東京理科大学「火災安全科学研究拠点」

Tokyo University of Science "Research Center for Fire Safety Science"

■研究成果概要報告書/ Report for Outline of Research Results

<table>
<tr><td colspan="2">研　究　課　題
Research Topic</td><td rowspan="2">Structural Fire Performance of Earthquake-Damaged Light-wood and Light-gauge cold-formed Steel Frames</td><td>実 施 年 度</td></tr>
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１． 研究の背景および目的／ Background and Aim of Research

Background

Post-earthquake fire performance of buildings is an important area of study when it comes to the resilience of the built environment in earthquake and its cascading hazards. Fire following earthquake is one of the major cascading hazard that is likely to occur during an earthquake. Although fire treated as a secondary hazard, its effects can sometimes be severely detrimental and may pose a threat to the life and property. As seen in multiple historical events such as San Francisco (1906), Kanto (1923), Hanshin (1995), Izmit (1995) and Fukushima (2011). However, some of the gravest incidents of fire following earthquake, where fire was the main damage causing earthquake are almost a century old. Many earthquakes in the past 30 years have reported small fires, large conflagrations and the fire whirls in their wake. One of the other reasons for an outbreak of fire in an earthquake is an increase in the ignition potential. Ignition sources, primarily gas and electric appliances have grown many folds over the years and remains a threat to cause large conflagrations. Lack of proper fire protection systems or their inability to function in an earthquake as well as a delay in the firefighting due to blocked streets and exits due to collapsed buildings, and loss of transportation infrastructure due to collapsed bridges force the structures to endure the fire. Most of the modern buildings constructed in earthquake prone zones adopt the strategy of reduction of the seismic weight during the design as it helps in performing better in earthquakes. However, this practice is likely a trade-off between seismic and fire performance of buildings. The light-weight materials such as light-gauge steel and wood (or timber) are known to perform poorly in fire. Additionally, the loss of fire protection systems or an insignificant structural damage in an earthquake may further affect the performance of the structures in fire. It is therefore imperative to study the structural response of earthquake damaged buildings in fire and estimate their collapse potential in the event of a post-earthquake fire.

Wood is regarded as an excellent material for construction in general as well as in earthquake prone zones due to wide availability, cost, extreme flexibility in renovation/reconstructing sustainability and light-weightiness. Wood is by far the most popular material used in the construction of residential and commercial buildings in the North America. Also, in recent years, there has been an increased use of an alternate building material, the cold formed steel (CFS). CFS framed building offer most of the structural advantages similar to wood. The main advantage of CFS over wood is its non-combustibility. CFS is used as a choice of building material in earthquake prone zones in many countries, including the USA. In Japan, residential timber construction analogous to the US is popularly known as two-by-four wood frame construction, which was popularized after its launch in 1974. However, the traditional construction Also, the birth of light-gauge steel construction is linked to construction of temporary housing in the wake of the Great Hanshin Earthquake, 1995 which further led to establishment of Kozai Club steel-framed house committee [1]. An added interest and expansion of light-gauge steel framed construction in the field of housing, public facilities, health and welfare facilities has also been expressed [2]. CFS is known for its strength, durability, stability, sustainability, non-combustibility and cost effectiveness over traditional material, wood. In Japan, CFS framed structures are regarded as quasi-fire resistant. CFS is also durable because of its inertness to rust, which makes it a suitable material for construction in all-weather zones. However, there is a sparse data set on the experimental performance of traditional wood framed structures and CFS framed structures in a sequential hazard situation, such as post-earthquake fire.

Aim of Research

The main objective of this study is to investigate the post-earthquake fire performance of light-wood and light-gauge cold-formed steel frames. Light-wood framing is commonly used building system in practice for residential structures across North America. In the recent years, cold-formed steel construction has become popular, which, unlike its wood counterpart is noncombustible. Light weightiness of these materials make them best suited for construction in the seismic zones since it helps in the reduction of seismic weight, which is to the advantage of building performance in earthquakes. However, earthquake engenders cascading hazards, and fire is one of the commonly reported event following an earthquake. Hence it is imperative to understand the building performance in such multi-hazard events. In the year 2016, three relevant projects on CFS framed construction were successfully completed in 2016 at NIST [3], UC San Diego [4-6] and Tokyo University of Science [7]. WPI's research team investigated the earthquake and post-earthquake fire performance of CFS framed construction at UCSD in summer 2016. A series of 7 seismic tests were conducted on the large outdoor shake table at UCSD on a 6-story cold-formed steel building. Given site restrictions, fire testing could not be conducted at a desired duration, or until structural failure. In parallel to this effort, Individual wall panel tests were conducted on damaged specimens at the National Fire Research Laboratory (NFRL) at NIST, Gaithersburg, MD to assess the structural fire performance of individual CFS panel systems. Furthermore, with the help of joint-usage grants from TUS, WPI conducted a full-scale test on loaded, undamaged CFS framed specimen in December 2016. However, the efforts at TUS in 2016 did not include the earthquake-damage component. The observations from the tests indicate that the frame reached a critical failure point much before its rated fire resistance under standard Temperature-time curve in response to a realistic fire load expected in natural fire scenarios.

In an interest to study the post-earthquake fire response, tests were conducted on light-wood and cold-formed steel framed test specimens by constructing the test specimens and loading them seismically at Building Research Institute (BRI), Tsukuba, and then transport to Centre for Fire Safety Science and Technology at TUS-Noda Campus, where, the damaged specimens were loaded to failure under the load in the *Multiple Horizontal Loading Full-Scale Furnace*.

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２．利用施設及び利用日/ Facility and Schedule

<u>**Facility**</u>

Seismic Loading (Pushover) Tests: Structural Composites Laboratory, Building Research Institute (BRI), Tsukuba

Pushover loading tests were conducted at BRI's Structural Composites Laboratory, where the lab space was used for fabrication of test specimens and the strong floor – reaction wall space was used for conducting the lateral load tests.

Fire Tests: Fire Research and Test Laboratory, Center for Fire Science and Technology, Tokyo University of Science (TUS), Noda Campus

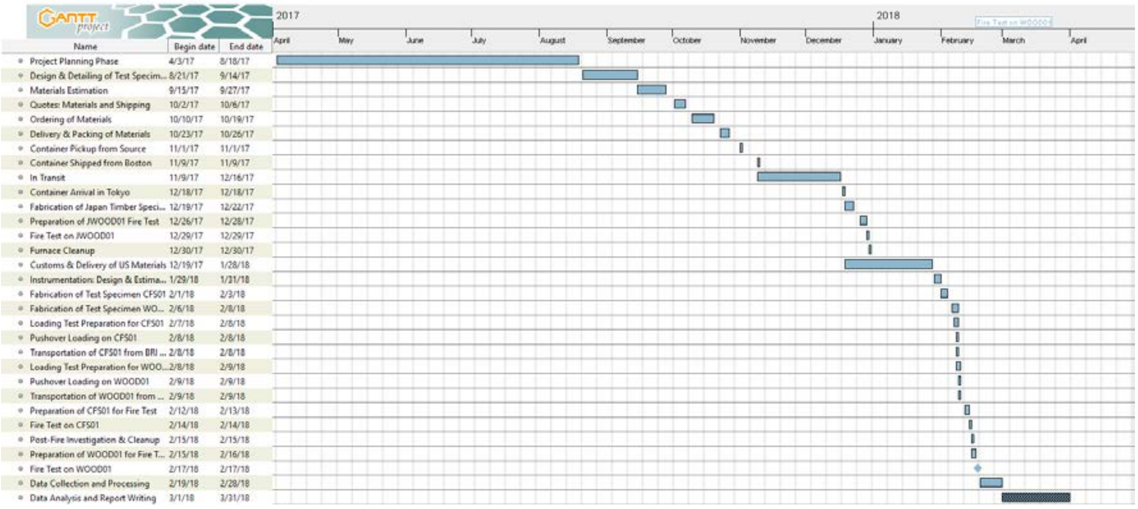
All the fire tests were conducted at TUS's Fire Research and Test Laboratory in Multiple Horizontal Loading Full-Scale Furnace (MHLFSF). With an external dimension of 7 m (W) x 10 m (D) x 6 m (H), the MHLFSF is capable of offering an internal heating area of 3 m (W) x 4 m (D) x 3.5 m (H). This dominated the specimen size.

<u>Schedule</u>

The seismic loading tests at BRI were conducted between 2018/02/03 and 2018/02/08

The furnace fire tests were conducted between 2018/02/08 and 2018/02/17.

The detailed schedule of the year's effort is presented below in the form of a Gantt chart.



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３． 実験方法・研究成果、および考察（申請時の計画に対する達成度合いも含む）

※継続課題の場合は，前年度との関係性，進展度合いについても記載すること。

/ Method, results, and conclusions (degree of achievement compare to application)

Test Specimen Design

The test specimens CFS01 and WOOD01 were specifically designed to achieve certain objectives. The main factors considered for the design of test specimen CFS01 are as follows:

- Repeatability of the tests conducted at UCSD.
- Repeatability of the tests conducted at NIST
- Size of the specimen based on the dimensions of the furnace
- Current practice of construction
- Proprietary construction (also in practice for shear walls)
- Fire rating

Refer WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report for further details.

Materials for the Test Specimens

nstruction of US test specimens.

Table 1 shows a quick list of materials used in the construction of US test specimens.

Table 1. Materials for test specimens

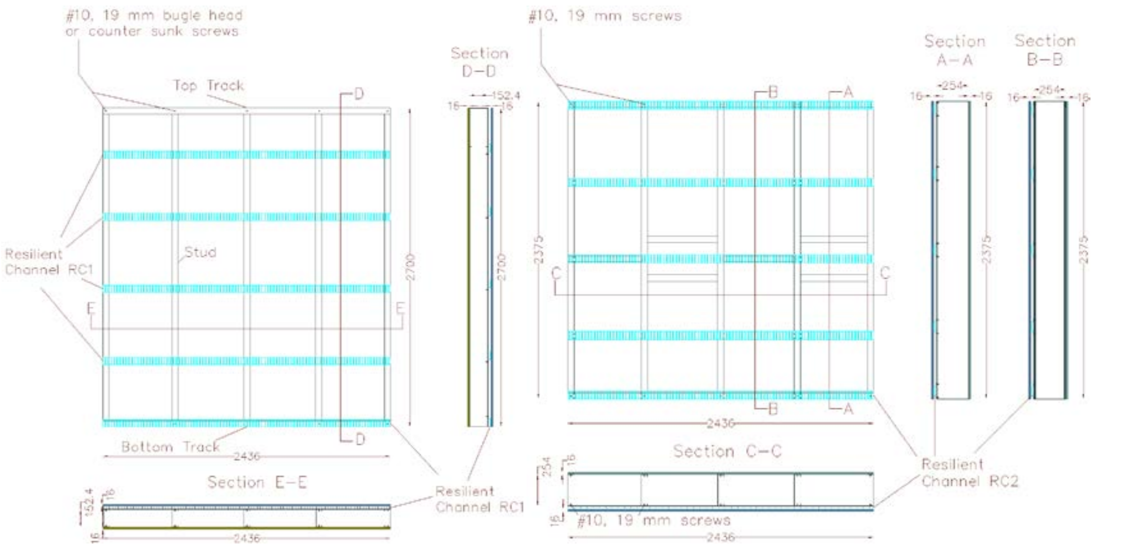
Wall System						
Material	**Internal Drywall**	**External Sheathing**	**Stud Spacing**	**Fasteners**	**Spacing**	**Connections (Sheathing)**
Dimensional Lumber Frame with Gypsum	Gypsum Board (Type-X)	Plywood	406 o.c.	Nails (16D and 8D)	300 o.c.	Drywall Screws (30 mm)
Light-Gauge Cold-Formed Steel Studs	Gypsum Board (Type-X)	Exterior Gypsum Board	610 o.c.	Self Drilling, Self Tapping Steel Screws (Pan Head)	300 o.c.	Self Drilling, Self Tapping Steel Screws (Pan Head)
Floor System						
Material	**Ceiling**	**Decking**	**Joist Spacing**	**Fasteners**	**Spacing**	**Connections (Decking)**
Dimensional	Gypsum	Plywood	406 o.c.	Nails (16D,	300 o.c.	Nails (16D and

Lumber Rim Joists and Floor Joists	Board (Type-X)			10D and 8D)		8D)
Cold-Formed Steel Rim Tracks and Floor Tracks	Gypsum Board (Type-X)	Steel-Gypsum Board Composite	610 o.c.	Self Drilling, Self Tapping Steel Screws (Pan Head)	300 o.c.	Self Drilling, Self Tapping Steel Screws (Pan Head)

Refer [WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report] for further details.

<u>Construction</u>

The test specimen CFS01 was designed considering repeatability of full-scale tests in UCSD and NIST. The test specimens were designed to represent an ideal exterior / interior wall test setup connected together with a diaphragm. The test frame consisted of two walls: one wall designed as an exterior wall and another wall designed as an interior wall. The size of both the wall panels was 8 ft (2436 mm) x 9 ft (2700 mm) as shown in the figure Figure 1 (a). The exterior wall (Wall A) was sheathed on the outside using water-resistant gypsum-based sheathing whereas the interior wall was covered with one-hour fire rated Type-X 5/8 in. (16 mm) gypsum board. The Interior wall (Wall B) was sheathed on the outside using composite shear panels. The panels were fabricated by gluing 20 ga Sheet steel to 5/8 in. Type-X gypsum wallboard using water soluble adhesive. The two wall panels were fabricated using 600S200-54 studs spaced at 24 in. (610 mm) and held together by 600T200-54 tracks. The two walls were joined together by a floor diaphragm of size 8 ft (2436 mm) x 7 ft 10 in (2375 mm) as shown in *Figure 1* (b).



(a) (b)

Figure 1. Framing for test specimen CFS01 (a) Wall (b) Diaphragm

The test specimen WOOD01 was designed to represent a typical 2 x 4 traditional wood framing residential construction in the United States. The traditional lumber test specimen was constructed using Spruce-Pine-Fir kiln-dried dimensional lumber. The walls were of size 8 ft (2436 mm) x 8 ft 1.5 in (2454 mm) and were framed using 2 in x 4 in (50 mm x 100 mm) wall studs pre-cut to build 8 ft walls spaced at 16 in (406 mm) on center as shown in *Figure 2* (a). The studs were connected to two 2 x 4 (50 mm x 100 mm) plates at the top and one 2 x 4 (50 x 100) plate at the bottom. The diaphragms were of size 8 ft (2436 mm) x 8 ft (2436 mm) constructed using 2 in x 12 in (50 mm x 300 mm) floor joists spaced at 16 in (406 mm) on center as shown in *Figure 2* (b). The floor joists were connected to the rim joists using joist hangers. The wall panels were sheathed using 15/32 in (12 mm) plywood panels on the exterior and 5/8 in (16 mm) Type-X gypsum wallboards on the interior. The Diaphragm panels consisted on 23/32 in (18.25 mm) plywood subfloor on the deck side and 5/8 in Type-X gypsum boards on the ceiling side.

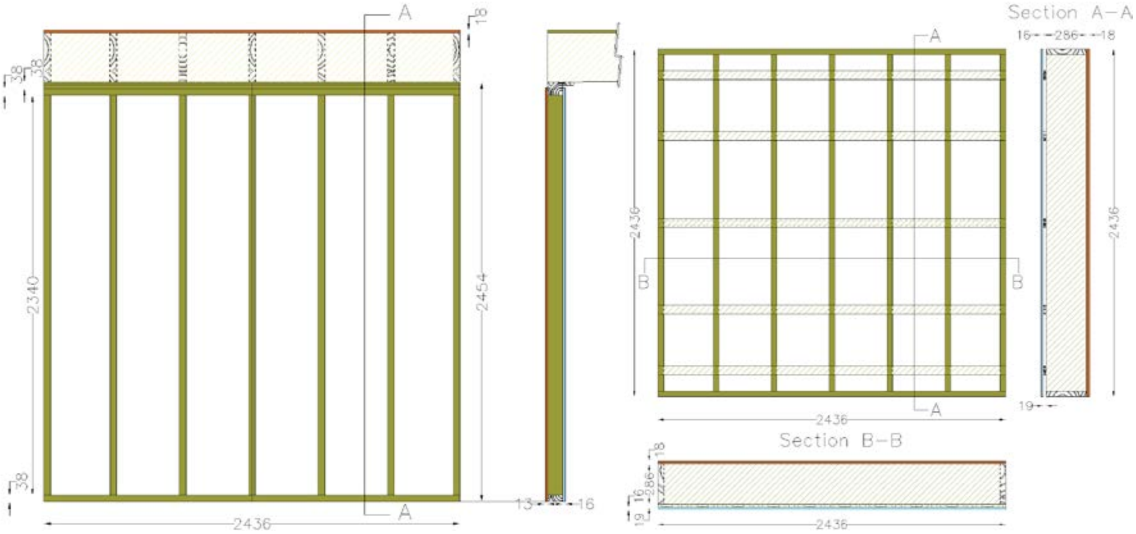


Figure 2. Framing for test specimen WOOD01 (a) Wall (b) Diaphragm

Refer WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report for further details.

Test Setup

Earthquake loading was the first phase of the test. The test specimens CFS01 and WOOD01 were imparted with quasi-static pushover loading to simulate the earthquake effects on the structure and induce damage to the test specimens. Once the specimens were constructed, they were moved to and attached to the foundation laid using stiffened structural steel H-sections using high strength bolts. The bottom tracks / Bottom plates of both the walls: Wall A and Wall B were bolted and fastened to the foundation to induce fixity. A secondary loading frame was built using four stiffened H-sections with a load spreader on one end. The load spreader was attached to the piston mount of a powerful hydraulic jack, which was attached to the reaction wall. The loading frame was additionally secured around the top of the specimen using four 1 in (25 mm) threaded rods along the walls. Figure 3 shows the pushover loading test setup.

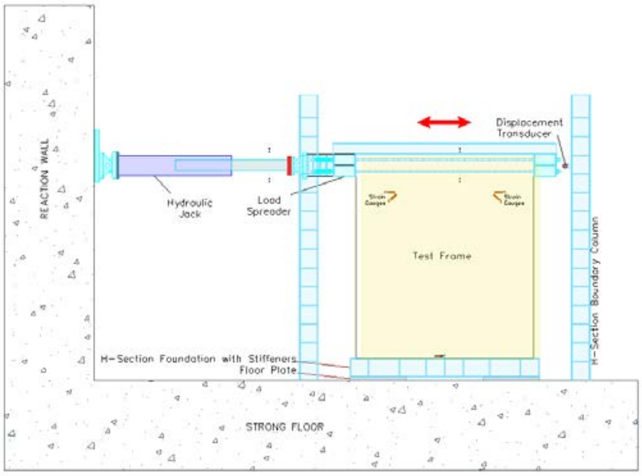
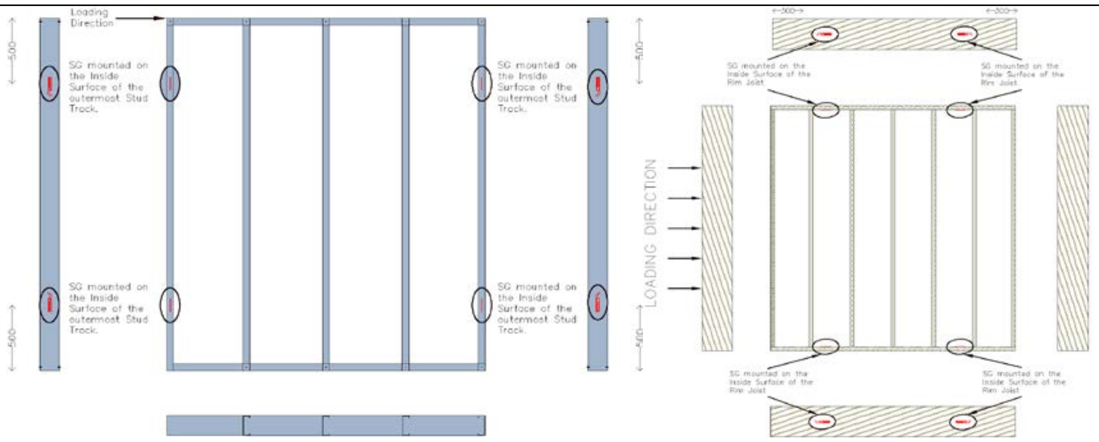


Figure 3. Pushover loading test setup

Refer [WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report] for further details.

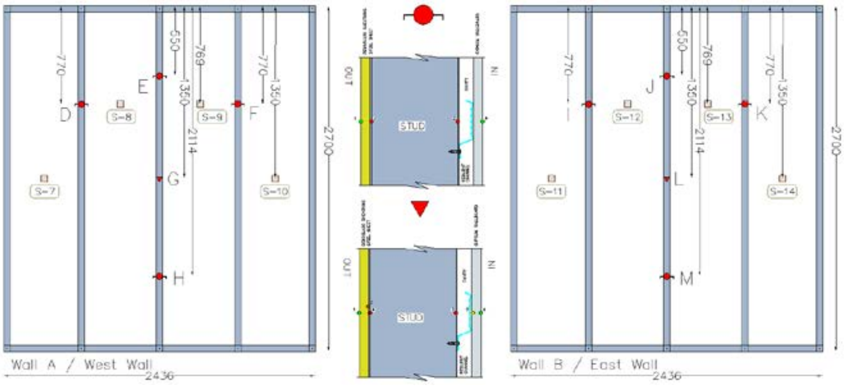
Instrumentation

Force, displacement, strains and temperature at various locations in the frame are the key parameters of measurement in both the test frames. The loading for this test was displacement controlled, meaning, the displacement was induced to the test specimens at the roof level in push and pull cycles up to a point where the desired level of damage was obtained. Input force was measured directly from the hydraulic jacks by the built-in pressure transducer. The displacements were measured using two types of displacement sensors. The displacement at the diaphragm level, associated with the applied load, was measured using non-contact displacement transducers whereas the displacements at the base (to measure the uplift if any) were measured using low-displacement spring-loaded linear variable displacement transducers. Strains were measured using special-use foil strain gauges to record the strains on wood, gypsum and steel surfaces. The strain gauges on the exterior sheathing of the specimen were mounted using a 2-gauge configuration. The two-gauge configuration comprised of two strain gauges: the first gauge in the direction of loading and the second gauge mounted at an angle of 45 degrees to the first gauge. The temperatures were measured using Type-K thermocouples: Bead thermocouples for measuring the temperatures at different depths and cavities whereas disc-head thermocouples were used to measure the surface temperatures on the wall. Figure 4 (a) and (b) show the strain gauge layout for the test specimens CFS01 wall and WOOD01 diaphragm respectively, whereas, Figure 5 (a) and (b) show the thermocouple layout for the test specimens CFS01 wall and WOOD01 diaphragm respectively.

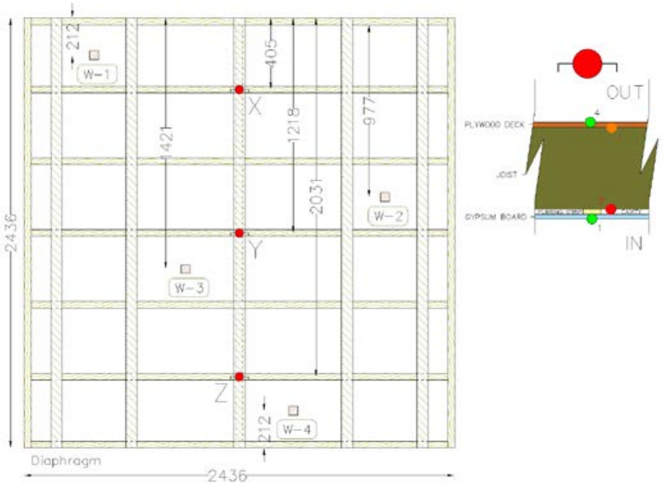


(a) (b)

Figure 4. Strain Gauge Layout (a) CFS01 Wall (b) WOOD01 Diaphragm



(a)



(b)

Figure 5. Thermocouple Layout (a) CFS01 Wall (b) WOOD01 Diaphragm

Refer WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report for further details.

Pushover Loading

Quasi-static loading was applied on the test frames according to ASTM E2126-11 "Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral

Force Resisting Systems for Buildings". The standard proposes the test methods for evaluating the shear stiffness, shear strength and ductility of the vertical elements of lateral force resisting systems (LFRS) under quasi-static cyclic (reversed) load conditions. For the tests mentioned in this report, cycling test method C is used. Test method C, also known as CUREE protocol was developed based on the statistical analysis of cyclic demands on light-frame buildings representative of California conditions. The CUREE loading history is a realistic and conservative representation of the cyclic deformation history to which a component of wood structure likely is subjected to Earthquake. Hence, the test method would be more appropriate for cold-formed steel and wood test specimens in the present study. For this method, a parameter reference deformation, Δ, is used. Reference deformation is a measure of the deformation capacity (Δ_u) of the specimen when subjected to cyclic loading history, which is used to control the loading history. The standard suggests that the value of reference deformation be based on a previous experience, the results of a monotonic tests or a consensus value that may prove to be useful for comparing the tests of different details or configuration. Hence, a reference displacement value of 1.5 in (38.1 mm) based on the NIST shear wall tests were adopted for cyclic loading of the test specimen CFS01. Also, the construction and dimensions of the test specimen CFS01 were similar to NIST CFS shear wall tests. For wood specimens, a reference displacement of 2.4 in (61 mm) was considered based on Langlois et.al. (2004). Again, the wood wall specimen construction and dimensions were similar to the tests conducted by Langlois et. al. and hence the reference displacement. Figure *6* shows the input displacement history for pushover loading for specimen CFS01 and Figure *7* (a) and (b) show the loading hysteresis obtained from pushover loading on the test specimens CFS01 and WOOD01 respectively.

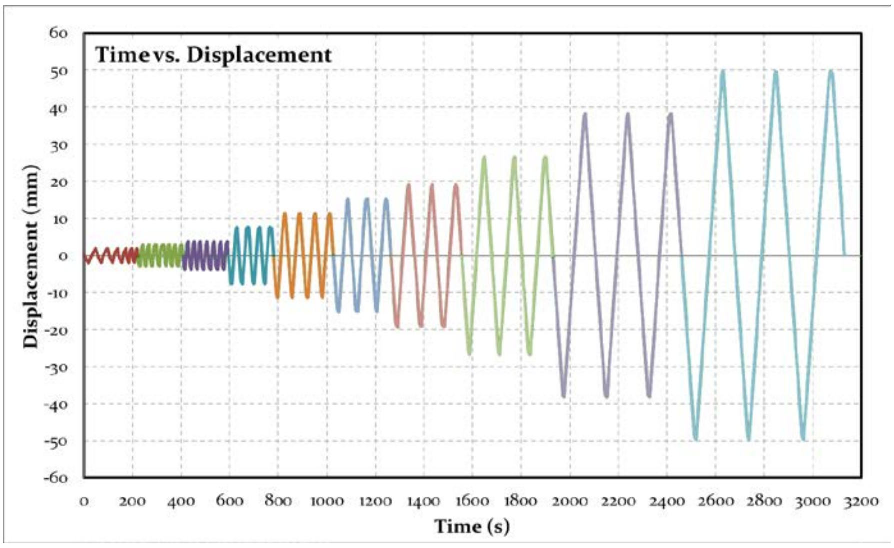
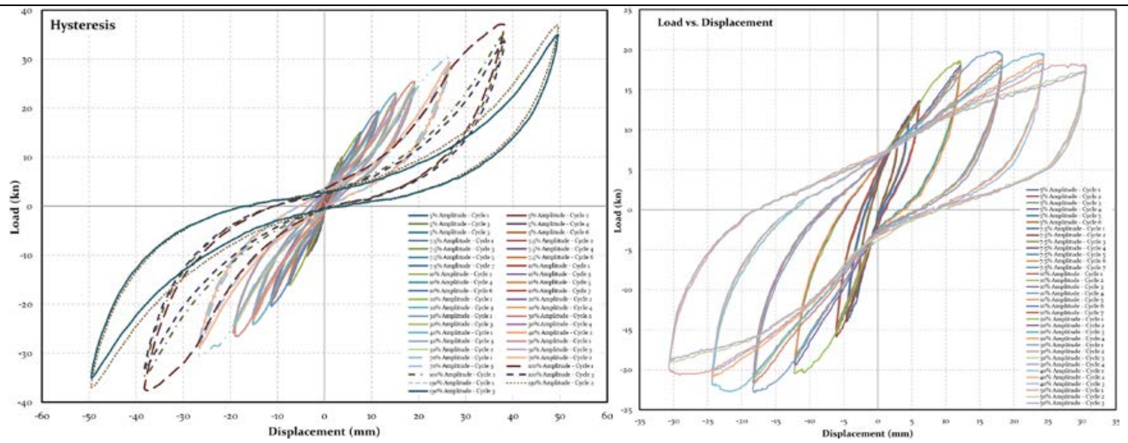


Figure 6. Input displacement history for pushover loading for specimen CFS01



(a) (b)

Figure 7. Hysteresis for pushover loading (a) CFS01 (b) WOOD01

Refer [WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report] for further details.

Results

Thermal Profiles

Figure *8* (a) shows the thermal profiles for Wall B of the test specimen CFS01. Wall B was designed as an interior shear wall, where the exposed face of the steel frame was protected by a one-hour fire rated gypsum board whereas the outer face was protected by a composite steel sheathed gypsum panel for additional shear strength. The thermal profiles on the Wall B followed a partially similar trend as compared to Wall A. The thermocouple on the gypsum surface followed the furnace temperature curve up to 1000°C and decreased thereafter, which is attributed to gypsum board releasing chemically combined water. Similar to Wall A, within two minutes from ignition, the temperature in the stud cavity started rising steadily up to around five minutes. Unlike in the Wall A, the temperature increased steeply thereafter and surpassed 800°C within 15 minutes. It is observed that the temperature in the stud cavity and the inner face of the steel stud (stud-resilient channel interface) followed a similar trend together throughout the test. The temperature ay the steel-stud and sheet steel interface on the exterior of the wall also increased. The temperatures inside the wall intercepted the temperature on the gypsum surface around fifteen minutes, which shows the gypsum board is no more acting as a thermal barrier protecting the underlying steel frame. The heat on the exterior layer, which was insulated started rising as early as seven minutes and showed a gradual increase. Around 30 minutes, the different thermal profiles converged indicating a potential thermal equilibrium, that triggered the softening of steel frame and triggered the collapse. Figure *8* shows the thermal profiles obtained in the diaphragm of the dimensional lumber test specimen WOOD01. Similar to all the other panels, Figure *8* includes the furnace T-t curve. The temperature on the ceiling gypsum board followed the trends of the furnace T-t curve for the initial phase of temperature rise within the furnace. The temperature on the exposed face of the ceiling gypsum board decreases after reaching a peak temperature of over

900°C, which is attributed to the release of chemically combined water

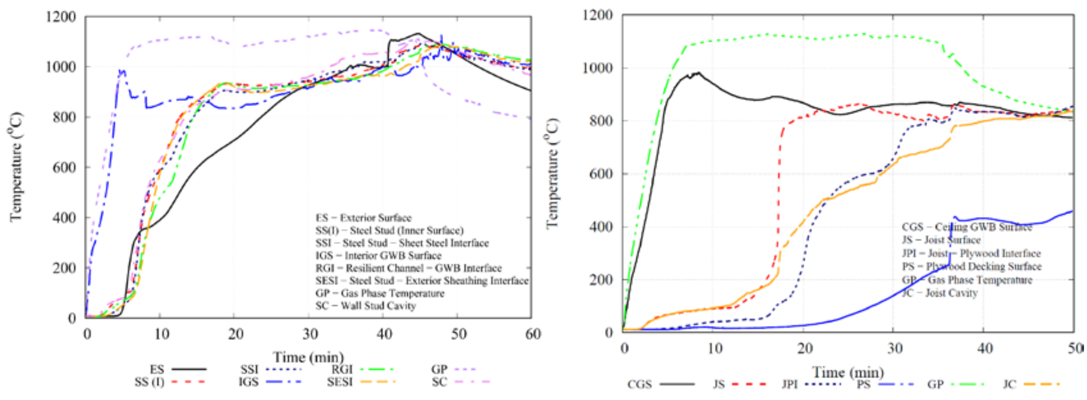


Figure 8. Thermal profiles (a) Wall B - CFS01 (b) Diaphragm - WOOD01

. It may also be observed that the thermal profiles on the diaphragm resemble the thermal profiles on Wall B. The temperatures on the exposed bottom face of the joist remained under 200°C for at least 15 minutes, which shows that no charring initiated in the joist for the initial 15 minutes. Thereafter, the temperature on the bottom face of the joist showed a steep rise, which indicates a potential fall-off of the gypsum board from the ceiling. Fall-off of the ceiling gypsum board is further evident from the rise of the temperature in the joist cavity. Furthermore, the temperature at the interface of the joist and the decking plywood starts rising steadily around 20 minutes. The temperature on the surface of the decking plywood does not show any increment for the first 20 minutes from the start of the test. Thereafter, the temperature increases slowly. The temperature reaches around 250°C at around 35 minutes, and shows an abrupt rise at around 36 minutes, which also corroborates with the failure of the test specimen.

Refer WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report for further details.

Post Fire Observations

Figure 9 shows the commonly observed damage patterns from the failed test specimen CFS01. It was apparent that the gypsum board disintegrated before the collapse of fire tests. The cement board deck was severely dehydrated. However, the collapse showed that the cement board did not disintegrate unlike the gypsum board into smaller fragments. This is because the cement board was adhered to the sheet steel underside and was protected on the top by the loading block and hence it came into contact with high temperature just before the collapse. However the sheet steel backing the gypsum board on the Wall B as well as cement board underwent high temperature oxidation as shown in Figure 9. High temperature oxidation was largely observed in all the structural members such as studs, joist tracks, rim tracks and blocking tracks as shown in the figure. Although high temperature oxidation of the self-drilling self-tapping screws was also observed, the position of the screws suggest that the failure did not happen due to shearing of the fasteners. The screws holes on the receiving end of the members showed that they underwent thermal expansion, due to which the separation of panels occurred.

Figure 9. Failure patterns in the test specimen CFS01

Refer WPI-TUS-BRI_Joint_Usage_Program_2017-18_Report for further details.

Summary / Conclusions

Two full-scale tests on lightweight frame systems were successfully conducted in an effort to evaluate their post-earthquake fire performance under the joint-usage program between Worcester Polytechnic Institute (WPI), USA and Tokyo University of Science, Japan for the fiscal year 2017-18. The two tests were planned and designed at the WPI. The materials required to construct the two test frames per the US cold-formed steel and light-wood frame specifications were shipped to Tokyo University of Science. The two test specimens were professionally fabricated at the Building Research Institute's Structural Composites Laboratory. The typical specimens composed of a diaphragm panel supported by two wall panels and cross-braced for stability and to prevent the out-of-plane deformation. Racking tests were conducted on the test specimens and their permanent residual drifts were locked in place, and the specimens were transported to the Tokyo University of Science (TUS). The damaged specimens were thereafter structurally loaded and exposed to a non-standard, severe fire to failure. In a parallel effort, Japanese wood framed specimen constructed according to Timber Framework method was exposed to an identical fire curve in the furnace with no prior damage induced. However, the testing and results of the Japanese wood-framed specimen is out of scope of this report and will be published as a separate report. The following observations were made from the current experimental study delineated in this report.

- Wall A of the cold-formed steel test specimen CFS01, which was constructed as an exterior load-bearing wall, suffered minimal damage on the interior and exterior sheathing in the form of full-height paper tape rupture, boundary crushing and loosening or partial withdrawal of drywall screws during the late cycle of displacements. No structural damage was observed on the framing members near the base. Whereas the Wall B of the test specimen, which was constructed as an interior load bearing shear wall showed lesser damage in the racking tests. The sheet-steel backed gypsum board used as exterior sheathing imparted significant shear stiffness to the wall and also prevented the crushing of the drywall unlike Wall A. However, paper tape rupture was observed on the boundary of two drywall panels. Loosening of drywall screws were also observed at the bottom of the Wall B panel. The damage observed on the walls resembled the type of damage observed in the prior tests conducted by researchers [3-6]. Gypsum board drywall on the interior serves as the thermal barrier providing passive fire protection. Any damage to the drywall system makes the underlying structural frame vulnerable in a fire scenario. Pushover tests on CFS01 did not induce a sizable damage that directly compromised the passive fire protection of the structure.
- Wall A and Wall B of the light-wood / dimensional lumber framed test specimen WOOD01, unlike CFS01 did not show full-height cracking or paper tape rupture. However, excessive warping of paper tape during the lateral loading was observed, which in some places caused localized rupturing of the paper tape. Shear cracks along the screws at the corner and the boundary of the drywall panels was observed. Drywall screw withdrawal was observed at multiple places at the base of the test specimen. The screw withdrawals were mainly due to the fact that the bottom plate of the wall panels fixed to the base of the strong floor ruptured due to the shear forces induced due to the lateral loading at the base. The connections in a wood framed specimen are considered semi-rigid. Nails offer a certain level of ductility to the framing. Similar behavior is also observed in the drywall screws as they seemed flexible and displaced along with the wood frame. Pushover tests on WOOD01 did not induce a sizable damage that directly compromised the passive fire protection of the structure.

- A permanent residual drift of 19 mm was observed during the pushover loading of the test specimen CFS01, whereas, the permanent residual drift measured in the test specimen WOOD01 was 36mm. A lower drift in the CFS01 test specimen indicates that the cold-formed steel test specimen was more ductile than the wood-framed test specimen and regained a higher percentage of lateral deformation induced during the last displacement cycle after the load was released. Also, the test specimen CFS01 was loaded to 130% of the target displacement whereas WOO01 was loaded to 50% of the target displacement to induce the desired level of damage to the test specimens. The target displacements reported by previous researchers on similar wall systems were considered for the racking tests conducted in this study.
- The thermal profiles in both the test specimens CFS01 and WOOD01 indicate that the failure initiated due to the yielding of one of the wall supports, which then led to the failure of wall-diaphragm connections, thus causing the overall collapse of the test frame. The thermal profiles in the test specimen CFS01 suggests failure initiated due to the softening and collapse of Wall B. In the test specimen Wood 01, the thermal profiles suggest that the loss of gypsum wall board led to early charring of wood studs on Wall A, which caused Wall A to fail, thus triggering the collapse of the test frame.
- The displacement of the loading panel on the test of the test specimen CFS01 initiated around 40:00 minutes. Final collapse of the test specimen occurred at 41:31 minutes. Differential displacements of the loading block suggests the load was trying to redistribute when the displacement initiated, which then aggravated as the stud tracks softened and began to yield.
- In the test specimen WOOD01, similar to CFS01, displacements were initially observed around 35:38 minutes, when the process of load redistribution tried to keep the load supported on the diaphragm. Furthermore, the displacements increased and in less than a minute after initiation, the structure collapsed at 36:16 minutes. The yielding in the light-wood framed specimen was quicker than the steel framed specimen as the wood members crack when the axial load capacity exceeds imparting no ductility to the frame system.
- The test frames were designed as one-hour fire rated assemblies. The systems performed well in imparting the simulated live load (50% of design load) until collapse. However, the collapse times of both cold-formed steel and light-wood systems show that they did not endure the code prescribed fire rating for one hour under realistic fire conditions. From this study, it may be inferred that real fire behavior of the systems could reduce as much as 31% for the cold-formed steel framed systems, and 41% for light-wood / dimensional lumber frame systems in a real, non-standard fires. The Temperature-time (T-t) curve used for the assessment of the fire rating of different systems should be upgraded to account for the added fire severity due to an enhanced fire load generated in the natural fire events.

４．今後の展望（今後の発展性，見込み等についても記述）/ Future Perspectives

Building construction industry is fast growing, and they manufacture new materials (structural, fire proof or both) to cater to the growing demand in building lightweight, modular, energy-efficient, hazard resilient structures using light-gauge steel as well as timber. Engineers and architects throughout the world envision sustainable construction using engineered wood such as wood-metal composites and cross-laminated timber. Wood/Timber is an excellent material to achieve multiple objectives to build in earthquake prone zones. Wood, being combustible faces new challenges in fire safety. Numerous efforts have been conducted to evaluate the fire performance of CLTs and other Engineered wood components across the globe. However, limited data exists on post-earthquake fire performance of such systems. Efforts are underway to conduct seismic tests on a 10 story CLT building in the United States in 2019 and a 6 or 7 story cold-formed steel frames structure with finishes in 2020. Parallel efforts relating to these projects, such as component level tests, may be envisioned in further joint usage efforts as appropriate.

５．成果の公表状況（学会への発表，学術誌への投稿等を記述。予定も含む）
/ Publishing (presentation, paper, etc. incl. plans in the future)

The results of the Year 1 effort (2016-17) were presented at the FIRE SAFETY 2017: International Conference on Research and Advanced Technology in Fire Safety, Santander, Spain October 2017 and published in their e-proceedings.

Since the tests in Year 2 effort (2017-18) were rather recently concluded, papers have not yet been prepared. However, a comprehensive report on the project has been prepared and will be attached as a separate document. It is also planned to submit abstracts to the following conferences, which have proceedings, as well as to submit to a journal, such as Fire Technology or Fire and Materials. Planned conferences include the 2018 Workshop on Advancements in Evaluating the Fire Resistance of Structures, Washington, DC, December 6-7 and NFPA Conference & Expo, June 2019, Boston.

６．経費の使用状況 / Usage of Budget

expendables・Meeting・Printing		Travel expense		Personnel expenses	
Contents	Cost	Contents	Cost	Contents	Cost
- Material Cost (US) - Shipping - Thermocouples - Import Cost - Material Cost (JPN)	229,670 430,736 278,778 317,703 77,420	- Air Fare (BM + PK) - Japan Local Travel -Accommodation	507,077 75,948 117,000	Specimen Fabrication Cost Experiment Preparation Work Cost	699,840 226,800
Subtotal	1,334,307	Subtotal	700,025	Subtotal	926,640
Burden of Tokyo University of Science / Total Yen					
Burden of 2,000,000 / 2,960,972					

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