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Behavior of steel-sheathed shear walls subjected to seismic and fire loads

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ABSTRACT

A series of tests was conducted on six 2.7 m×3.7 m shear wall specimens consisting of cold-formed steel framing sheathed on one side with sheet steel adhered to gypsum board and on the opposite side with plain gypsum board. The specimens were subjected to various sequences of simulated seismic shear deformation and fire exposure to study the influence of multi-hazard interactions on the lateral load resistance of the walls. The test program was designed to complement a parallel effort at the University of California, San Diego to investigate a six-story building subjected to earthquakes and fires. The test results reported here indicate that the fire exposure caused a shift in the failure mode of the walls from local buckling of the sheet steel in cases without fire exposure, to global buckling of the sheet steel with an accompanying 35% reduction in lateral load capacity after the wall had been exposed to fire. This behavior appears to be predictable, which is encouraging from the standpoint of residual lateral load capacity under these severe multi-hazard actions.

1. Introduction

In June of 2016, experimental investigations of the performance of a six-story, cold-formed steel (CFS) framed building (Fig. 1) were conducted on the Large High-Performance Outdoor Shake Table (LHPOST) at the University of California, San Diego (UCSD). The building's lateral load resistance system consisted of cold-formed steel framing members sheathed by panels of sheet steel adhered to gypsum board. These and other light-weight construction material lateral load-resisting systems are widely used in seismic regions in the western United States, where they offer significant advantages in construction costs and speed. For information about the design and construction of these wall systems for seismic applications, interested readers are referred to the National Earthquake Hazards Reduction Program (NEHRP) document *Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems - A Guide for Practicing Engineers* [1]. The aim was to study the earthquake performance of this construction method for midrise structures (five to ten stories), as well as the earthquake-damaged building's response to fire. After the fire tests, additional earthquake shaking was conducted to study the response of the fire-damaged building to earthquake aftershocks. The aftershock test results were intended to help inform decisions about first-responder access to a building in the case of fire following earthquake, as well as repair versus replace assessments. Details about the six-story building tests are provided in [2].

The tests reported in this paper were conducted immediately prior to the six-story building shake table tests. The objective was to experimentally determine the influence of a specific fire load – the one to be used at UCSD – on the lateral load resistance of the investigated shear walls to help inform the selection of the earthquake motion intensities used in the UCSD tests before and after the fires. These tests enhanced the value of the full structure experiments and provide insight into multi-hazard interaction for this construction method.

2. Test program

The tests were conducted using six wall specimens at the National Fire Research Laboratory (NFRL) at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. Table 1 provides an overview of the test program. The specimens were subjected sequentially to varied combinations of mechanical (shear) deformation and thermal (fire) loading. Specimen 1 was used to establish the monotonic "pushover" load-displacement capacity of the wall system and subsequently to shake down the fire test setup. Specimen 2 was loaded by symmetric-amplitude reverse-cyclic shear deformation to destruction (defined here as 2.8% drift ratio) to establish the cyclic load-displacement response. Specimen 3 and 4

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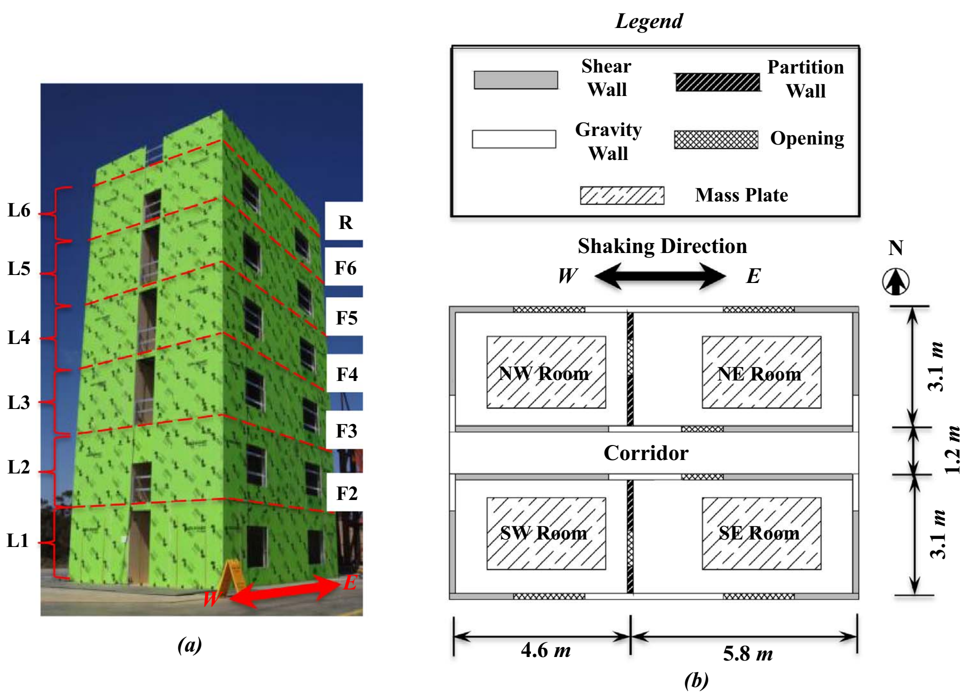

Fig. 1. Cold-formed steel framed building at the LHPOST facility: (a) Photograph of the building on the shake table (looking at south west corner); (b) Typical floor plan (after [2]).

Table 1
Test program.

Test name	Specimen	Description	Loading rate / Amplitude
CFS01a CFS01b	CFS01	Monotonic pushover 10 min burn	Push @ 2.54 mm/min Multiple steps to 1900 kW
CFS02	CFS02	Cycling to failure	1.52 mm/s
CFS03a CFS03b CFS03c	CFS03	Cycling to 1% drift 13 min 20 s burn Continue cycling until failure	1.52 mm/s Step to 1900 kW 1.52 mm/s
CFS04a CFS04b CFS04c	CFS04	Cycling to 1.8% drift 13 min 20 s burn Continue cycling until failure	1.52 mm/s Step to 1900 kW 1.52 mm/s
CFS05a CFS05b	CFS05	13 min 20 s burn Cycling to failure	Step to 1900 kW 1.52 mm/s
CFS06a CFS06b CFS06c	CFS06	Cycling to 1% drift 26 min 40 s burn Continue cycling until failure	1.52 mm/s Step to 1900 kW 1.52 mm/s

were cycled to deformations just before and after the peak load was achieved, respectively, burned for 13 min and 20 s and then cycling was continued until destruction of the wall. For Specimen 5, an undamaged wall was exposed to fire for 13 min and 20 s and then cycled to destruction. Specimen 6 was tested similarly to Specimen 3, however, the burn duration was doubled. The test program was intended to bound the effects of fire and earthquake shaking on the shear capacity of the walls.

2.1. Specimens

Six 2.7 m×3.7 m shear wall test specimens consisting of cold-formed steel framing sheathed on one side with sheet steel adhered to gypsum board and on the opposite side with plain gypsum board were fabricated. The walls were full-scale, and selected 1) to emulate a common geometry found in multi-residential building construction and 2) to approximate a shear wall along one side of the corridor on the 2nd floor of the UCSD six-story building (Fig. 1b). They were designed in compliance with current building code provisions within the American Society of Civil Engineers (ASCE) standard ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures* [3] and the American Iron and Steel Institute (AISI) documents AISI S100 *North American Specification for the Design of Cold-Formed Steel Structural Members* [4] and AISI S213 *North American Standard for Cold-Formed Steel Framing—Lateral design* [5]. Dimensional details of the test specimens are given in Fig. 2. Additional details can be found in [6].

All vertical framing members were 1.7 mm thick cold-formed steel studs (600S200-68) 152 mm wide with a flange width of 51 mm. The top and bottom tracks were 1.4 mm thick cold-formed steel channels (600T150-54) 152 mm wide with a flange width of 38 mm. The top and bottom tracks were drilled with two rows of 17.5 mm diameter holes at 305 mm on center (OC) to allow for attachment to the loading frame. All of the cold-formed steel sections were Structural Grade 50, Type H (ST50H) conforming to the American Society for Testing and Materials (ASTM) standards ASTM A653 [7] and ASTM A1003 [8] with a minimum specified yield strength of 345 MPa. All fasteners used to connect framing members were 19 mm long self-tapping, self-drilling sheet metal screws with shank diameter of 4.8 mm. The boundary elements (stud packs) were secured back-to-back with two rows of screws at 305 mm on center. All other joints had one screw where flanges met.

The side of the wall to be fire tested (corridor side) was sheathed with one layer of 2.7 m×1.2 m Sure-Board 200® panels which consisted of 0.686 mm thick sheet steel adhered to 16 mm thick type X gypsum board. The panels were attached with 45 mm long self-tapping, self-drilling sheet metal screws with shank diameter of 4.2 mm. The screw spacing was 76 mm on center on the board perimeter and 305 mm on center in the field. The opposite side of the wall (cold side) was sheathed with one layer of 2.7 m×1.2 m type X gypsum boards 16 mm thick. The panels were attached with 32 mm long self-tapping, self-drilling sheet metal screws with shank diameter of 4.2 mm. The screw spacing was 152 mm on center on the board perimeter and 305 mm on