CFS NEES

Advancing Cold-Formed Steel Earthquake Engineering

ABSTRACT

NSF 09-524 NEESR Proposal 1041578

NEESR-CR: Enabling Performance-Based Seismic Design of Multi-Story Cold-Formed Steel Structures

This award is an outcome of the National Science Foundation (NSF) 09-524 program solicitation ''George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) Research (NEESR)" competition and includes Johns Hopkins University (lead institution) and Bucknell University (subaward). This project will utilize the NEES equipment site at the University of Buffalo, which enables testing of full-scale buildings under simulated earthquake ground motions. The project team is strengthened by collaboration with Canadian supported researchers at McGill University, and by the engagement and support of industry facilitated by the American Iron and Steel Institute (AISI) and Bentley Systems. The research associated with this award will increase the seismic safety of buildings that use lightweight cold-formed steel for the primary beams and columns, and will greatly enhance the ability of engineers to account for complete building performance in predicting the response of these buildings to earthquakes.

The metal stud, produced from folding sheet steel (about 1mm thick) typically into the shape of a "C", is used in far more buildings than commonly realized and new NSF research will improve how we understand the performance of buildings made from these materials when they experience earthquakes. When you decide to design an entire building, using thin sheet steel for the backbone, you have to take on some special responsibilities. The behavior of these lightweight cold-formed steel members is in the realm of structural engineering known as thin-walled structures. The cold-formed steel structural (building) engineer must understand how and when buckling of their thin-walled steel members occurs, at the same time, they learn to account for the remarkable post-buckling strength and strength-to-weight characteristics of these members. This research award is aimed directly at providing cold-formed steel structural engineers with next-generation computer modeling tools and advancing fundamental knowledge so the engineers can predict behavior of these buildings under earthquakes without resulting to overly simplistic assumptions about behavior which can lead to wasteful, inefficient designs.

To solve this complicated problem the research team will reduce the behavior of cold-formed steel buildings down to its basic elements and then build it back up again. Through testing and computer modeling they will explore each piece (a beam, a column) then each system (walls, floors) then how systems interact with one another, then finally whole buildings. This final, whole building, stage will be conducted at the special NSF sponsored laboratory for earthquake engineering at the University of Buffalo, and will be the first time a complete, full-scale, cold-formed steel building has been tested. At each stage the knowledge generated will be utilized to improve computer modeling capabilities, and to expand design guidelines available to cold-formed steel structural engineers.

It takes an enormous effort to study buildings at this level of detail and a large number of people are contributing at all levels. The research project team will include professors, technicians, graduate students, undergraduate students, and even high school researchers who will join in the effort from Baltimore Polytechnical High School. Numerous professional engineers will be involved, including those from DEVCO Engineering, who will assist in designing the prototype buildings that will be tested. These people combined with the support of NSF and the assistance of AISI will work for the next 3 years to advance seismic structural safety of cold-formed steel buildings. Data from this project will be archived and made available to the public through the NEES data repository. This award is part of the National Earthquake Hazards Reduction Program (NEHRP).


photo credit Don Allen

Research Activities

	Experiment	Computational modeling High fidelity	 High efficiency	AISI Spec.[4] Design target
Component				
Stud, joist, track	(1)	(1)	CM-1	S100
Sub-system				
Stud-to-track / joist-to-rim	EXP-1	(1)	CM-2a	S211 / S210
Stud-to-wall / joist-to-floor	(1)	(1)	CM-2b	S211 / S210
Systems				
Gravity walls	(1)	(1)	(1)	S211
Shear walls	(2)	CM-3a	(2)	S213
Floor / roof diaphragms	(3)	CM-3b	CM-4a	S210
System interactions				
Gravity and shear walls	EXP-2	CM-3c	CM-4b	S211 / S213
Walls with diaphragms	EXP-3	CM-3d	CM-4c	S211 / S210
Multi-story walls	McGill[5]	CM-3e	McGill[5]	S213
Multi-story building				
LFRS only	EXP-4a	CM-5a	CM-6a	TBD
All Structural	EXP-4b	CM-5b	CM-6b	TBD
Whole Building	EXP-4c	-	CM-6c	TBD
Incremental Dynamic Analysis	-	-	CM-7	TBD

(1) Prior research by PI Schafer et al. see sections 6.1.1 and 6.2.1 covers this area and will be utilized by the team

(2) Prior research by Int'l. Collaborator Rogers et al. see section 6.1.2 covers this area and will be utilized by the team

(3) Prior research in cold-formed steel literature see section 6.1.3 covers this area and will be utilized by the team

(4) AISI Spec.'s for Cold-formed Steel design, e.g., S100 = AISI-S100-07, S2XX refer to the AISI COFS Standards

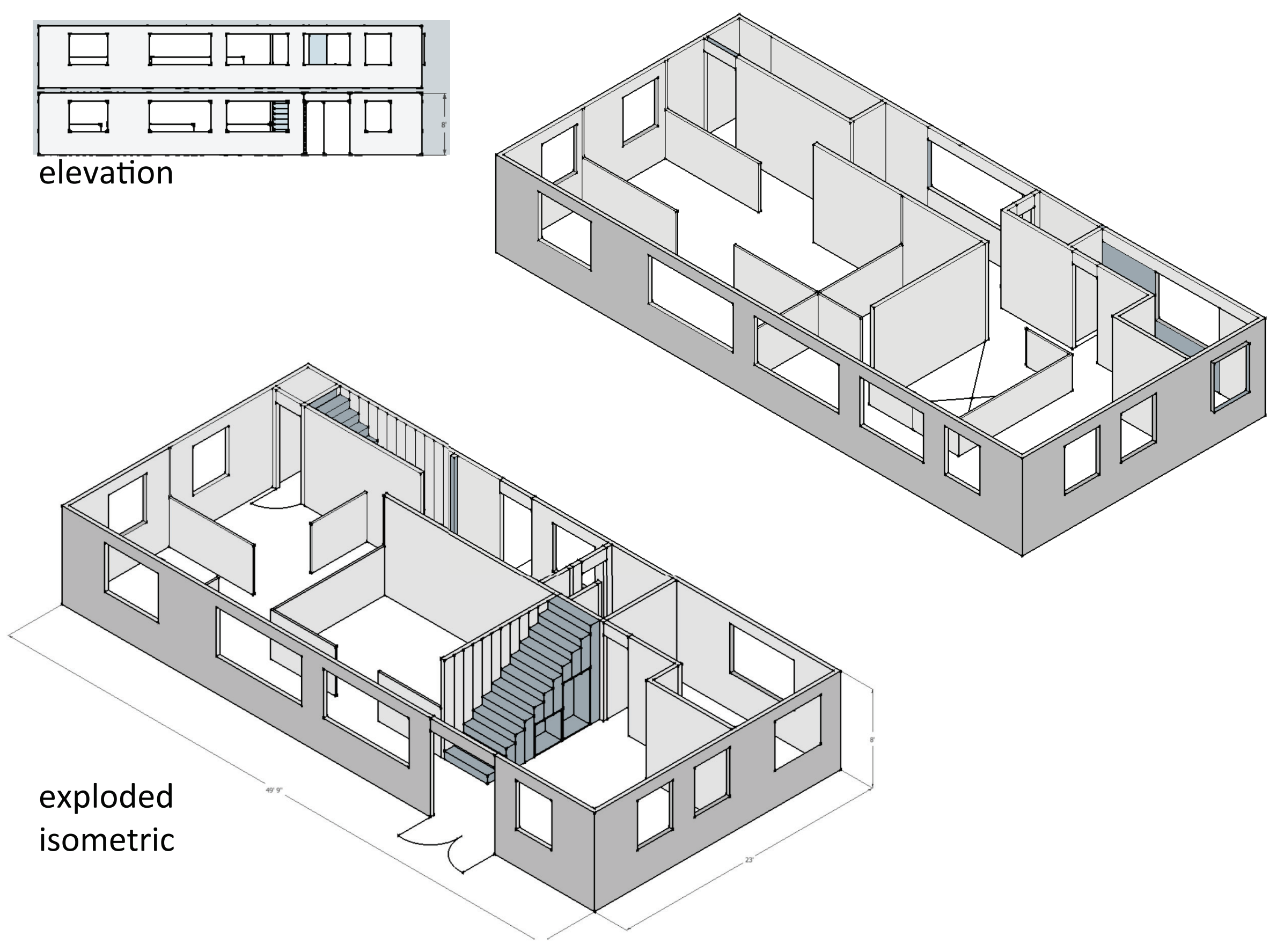
(5) Current NSERC research of Rogers on multi-story shear walls, is integrated into the project tasks

TBD = To be determined, final target for system level seismic design could be AISI-S110, S213 or other standards

EXP = Experimental modeling task CM = Computational modeling task

Multi-story CFS building

(Architectural only)



Project Relation to Existing NEES Research

While this project makes the case that cold-formed steel requires separate treatment, this is not to say that related wood research has no bearing on the work performed herein. In particular the CUREE-Cal Tech Woodframe Project (www.curee.org/projects/woodframe) and the current NEESWood (www.engr.colostate.edu/NEESWood) project are important contributors to the overall state of knowledge for low-rise repetitively framed construction.

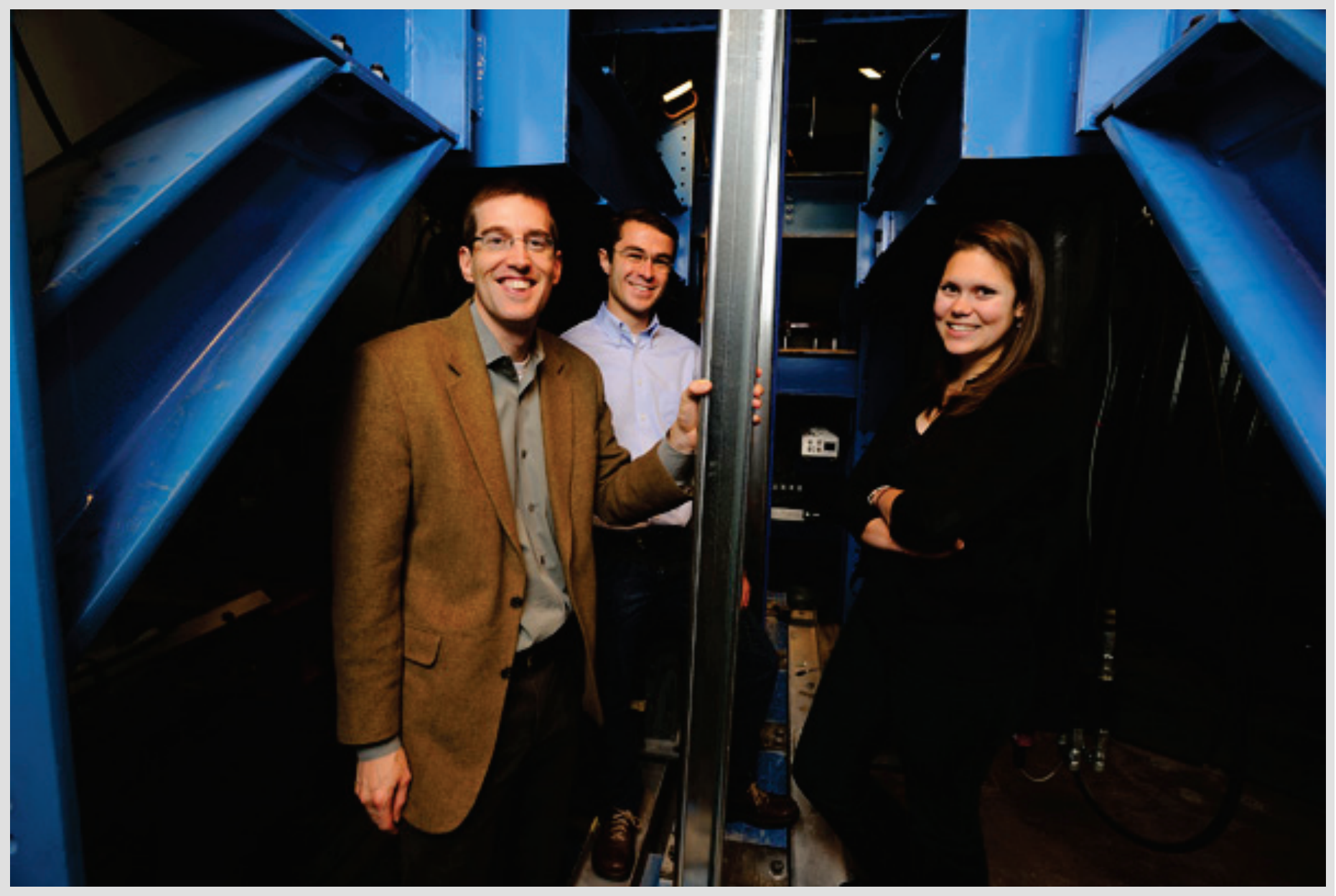
Earlier work developed nonlinear models for wood shear walls that share some features in common with reduced order models needed for cold-formed steel shear walls (Easley, Foomani et al. 1982; Gupta and Kuo 1985). These models have been continuously improved upon (Folz and Filiatrault 2001; 2004; 2004b; Judd and Fonseca 2005), and formal reliability efforts initiated (Rosowsky 2002; van de Lindt and Walz 2003; Li and Ellingwood 2007). Summaries of the full body of work are available (van de Lindt 2004). Whole building models have been created to examine load sharing (Kasal, Collins et al. 2004), though the fidelity of these models is not as high as envisioned herein. The NEESWood shake table tests at UB-NEES by Filiatrault et al. (2010) form the basis for the whole building tests proposed herein and the 3D modeling of van de Lindt et al. (2010) demonstrates the current state of the art for modeling wood-framed construction.

The recent NEESWood capstone testing in Japan provides an intriguing simulation target for the modeling proposed herein, but is not the focus here. Finally, in addition to the NEESWood project the NEES nonstructural project (www.nees-nonstructural.org) involves cold-formed steel in much of the planned testing, and provides a general framework for the integration of testing and modeling of secondary systems in OpenSees and their use in whole building models; a task that this project also shares in many respects.

GENERAL INTEREST

'Shaky' plan: Earthquake study could lead to sturdier buildings

JHU Gazette
December 13, 2010
By Phil Sneiderman


Ben Schafer with grad students Luiz Vieira and Kara Peterman in the lab where he is studying how seismic forces affect mid-rise cold-formed-steel buildings. Photo: Will Kirk/Homewoodphoto.jhu.edu

Cold-formed steel has become a popular construction material for commercial and industrial buildings, but a key question remains: How can one design these structures so that they are most likely to remain intact in a major earthquake?

To help find an answer, Johns Hopkins researchers have been awarded a three-year $923,000 National Science Foundation grant to study how seismic forces affect mid-rise cold-formed-steel buildings, up to nine stories high. The work will include development of computer models as well as testing of two-story buildings placed atop full-size "shake tables" that replicate forces up to and greater than those of any modern-day earthquake.

Lead researcher Benjamin Schafer of the university's Whiting School of Engineering said that there is a critical need for the data these experiments should yield.

"We do have a conservative framework for how to build cold-formed-steel structures to withstand earthquakes, but we don't have all of the details," said Schafer, the Swirnow Family Scholar, professor and chair of the Department of Civil Engineering. "Beyond avoiding complete collapse, we don't know how a lot of building materials will be damaged when certain levels of earthquakes occur. Information gaps exist for a lot of building materials, but the gaps for cold-formed steel are really big. We're trying to fill in some of those gaps in knowledge."

The cold-formed-steel pieces that are commonly used to frame low- and mid-rise buildings are made by bending about 1-millimeter-thick sheet metal, without heat, into structural shapes. These components are typically lighter and less expensive than traditional building systems and possess other advantages. For example, cold-formed-steel pieces are more uniform than wooden components and do not share wood's vulnerability to termites and rot. Cold-formed steel also is considered a "green" material because modern producers use 100 percent recycled metal.

Structural engineers who design cold-formed-steel buildings need more information about how the material will perform during earthquakes, Schafer said, in part because of revised thinking in the construction industry. "The old approach was to just make sure the building didn't fall down in an earthquake, even if it was no longer safe or was too badly damaged to be used afterward," he said. "Now, we're focusing on what you can do to bring it up to a higher level of performance to make sure that the building can still be used after an earthquake, when desired."

Some of the motivation for this is coming from the insurance companies and business owners who are economically tied to such structures. If a critical warehouse or a major customer service center can continue to operate after an earthquake, the business owners will likely incur lower losses. "For this reason, a sturdier building can lead to lower insurance rates and provide a level of business confidence for certain owners," Schafer said.

But how can a business owner or insurance company predict how well a cold-formed-steel building will stand up to an earthquake? Current estimates rely on a technique that tests how quakelike forces affect a single portion of a wall. Schafer's study, in contrast, will treat the structure as a full system that includes complete walls, floors, roofs, interior walls and exterior finishes, all of which can contribute to how well the building stays intact when severe shaking occurs.

To compile this data, Schafer and his colleagues will test building components in a structural engineering lab at Johns Hopkins. They will also develop computer models aimed at predicting how well these building components and structural designs will resist earthquake forces. In the third year of the study, the researchers will conduct full-scale building experiments at the Network for Earthquake Engineering Simulation equipment site at the University of Buffalo, State University of New York. This site has full-size shake tables that will allow the researchers to mimic the effect of an earthquake on various configurations of multistory cold-formed-steel-framed buildings.

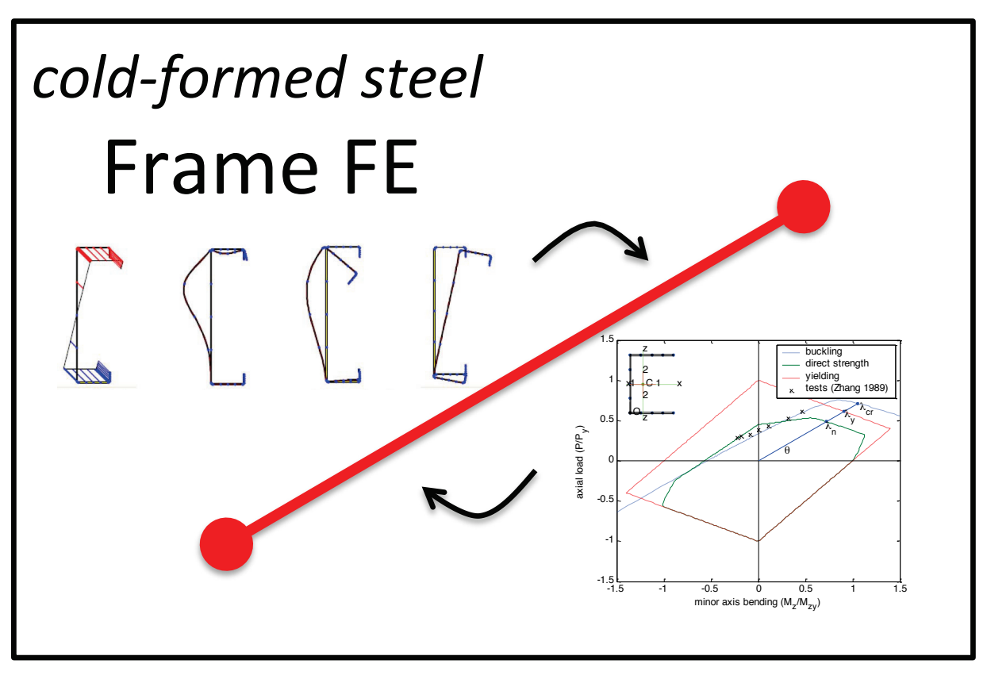
"We will attempt to 'fail' the buildings," Schafer said, meaning that the level of shaking will increase until the buildings collapse. The goal will be to find structural designs that hold up at the level of the most severe modern-day earthquakes.

"The ultimate purpose of this project," he said, "is to give structural engineers better tools to make predictions about what will happen to cold-formed-steel buildings in an earthquake. That will give them more flexibility to design the whole building and will give them the validation to know that it will stand up to a certain magnitude of earthquake forces."

Schafer's collaborators in the study include Narutoshi Nakata, an assistant professor of civil engineering at Johns Hopkins; a Bucknell University team led by Stephen G. Buonopane, an associate professor of civil and environmental engineering, who earned his civil engineering doctorate at Johns Hopkins; researchers from McGill University in Canada; and professional engineers from Devco Engineering, based in Oregon. Additional funding and support will be provided by the American Iron and Steel Institute and by Bentley Systems, a developer of engineering software.

As part of an outreach effort, students from Johns Hopkins, Bucknell and Baltimore Polytechnical High School also will take part in the research project.

For more on the research project, go to www.civil.jhu.edu/cfsnees.



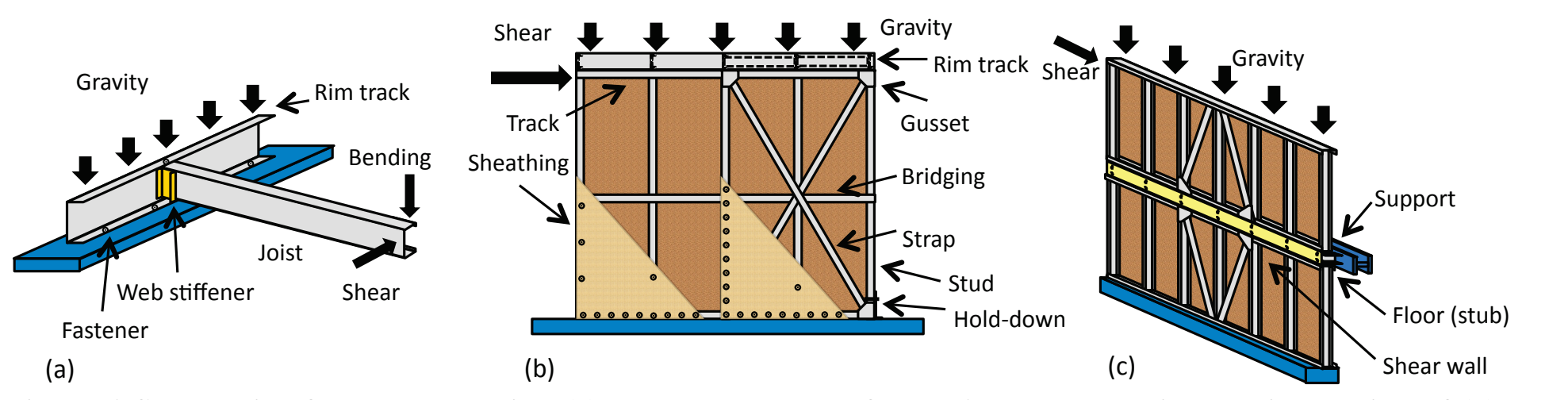
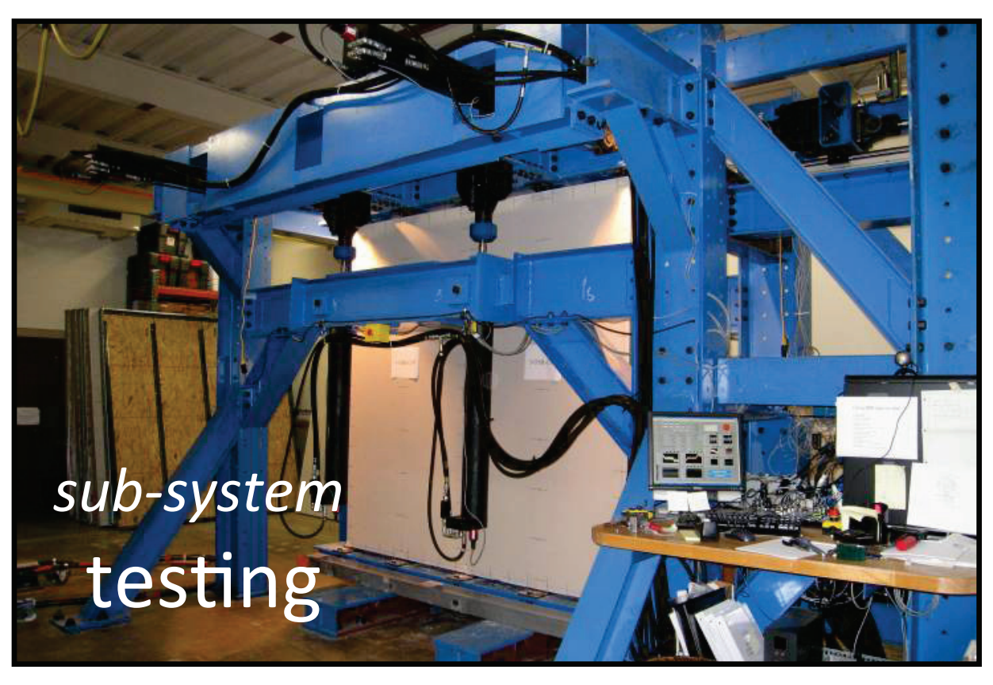


Figure 1 Schematic of proposed testing (a) sub-system tests of EXP-1, and system interaction testing of (b) a wall line with gravity and shear walls, EXP-2, and (c) a shear wall with floor detailing included, EXP-3



Modeling and Simulation

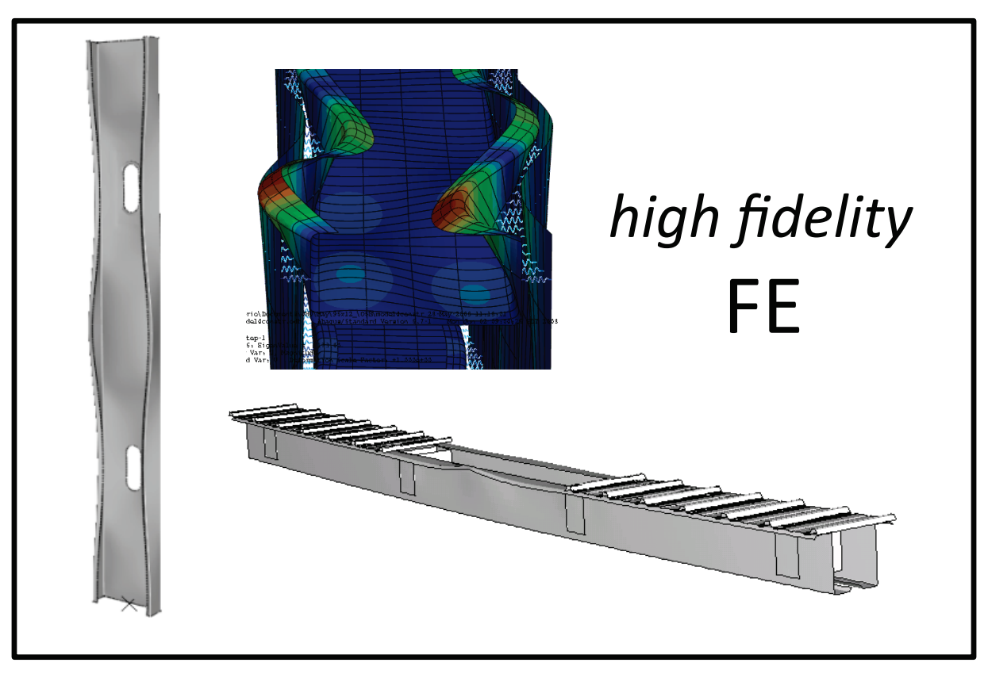
Advancing seismic structural safety and enabling performance-based design for lightweight cold-formed steel framed buildings requires that significant progress is made in computational modeling. As outlined in the Research Activities Summary Table the modeling research tasks build from the component scale up to the whole building and are divided into two classes: high fidelity, and reduced order models. The high fidelity models directly support the experimental tasks allowing local details (fastener demands, developed cross-section failure mechanisms, etc.) to be explored, and also providing the opportunity to extrapolate results. The reduced order modeling includes new element development, encapsulates the key features from the experimental testing, and enables efficient inelastic time history analysis.

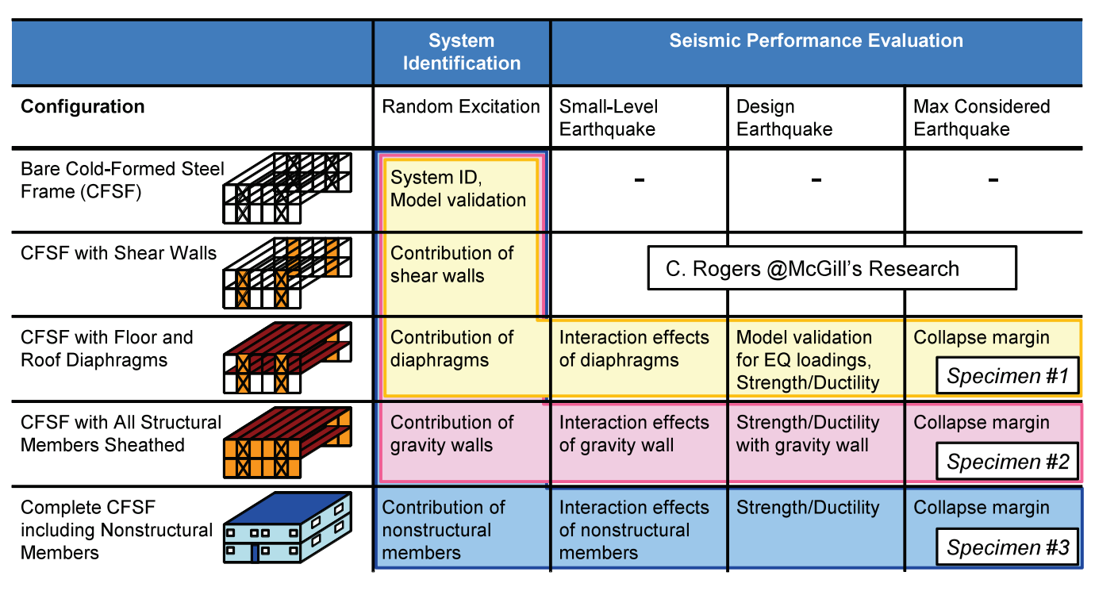
Expected Outcomes

The proposed research provides a means to understand fully how lateral forces are resisted in a cold-formed steel building including contributions beyond the designated LFRS. High-fidelity and reduced order models in ABAQUS and OpenSees respectively will be developed that allow the full variety of potential cold-formed steel systems to be explored. The advances in OpenSees will provide a means to consider the wider class of thin-walled structures under seismic hazards. By enabling reliable inelastic time history analysis for cold-formed steel buildings the promise of building specific performance-based design can be exploited. Further, the advances in experimental knowledge and modeling capability provide the needed building blocks to rationally develop traditional engineering methods (R, Ω_o, C_d).

Experimentation

Common lateral force resisting systems (LFRS) for consist of specifically detailed sheathed walls, and other systems (AISI-S213-07). The two system-level load paths into the LFRS are: (1) the floor diaphragm, and (2) the wall along the same framing line as the LFRS. Conventionally, one assumes the diaphragm and wall simply deliver forces to the shear wall, and collector elements are designed to enable this force transfer. However, the distribution of forces in an actual building deviate from this idealization. Advancing seismic structural safety requires that the secondary systems, repetitively framed floors and walls, which are in the load path for the LFRS be understood in far greater detail: planned experimental activities to this end span from sub-system, to system, to whole building, and culminate in full-scale tests at UB-NEES.





	System Identification	Seismic Performance Evaluation		
Configuration	Random Excitation	Small-Level Earthquake	Design Earthquake	Max Considered Earthquake
Bare Cold-Formed Steel Frame (CFSF)	System ID, Model validation	-	-	-
CFSF with Shear Walls	Contribution of shear walls	C. Rogers @McGill's Research		
CFSF with Floor and Roof Diaphragms	Contribution of diaphragms	Interaction effects of diaphragms	Model validation for EQ loadings, Strength/Ductility	Collapse margin *Specimen #1*
CFSF with All Structural Members Sheathed	Contribution of gravity walls	Interaction effects of gravity wall	Strength/Ductility with gravity wall	Collapse margin *Specimen #2*
Complete CFSF including Nonstructural Members	Contribution of nonstructural members	Interaction effects of nonstructural members	Strength/Ductility	Collapse margin *Specimen #3*


photo credit NEESWood

Sponsors, Affiliates, and Project Team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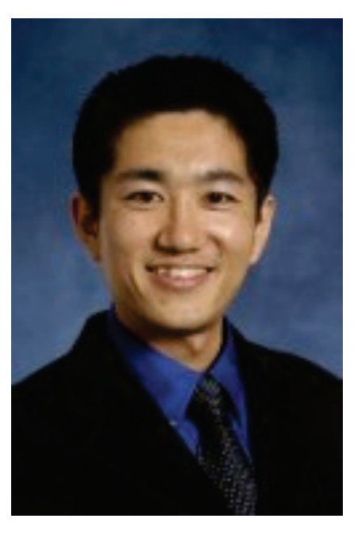
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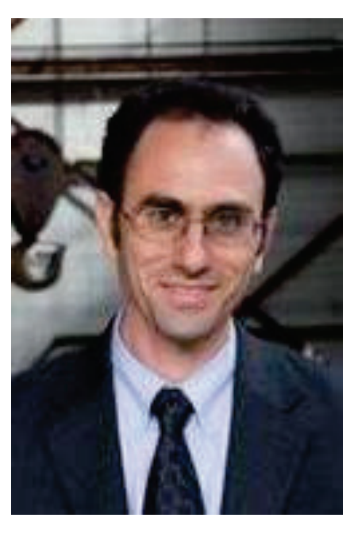
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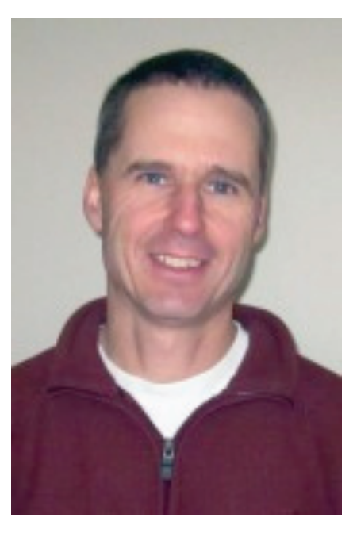
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