Eleventh U.S. National Conference on Earthquake Engineering
Integrating Science, Engineering & Policy
June 25-29, 2018
Los Angeles, California

INFLUENCE OF FIRE ON THE SEISMIC SHEAR CAPACITY OF COLD-FORMED STEEL SHEAR WALLS

B. Andres[1] and M. S. Hoehler[2]

ABSTRACT

Lightweight construction using cold-formed steel (CFS) studs represents roughly 20 % of the multi-story nonresidential building market in the United States. During an earthquake, these buildings rely on the performance of their lateral force-resisting system (LFRS). While there is extensive information about the structural performance and fire resistance of cold-formed steel construction, there is scarce knowledge about the performance of CFS-LFRS under combined hazards, such as mechanical and fire loading. Initial tests on earthquake-damaged steel-sheathed cold-formed steel shear walls under fire load (Phase 1) showed a change in failure mode from local to global buckling and highlighted the significance of the response of the gypsum on the overall fire and load-bearing behavior. A second phase of the project extends the study to multiple levels of fire severity and two additional CFS-LFRSs: (1) Oriented Strand Board shear panels, and (2) steel-strap braced cold-formed steel walls. Walls are tested under sequential mechanical and thermal loading. The mechanical loading setup is similar to ASTM E2126, and the fire load is provided by a natural gas burner located in a compartment placed next to the wall. Tests are performed at ambient conditions and under three fire loads representing (1) the ASTM E119 standard fire, (2) a severe fire, and (3) a mild fire. Results from this study are intended to provide data for a range of system performance under realistic conditions and will inform fire compartmentation design when significant lateral deformation of the building is anticipated, post-fire assessment to repair or replace a structure, as well as first responder decisions to enter a building when earthquake aftershocks are likely.

---

[1]Research Consultant, Danish Institute of Fire and Security Technology, Jernholmen 10, 2650 Hvidovre, Denmark (email: bav@dbi-net.dk)
[2]Research Structural Engineer, National Fire Research Laboratory, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899

Andres B, Hoehler M, Influence of fire on the seismic shear capacity of cold-formed steel shear walls. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

Influence of Fire on the Seismic Shear Capacity of Cold-Formed Steel Shear Walls

B. Andres[1] and M. S. Hoehler[2]

ABSTRACT

Lightweight construction using cold-formed steel (CFS) studs represents roughly 20 % of the multi-story nonresidential building market in the United States. During an earthquake, these buildings rely on the performance of their lateral force-resisting system (LFRS). While there is extensive information about the structural performance and fire resistance of cold-formed steel construction, there is scarce knowledge about the performance of CFS-LFRS under combined hazards, such as mechanical and fire loading. Initial tests on earthquake-damaged steel-sheathed cold-formed steel shear walls under fire load (Phase 1) showed a change in failure mode from local to global buckling and highlighted the significance of the response of the gypsum on the overall fire and load-bearing behavior. A second phase of the project extends the study to multiple levels of fire severity and two additional CFS-LFRSs: (1) Oriented Strand Board shear panels, and (2) steel-strap braced cold-formed steel walls. Walls are tested under sequential mechanical and thermal loading. The mechanical loading setup is similar to ASTM E2126, and the fire load is provided by a natural gas burner located in a compartment placed next to the wall. Tests are performed at ambient conditions and under three fire loads representing (1) the ASTM E119 standard fire, (2) a severe fire, and (3) a mild fire. Results from this study are intended to provide data for a range of system performance under realistic conditions and will inform fire compartmentation design when significant lateral deformation of the building is anticipated, post-fire assessment to repair or replace a structure, as well as first responder decisions to enter a building when earthquake aftershocks are likely.

Introduction

In recent decades, the building industry has reduced construction costs by using building typologies that use less material and require less time to construct compared to traditional methods. This has led to the increased use of pre-fabricated and lightweight framing systems. Today, lightweight frame structures represent the vast majority of single and multi-family residential housing in the United States [1], as well as a large proportion of the non-residential building market. Lightweight framing systems are commonly used as the primary structural system in single-story buildings. However, it is increasingly common to find lightweight framing systems used as structural elements in multi-story buildings [2]. In multi-story non-residential structures, lightweight frame structures represent 40 % of the U.S. construction market with approximately 20 % cold-formed steel (CFS) and 20 % timber; the remainder of the market being hot-rolled steel and concrete [3]. While only about 5 % of the cold-formed steel material is

---

[1]Research Consultant, Danish Institute of Fire and Security Technology, Jernholmen 10, 2650 Hvidovre, Denmark (email: bav@dbi-net.dk)
[2]Research Structural Engineer, National Fire Research Laboratory, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899

Andres B, Hoehler M, Influence of fire on the seismic shear capacity of cold-formed steel shear walls. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

used to construct the building's lateral force-resisting system (LFRS), the building relies on these systems to resist wind or earthquake loads. Over the past 30 years, extensive research has examined the structural performance and fire resistance of cold-formed steel construction [4–6]. There is, however, little information about the performance of CFS-LFRS [7] for cold-formed steel framed structures under combined mechanical and fire loading in spite of their increasing prevalence in the building market.

In 2016, a limited number of tests were conducted at the National Institute of Standards and Technology (NIST) National Fire Research Laboratory to characterize the response of earthquake-damaged CFS sheet-steel shear walls to fire [8]. The Phase 1 work was performed in conjunction with the project *Earthquake and Post-Earthquake Fire Performance of Mid-Rise Light-Gauge Cold-Formed Steel Framed Buildings* conducted at the University of California San Diego [9]. The results showed a change in failure modes in the walls from local to global buckling of the sheet steel, and highlighted the importance of the response of the gypsum on both the fire and structural behavior. Phase 2 extends the results to two additional types of CFS shear walls and two additional levels of fire exposure. The aim is to understand the thermal response of these systems to fires and characterize changes in the load-deformation behavior after various degrees of fire exposure and mechanical loading.

Experimental Program

The test program is designed to provide information about:

1. *Post-fire lateral capacity* - strength to withstand horizontal loads (wind, earthquake) after a fire;
2. *Post-earthquake fire behavior* - ability of the building to limit the spread of fire in the case of fire following earthquake; and
3. *Post-earthquake, post-fire lateral capacity* - residual lateral strength after a fire following earthquake event; e.g. an aftershock or another earthquake before repairs are made.

The study investigates the following CFS walls [2] designed according to AISI S400-15 [10]:

Type I: Steel-sheathed shear panels (similar to Phase I)
Type II: Oriented Strand Board (OSB) shear panels
Type III: Steel strap braced walls

The fire exposures were selected with a focus on risk associated with the severity of the fires:

1. *Ambient:* Baseline load-deformation behavior and lateral capacity.
2. *Standard ASTM E119* [11]*:* Characterized by a monotonic increase of temperature with time (Figure 1). Tests performed under standard ASTM E119 will target a 1-hour fire resistance rating.
3. *Severe Fire Exposure:* Designed to represent a post-flashover compartment fire which will compromise the structural capacity. Test results will provide information about failure mechanisms in fire damaged structures.
4. *Mild Fire Exposure:* This exposure also represents a post-flashover compartment fire, but with a lower maximum temperature and a short duration of the fire. Test results will help assess the impact of less severe fire on the structural capacity.

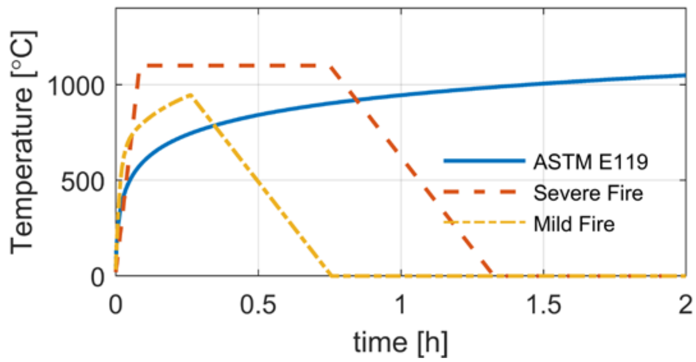

Figure 1. Temperature-Time Fire Curves.

The thermal load is achieved placing a compartment with a natural gas diffusion burner capable of generating fires up to 4 MW heat release rate next to the wall (Figure 2). The thermal exposure to the wall is monitored using: (1) two vertical thermocouple arrays placed in the compartment with nine bare-bead, K-type (Chromel-Alumel) thermocouples spaced 28 cm apart, (2) six plate thermocouples and, (3) two heat flux gauges. The cyclic mechanical loading follows ASTM E2126-11 Method C (CUREE Basic Loading Protocol). Horizontal and vertical displacements are measured on the corners of the shear walls, and the out-of-plane displacement is measured at the mid-upper point of the wall. Temperatures on the unexposed side and through the cross-section are recorded by K-type thermocouples. The test program is shown in Table 1. In ambient tests, walls are cycled mechanically until failure. In standard ASTM E119 and the severe and mild fires, the walls are mechanically cycles after the fire to assess for their residual strength. In the severe fires the walls are also mechanically loaded prior to fire exposure to pre-damage the walls and to assess the residual capacity in case of fire following an earthquake.

Table 1. Test Program.

Wall Type	**Specimen Name**	**Loading**		
		Cycling (before fire)	**Fire**	**Cycling (after fire)**
Steel sheathed	SB01	Cyclic until failure	-	-
	SB02	-	ASTM E119 (1-hour)	Cyclic until failure
	SB03	-	Severe	Cyclic until failure
	SB04	-	Mild	Cyclic until failure
Oriented Strand Board (OSB)	OSB01	Cyclic until failure	-	-
	OSB02	-	ASTM E119 (1-hour)	Cyclic until failure
	OSB03/OSB04	-	Severe	Cyclic until failure
	OSB05/OSB6/OSB7	3 Drift levels (0.5%, 1%, 1.5%)		Cyclic until failure
	OSB08	-	Mild	Cyclic until failure
Strap braced	S01	Cyclic until failure	-	-
	S02	-	ASTM E119 (1-hour)	Cyclic until failure
	S03/S04	-	Severe	Cyclic until failure
	S05/S06/S07	3 Drift levels (0.5%, 1%, 1.5%)		Cyclic until failure
	S08	-	Mild	Cyclic until failure

Figure 2. Mechanical and Fire Loading Test Setup [8].

Conclusions

The experimental program identifies specific potential failure modes and begins to quantify the loss of strength of cold-formed steel shear walls under a combination of earthquake load and fire exposure. Initial tests on earthquake-damaged steel-sheathed shear walls under fire load showed a shift in failure mode from local to global buckling of the sheet steel and highlighted the significance of the response of the gypsum on the overall fire and load-bearing behavior. The levels of drift prior to fire loading did not significantly reduce their post-fire mechanical resistance. The Phase 2 testing is ongoing. The data from this study can provide insight into seismic design and for fire compartmentation design when significant lateral deformation of the building is anticipated.

References

1. U.S. Department of Commerce. Characteristics of New Housing. 2015;
2. Madsen RL, Castle TA, Schafer BW. NEHRP Seismic Design Technical Brief No . 12 Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems A Guide for Practicing Engineers. (12). doi:10.6028/NIST.GCR.16-917-38.
3. Steel Framing Industry Association (SFIA). Market Share and Comparative Report,. 2016;
4. Sultan MA. A Model for Predicting Heat Transfer through Noninsulated Unloaded Steel-Stud Gypsum Board Wall Assemblies Exposed to Fire. Fire Technology [Internet]. 1996;32(1):239 – 257. Available from: http://link.springer.com/article/10.1007/BF01040217
5. Keerthan P, Mahendran M. Numerical modelling of non-load-bearing light gauge cold-formed steel frame walls under fire conditions. Journal of Fire Sciences. 2012;30(5):375–403. doi:10.1177/0734904112440688.
6. Takeda H. A model to predict fire resistance of non-load bearing wood-stud walls. Fire and Materials. 2003;27(1):19–39. doi:10.1002/fam.816.
7. Madsen RL, Castle TA, Schafer BW. Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems: A Guide for Practicing Engineers. Gaithersburg, MD: 2016.
8. Hoehler MS, Smith CM. Influence of Fire on the Lateral Load Capacity of Steel-sheathed Cold-Formed Steel Shear Walls - Report of Test. 2016.
9. Wang X, Hutchinson TC, Hegemier G, Gunisetty S, Kamath P, Meacham B. Earthquake and fire performance of a mid-rise cold-formed steel framed building – test program and test results: rapid release (preliminary) report (SSRP-2016/07). 2016;(December).
10. AISI S400-15, North American Standard for Seismic Design of Cold-Formed Steel Structural Systems. 2015;
11. ASTM International. ASTM E119-16a Standard Test Methods for Fire Tests of Building Construction and Materials. 2016; doi:http:// dx.doi.org/10.1520/E0119.