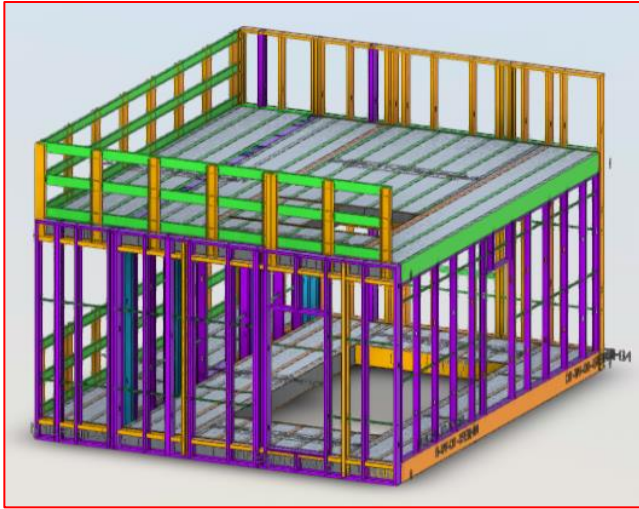
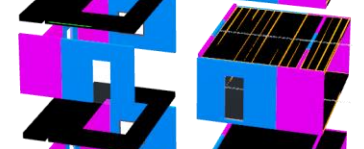
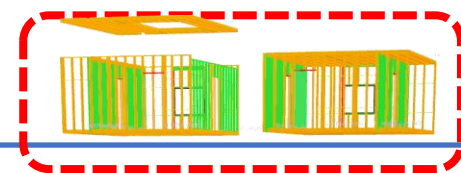
6-sided volumetric units, assembled with prefabricated panels, hoisted to building as a 3D unit, to evaluate efficiency of modular construction, emerging construction method



CFS10: Design Updates

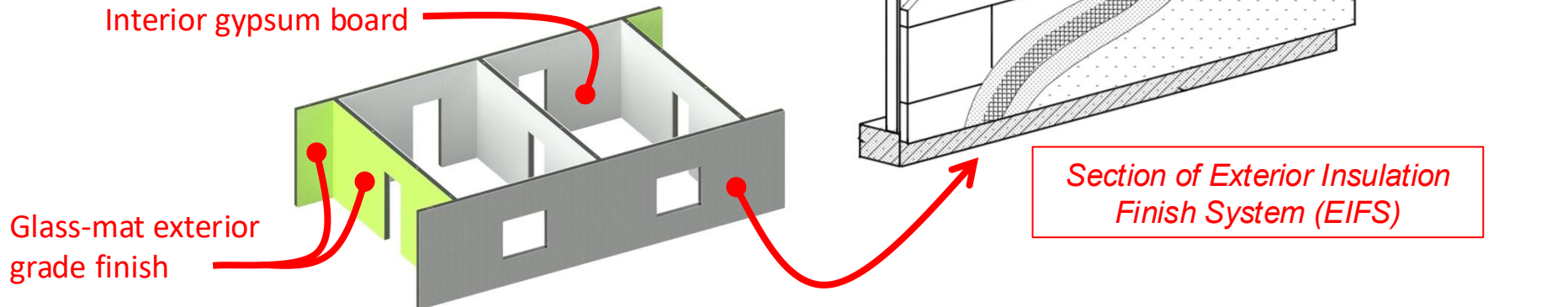
Volumetric modular units (3D) [L2-9 West rooms & L10]:

6-sided volumetric units, assembled with prefabricated panels, hoisted to building as a 3D unit, to evaluate efficiency of modular construction, emerging construction method



Functional Recovery (FR): *Building Envelope*

- Interior Finish
 - 5/8" Fire Rated Type X Gypsum Board
- Exterior Finish:
 - Substrate: 5/8" Fire Rated Type X Glass-mat Sheathing Board
 - North face: weather Resistant Barrier, 1" thick EPS Boards and base coat & finish coat



Interior Finish

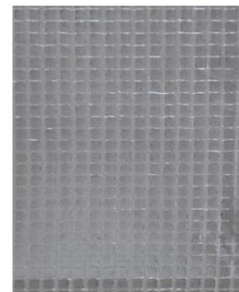


Rasping



Base coat

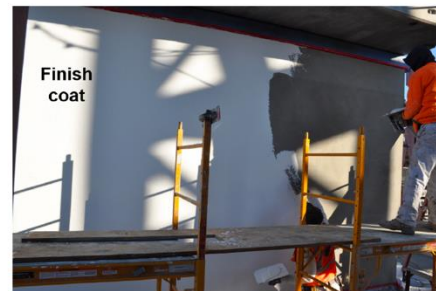
(c) Rasping of foam boards before application of base coat



2nd coat



(d) Embedded reinforcing mesh in base coat and application of second layer



Finish coat

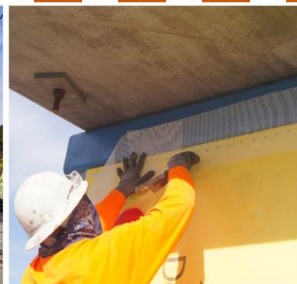


(e) Application of finish coat

Exterior Finish



Glass-mat sheathing



(a) Installation of glass-mat sheathing panels



Adhesive



EPS boards



(b) Application of EPS foam boards using adhesive onto panel substrate

Ships ladder for roof access

Drift-compatible

- Independent Stringer connection
- Released grabrail

Revised drift-compatible connections

- Independent Stringer connection
- Rigid grabrail

Torsion Bar connection

- Continuous landing span channel
- Rigid grabrail

Drift-compatible connections

- Continuous landing span channel
- Rigid grabrail

Drift-compatible connections

- Continuous landing span channel
- Released grabrail

Drift-compatible connections

- Split channel
- Released grabrail

Torsion Bar connection

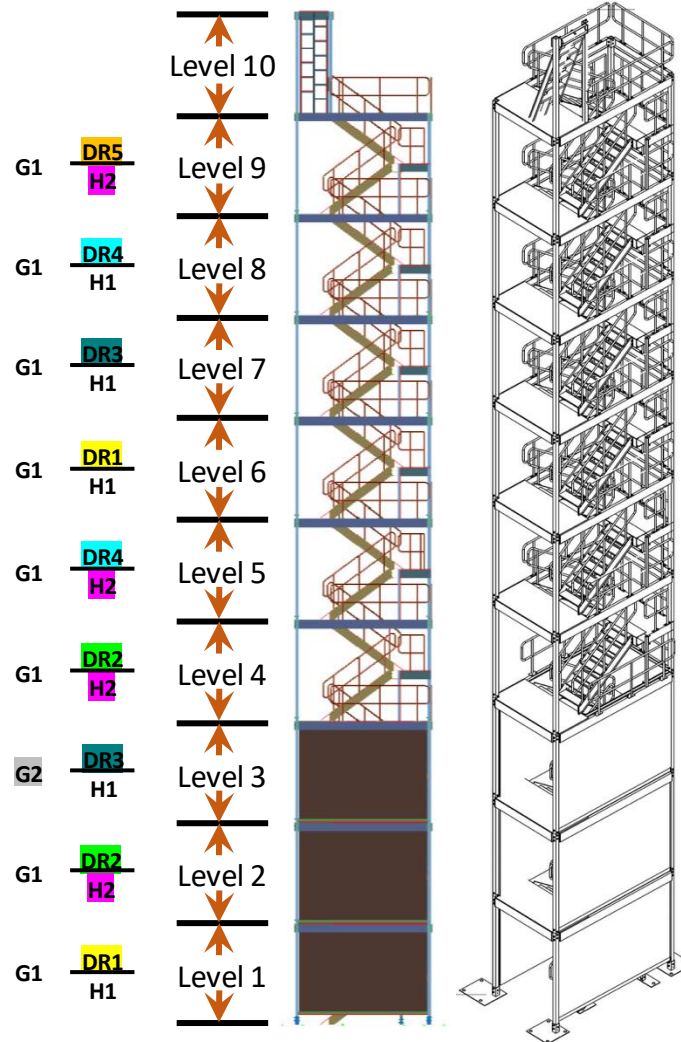
- Continuous landing span channel
- Rigid grabrail
- Fire-rated shaft wall
- Level 3 mid-landing w/ hanging rod

Drift-compatible connections

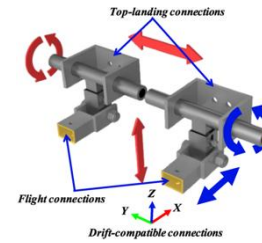
- Split landing span channel
- Released grabrail
- Fire-rated shaft wall

Drift-compatible connections

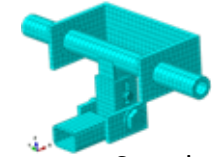
- Continuous landing span channel
- Rigid grabrail
- Fire-rated shaft wall



FR: Resilient Stair System



As-installed
(Tallwood project, 2023)



Sorosh et al. (2022)

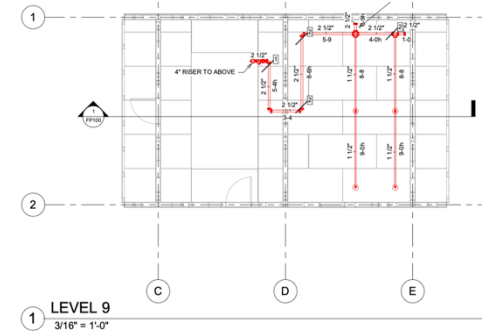
CS-Group (2024)

Notes:

- All modular stair systems (L1 – L9)
- 2-hr fire rated shaft walls at L1-L3
- 5 types of “drift-release” (DR#) tested
 - DR1: “Drift-Ready” (as designed, cont. channel)
 - DR2: “Drift-Ready” (split channel)
 - DR3: Torsion Bar
 - DR4: DRC V2
 - DR5: DRC V2 Coil

Note: All DR connections will be designed for locking mechanism for white noise
- 2 types of mid-landing gravity system
 - G1: Gravity columns
 - G2: Hanging rods
- 2 types of handrails tested
 - H1: Rigid connection (Normal)
 - H2: Released grabrail

The diagram illustrates a 11-story building with a vertical shaft. A fire originates on Level 2 (10' - 0") and spreads upwards through the shaft, reaching Level 11 (100' - 0"). The fire is shown as a red flame icon on each level. The shaft is a central vertical corridor, and the fire spread is indicated by red lines and arrows. The building's structure is shown in a 3D perspective view.



- Performance of branch lines with long spans between supports (brace spacing)
- Acceleration amplification (branch line run length, multi-directional loading)
- Four different layouts, across five floors
- Vertical riser (L1-L10) [L11 not connected to riser]

- Activation verification
- Minimum sprinklers versus overload sprinklers (L9/L3 vs L6)

- Implementation within panelized versus modular spaces

CFS10: Live Fire Test Program

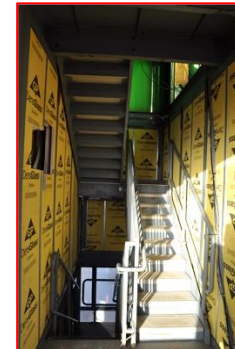
Objectives:

Investigate multi-hazard performance of CFS10 (fire following earthquake, FFE):

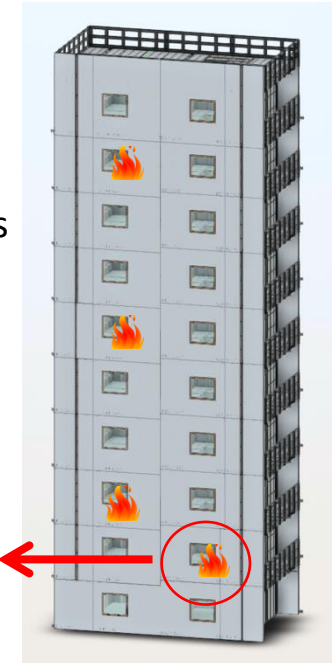
- Thermal loading (intensity & duration) from compartment fire scenarios
- Systematic assessment of gypsum thermal-mechanical performance
- Thermo-mechanical performance reduction of the structural frame
- Flame and smoke propagation in the building
- Impact of air leakages on the fire severity and the ability to predict fire behavior
- Response of standard active (sprinkler piping) and passive (fire stopping) FP systems
- Performance of fire rated doors and fire resistive features (ceiling, gypsum etc)

Methods:

- Conduct (4) live-fire tests post-seismic testing
 - Fire compartments (lower, middle, upper levels) (L3, L6, L9)
 - Stair compartment (lower) (L2)
- Full fire sequence: Growth, fully-developed duration, cooling phase
- Post-flashover
- Duration: 60min
- $T_{\max} = 650^{\circ}\text{C}$



Fire shaft



CFS10: Unique opportunities

- Innovative CFS seismic design detailing and construction protection
 - Taller building systems
 - Faster modular construction, no wet components
- Meet functional recovery needs through integration of nonstructural components
 - Stairs – key means of egress/ingress
 - Windows/doors
 - Fire Sprinklers
 - Flexible gas piping
- Repair actions, functional recovery downtime & cost evaluation
- Post-earthquake live fire vulnerability: multi-hazard building resilience
- Investigation of low-cost seismic & fire instrumentation
 - Unmanned Aerial Vehicles (CalOES payload effort)
 - CSN (community seismic network) + CA Strong Motion Instrumentation Program (CSMIP) (CA DOC effort)

Milestones & target date

May-June 2024
July 2024
Sep 2024

Material Procurement
Fabrication (off-site)
Construction on Table

May-June 2025
July-Aug 2025

Seismic Test Program
Live Fire Test Program

CFS-NHERI Support

Thank you to our amazing partners thus far in this program!

Materials, Engineering, Design and Financial Support



**American
Iron and Steel
Institute**



NIST



Alfred E. Alquist
**SEISMIC SAFETY
COMMISSION**



Cal OES
GOVERNOR'S OFFICE
OF EMERGENCY SERVICES



ClarkDietrich



Construction Specialties

