Collaborative Research (CFS-NHERI): Seismic Resiliency of Repetitively Framed Mid-Rise Cold-Formed Steel Buildings

As part of the project aimed at advancing understanding and design methodologies for CFS building systems, cshake table tests will be performed at the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) Large High Performance Outdoor Shake Table at UC San Diego, in June-July 2018 (phase 1) and Nov-Dec 2018 (phase 2). These two phases of large-scale shake table tests, which will guide the design of a third and final phase of testing of a full-scale building system (2019), will provide excellent opportunities for payload experiments and NHERI researchers are encouraged to consider taking advantage of either.

Project Summary

The need for low cost, multi-hazard resilient buildings constructed of sustainable, low-carbon footprint materials is urgent. Mid-rise buildings framed from thin-walled, cold-formed steel (CFS) have the ability to support this urgent need. The potential benefits of CFS-framed structures include low installation and maintenance costs, high durability and ductility, lightweight framing, and use of a non-combustible material. By using framing schemes with closely-spaced vertical members repetitively placed in the walls, CFS buildings develop lateral resistance through sheet, or sheathing attached to these vertical members.

The response of these building systems under earthquake loads and, in particular, the contribution of portions of the building system not specifically designated by the design engineers to resist earthquake loads are not well understood. It is notable that two recent system-level CFS test programs were conducted to analyze the seismic structural performance in mid-rise buildings, however, these tests showed a unique behavior that requires further study. Two important factors were identified: 1) the full impact of architectural finishes, both exterior and interior on CFS wall systems, and 2) the impact of gravity framing and all other framing that is along the same wall line as the lateral force resisting system. The over strength provided by the non-seismic wall and/or finish elements is now known to be crucially important to behavior, however it has not been well characterized experimentally and there are not validated engineering tools to predict this response. In this project, a series of experiments and complementary numerical modeling to characterize the relationship between the designated lateral force resisting system, i.e., the shear walls, and the complete CFS building system response, including the impact of the gravity walls, finish materials, and interior partitions, during seismic events. To this end, a building-block type experimental program is planned, whereby the seismic performance (1) in-line wall systems and (2) diaphragm-wall systems, are investigated using full-scale shake table tests. The culmination of this program (phase 3) will involve a mid-rise full-scale building shake table test.

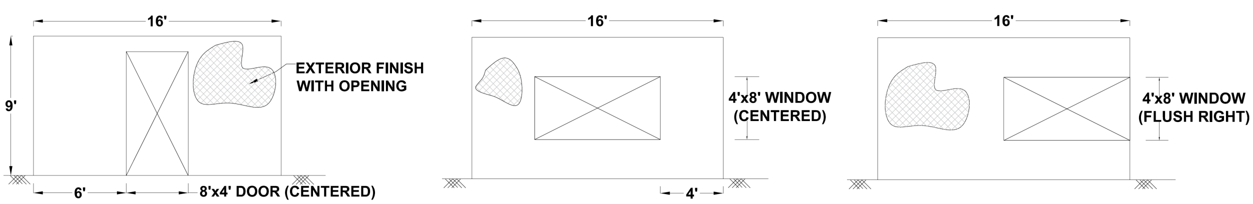
Phase 1: In-Line Wall Shake Table Tests

The seismic resistance of repetitively framed structures is unique due to the large over-strength and the significant contribution of non-designated systems in the lateral response. For this first phase of experiments, a set of models de-constructing the building into wall lines and separate components will be conducted to provide unique information in understanding benchmark full-scale systems. For the first set of experiments within phase 1, two suites of in-line walls will be tested. The details of these suites are provided in Figures 1 and 2. Suite 1 of experiments examine the effect of location and size of opening on the lateral resistance of CFS-framed walls (shear/gravity) provided with or without an exterior finish. Various configurations of walls to be tested are shown in Figure 1. Lateral load sharing between shear walls and gravity walls is examined in Suite 2 of this phase of experiments. Figure 2 shows the different configurations of combination of shear and gravity walls to be tested. Multiple walls will be tested simultaneously under dynamic loading on the shake table as shown in Figures 3 and 4.

The deformation of the walls and tie rods will be monitored with displacement transducers and strain gauges, and the accelerations of the specimen at the inertial mass level will be measured with accelerometers.

Phase 1 tests are scheduled for June and July 2018 (Figure 5).

Suite 1	Specimen	Length (ft)			Finish	Gravity load	Comments
		L_{SW}	L_{GW}	L_{total}			
Wall with openings	WO-1	0	12	12	none	heavy	16'L with 8'x4' (HxW) (door) opening
	WO-2	0	12	12	F1	heavy	16'L with 8'x4' (HxW) (door) opening (ext finish)
	WO-3	0	8	8	F1	heavy	16'L with 4'x8' (HxW) (window) opening (ext finish) [window centered]
	WO-4	8	0	8	F1	heavy	16'L with 4'x8' (HxW) (window) opening (ext finish) [window centered]
	WO-5	12	0	12	none	heavy	16'L with 8'x4' (HxW) (door) opening
	WO-6	12	0	12	F1	heavy	16'L with 8'x4' (HxW) (door) opening (ext finish)
	WO-7	0	8	8	F1	heavy	16'L with 4'x8' (HxW) (window) opening (ext finish) [window end]
	WO-8	8	0	8	F1	heavy	16'L with 4'x8' (HxW) (window) opening (ext finish) [window end]



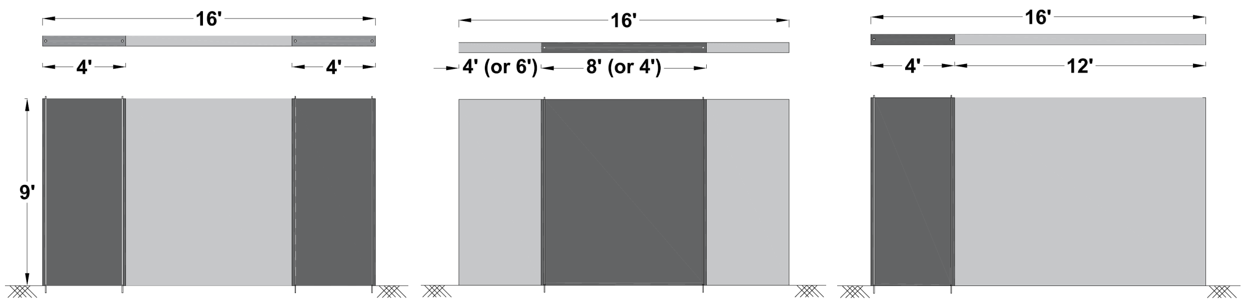
a) Door opening

b) Window opening (centered)

c) Window opening (end)

Figure 1: Phase 1: Inline Wall Experiments – Suite 1 Details

Suite 2	Specimen	Model Type	Length (ft)			Finish	Gravity load	SW details	GW details
			L_{SW}	L_{GW}	L_{total}				
Combination of Shear and Gravity Walls	CW-1	End SWs (type 1)	4	8	16	none	heavy	Type 1	a
	CW-2	End SWs (type 2)	4	8	16	none	light/heavy	Type 2	a
	CW-3	End SWs (type 1)	4	8	16	F1	heavy	Type 1	a
	CW-4	Middle SWs	4	6	16	none	heavy	Type 1	a
	CW-5	Middle SWs	4	6	16	F1	heavy	Type 1	a
	CW-6	Middle SWs	8	4	16	none	heavy	Type 1	a
	CW-7	Asymmetric (SW)	4	12	16	none	light/heavy	Type 1	a
	CW-8	Asymmetric (SW)	4	12	16	F1	heavy	Type 1	a



a) End SWs b) Middle SWs c) Asymmetric SW

Figure 2: Phase 1: Inline Wall Experiments – Suite 2 Details

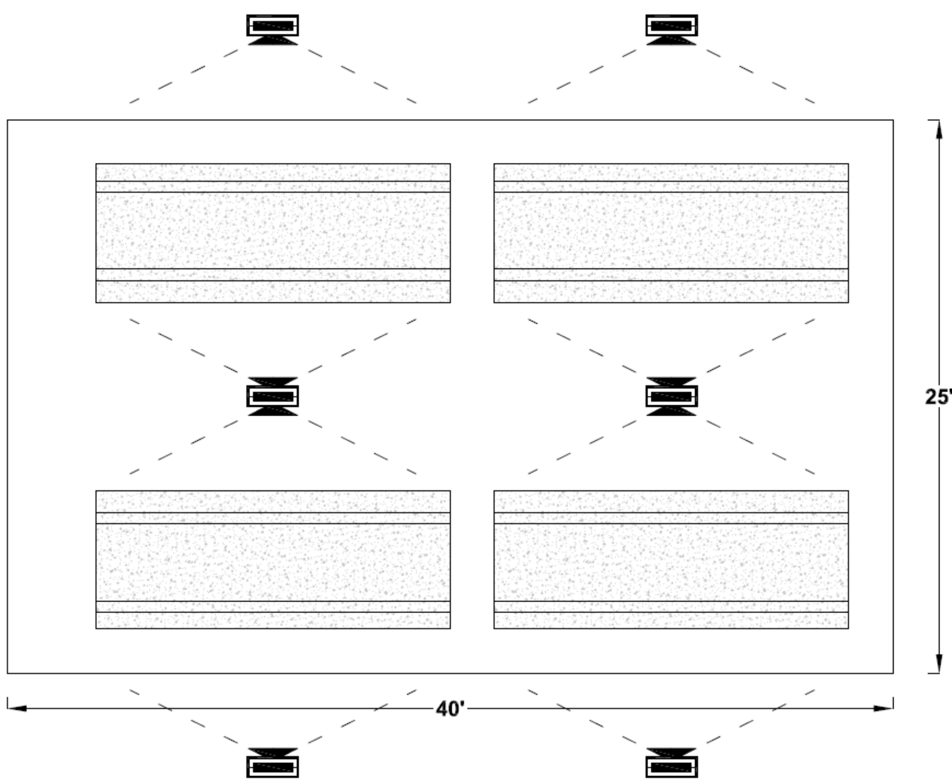


Figure 1: Plan View of test setup for suite 1 and 2 (pairs of specimen are identical) atop the NHERI@UC San Diego shake table

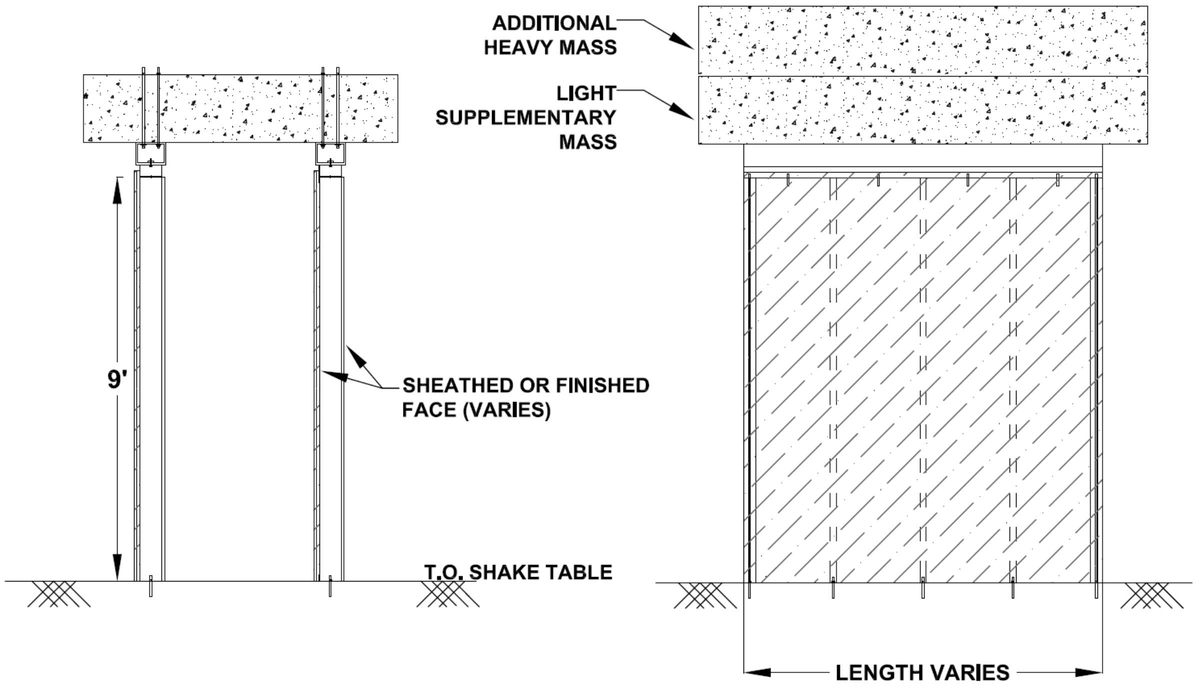


Figure 2: Elevation View

		Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8
Suite 1	Specimen Setup	■		■					
	Instrumentation	■	■	■	■				
	Testing & Data Analysis		■		■				
	Spec. Demo & Removal		■		■				
Suite 2	Specimen Setup					■		■	
	Instrumentation					■	■	■	■
	Testing & Data Analysis						■		■
	Spec. Demo & Removal						■		■

Figure 3: Phase 1: Test schedule for two suites of in-line wall specimens (June 2018 - July 2018)

Phase 2: Diaphragm-Wall Shake Table Tests

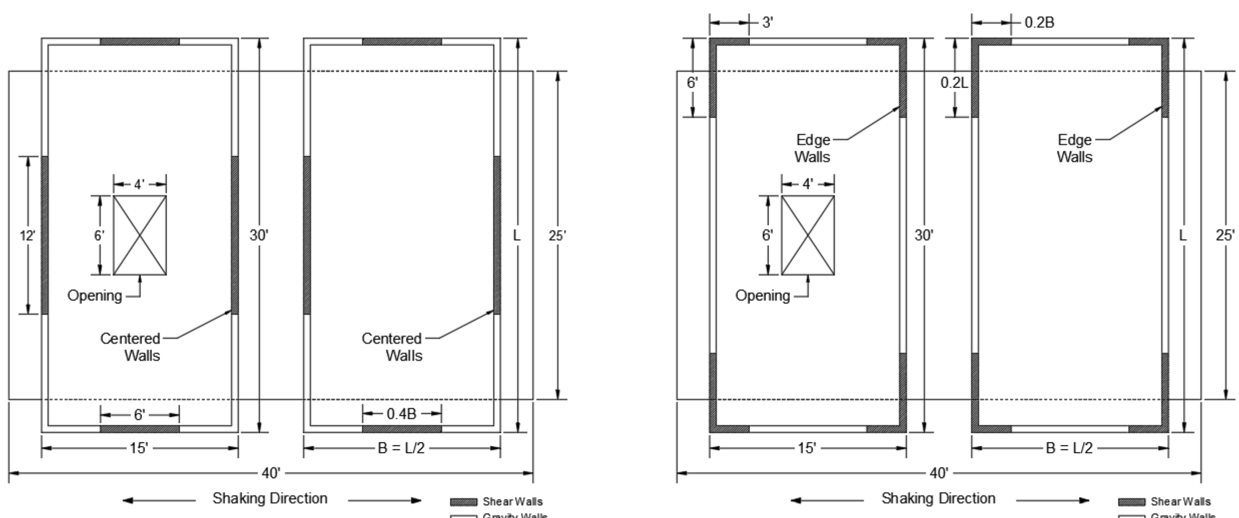
Examination of the diaphragm alone in prior full-scale system-level CFS tests has demonstrated that its rigidity can be very different than what the engineer assumes in design. The interaction of the diaphragm with walls and/or finish elements deserves additional study so that the flow of forces from the diaphragm to the lateral force resisting systems can be better understood.

In this phase, experimental and numerical studies will be carried out to quantify: (1) the influence of walls on load distribution; (2) the influence of openings and shear wall placement; and (3) the influence of higher mass and higher stiffness in the diaphragm system.

As such, the second phase of this program will involve shake table testing of eight full-scale floor/roof diaphragms tested under destructive and non-destructive ground motions on the outdoor shake table at the UC San Diego NHERI site. As is shown in Figure 6, the main parameters to be investigated are the location of shear walls and gravity walls, the presence of openings, and three different floor systems. Deformation of the diaphragm system will be monitored with displacement transducers and strain gauges, and the accelerations of the specimen will be measured with accelerometers.

These tests are scheduled to be carried out in a six week time period between November and December 2018. The test schedule for the various specimens is shown in Figure 6.

Structural system	Joist spacing	Shear Walls	Opening
OSB sheathing on CFS joists	~2'	centered	yes
CFS deck on CFS joists (composite or non-composite)	~2'	centered	yes
		centered	no
		edge	yes
		edge	no
Fiber cement board on CFS joists	2-4'	centered	yes
		centered	no
		edge	yes



a) Centered shear walls; opening/ no opening

b) Edge shear walls; opening/ no opening

Figure 5. Phase 2: Plan view of diaphragm-wall specimens

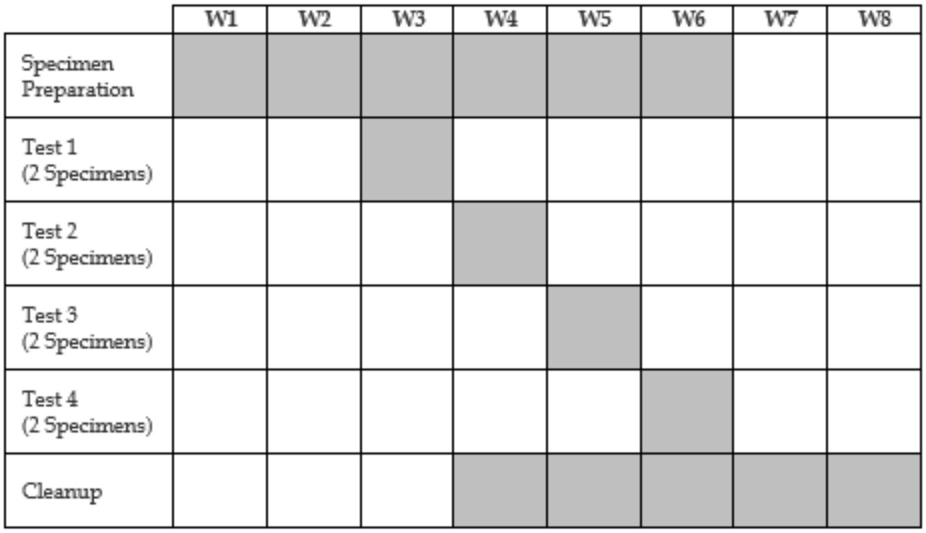


Figure 6. Phase 2: Diaphragm-wall test schedule

Payload Project Opportunities

The shake-table tests provide payload research opportunities, which could be supported by the NSF. Examples of possible payload projects include the deployment and validation of innovative sensing and measuring technologies for motion and damage evolution tracking. Interested researchers may contact the project team members: Dr. Tara Hutchinson, Dr. Benjamin Schafer, or Dr. Kara Peterman at tara@ucsd.edu, schafer@jhu.edu, or kdpeterman@umass.edu for any information needed for their payload project planning and proposals to the NSF.

Sponsors

This project is sponsored through NSF (CMMI #1663569), Steel Framing Industry Association (SFIA) and American Iron and Steel Institute (AISI). Support for conducting experiments at the UCSD NHERI facility are provide by NSF (CMMI #1520904).