



Photo 1: A six-story building was panelized and erected on a shake table at UCSD.



Photo 2: After a series of simulated earthquakes, the second and sixth floor were set on fire to analyze the full effects of a natural disaster.

Shaked and Baked **BUT STILL STANDING**

by Don Pilz, CEMCO

Last summer, a six-story steel framed structure withstood multiple, massive earthquakes and fires in San Diego. If you didn't hear about such an event, here's the story. Researchers at UCSD Jacobs School of Engineering put a 6-story, lightweight, cold-formed steel building through a series of scaled motion earthquakes.

The six-story building layout was designed to replicate a multi-family residential structure. The test summary video can be observed at: www.youtube.com/watch?v=AVvII76OgmU.

One of the main purposes of the tests was to see if it was even possible to withstand a historic earthquake combined with an ensuing fire in a multi-story, multi-family structure. The results of the tests, as outlined in this article, proved that cold-formed steel framing could not only withstand the earthquakes and fire but could also be built much more efficiently than traditional wood or concrete structures.

This project was a collaboration between two academic institutions (University of California, San Diego and Worcester Polytechnic Institute), two government or institutional granting agencies (Department of Housing and Urban Development and the California Seismic Safety

Commission) and more than 15 industry partners. Industry sponsors included California Expanded Metal Products Inc. (CEMCO) and Sure-Board®, which provided financial, construction and materials support, as well as DCI Engineers, SWS Panels, Rivante, State Farm Insurance, the Insurance Institute for Business and Home Safety, DPR Construction, Walters & Wolf and MiTek, which also provided support.

The test building was subjected to a sequence of seven earthquake motions prior to fire tests on the second and sixth floors, with two more earthquake motions following. The input earthquake motions adopted for the shake table testing were selected from four historical earthquake records, namely: Rio Dell Overpass from the 1992 Cape Mendocino earthquake in California; both Canoga Park and Rinaldi Receiving Station from the 1994 Northridge earthquake in California; and Curico from the 2010 Maule earthquake in Chile.

This was the tallest cold-formed structure (CFS) steel building to ever undergo tests on a shake table. This type of building is lighter than a concrete building of the same height, so it has less mass to generate damaging forces.

The purpose of the UCSD shaker table test was to construct a building per the current CBC & ASCE 7-10 design requirements at an $R = 6.5$. Using a combination of cold form steel framing, Sure-Board® wall and diaphragm shear (series 200 & 200S), as well as Zone 4 tie down system, the building was then subjected to a real-world earthquake scenario. This building was not built on "performance-based design" as most of the predecessors before, thus giving a *true outcome* of how a field built structure might react in a real earthquake. Some of the benefits that this system can offer in this type of construction are its inherent non-combustibility, higher shear and diaphragm capabilities compared to

similar types of construction methods, as well as offering the ability to have a habitable and safe structure after such a large natural event.

The Sure-Board® system is a non-combustible floor sheathing. The series 200S is unique in its ability to be installed by a single person, as well as eliminating the necessity for blocking at panel joints due to its proprietary tab feature. While series 200 shear panels have the finish board already laminated to the .027 (22g) sheet steel, the installer is applying their lateral shear and non-combustible finish board in one step of labor instead of two. Beyond just their installation benefits, these products, installed in conjunction with the Zone 4 tie down system, created a dynamic and ductile building. This structure could withstand multiple ground movements, including a 150 percent MCE (Maximum Considered Earthquake) of the 1994 Northridge earthquake, while only suffering superficial cracking on exterior walls. This system proved not only resilient but also capable of handling future unseen events while keeping the occupants safe.

Though the UCSD shaker table program was designed to test this system's seismic shear capabilities, as well as fire resistance and



Photo 3: The results of the traditional method at the non-fire side where the paper tape cracks and pulls apart, which, in return, allows smoke to pass through the head-of-wall joint.



Photo 4: The HOT ROD Compressible Firestopping on the non-fire side. Although the double metal door failed and allowed fire and smoke to pass through the door, fire or smoke was unable to pass through the head-of-wall joint as indicated in the clean, off-white seal between the ceiling and the wall.

resilience, this type of construction has many other benefits that can be useful nationally, even worldwide. It can be easily panelized and erected quickly on-site, and the products used are mold, termite and weather resistant. This system has been tested as well for use in catastrophic events, such as hurricane force winds, flying debris and even as far as blast and ballistic protection. With these accomplishments, there is great opportunity for future designs.

CFS framed structures can offer lower installation and maintenance costs than other structural types, particularly when erected with prefabricated assemblies. They are also durable, formed of an inherently ductile material of consistent behavior, lightweight and manufactured from recycled materials. Compared to other lightweight framing solutions, CFS is non-combustible, an important basic characteristic to minimize fire spread.

Knowing that the structure would be tested under substantial movement before and after a fire, it was important to see how the fire-rated building joints would perform. For the head-of-wall joints, two different forms of fire protection were installed and observed. The traditional method of paper tape and joint compound was applied to some of the perimeter joints while other head-of-wall joints were treated with CEMCO HOT ROD Compressible Intumescent Firestopping. Photo 3 shows the results of the traditional method at the non-fire side where the paper tape cracks and pulls apart, which, in return, allows smoke to pass through the head of the wall joint. Photo 4 shows the HOT ROD Compressible Firestopping on the non-fire side. Although the double metal door failed and allowed fire and smoke to pass through the door, fire or smoke was unable to pass through the head of the wall joint as indicated in the clean, off-white seal line between the ceiling and the wall. Photo 5 shows HOT ROD on the fire side. As shown in the photo, the intumescent material expands under fire and seals against the ceiling, which prevents any smoke from passing to the non-fire side.

Test Results

Pre-Fire Earthquake Tests: The test building suffered minimal damage during the service level earthquake tests and remained largely in the quasi-linear range, with very low drift demands imposed on the specimen (interstory drift < 0.2%).

Fire Tests: Post-flashover conditions were achieved in all six compartment fire tests at the given ventilation conditions, with the corresponding maximum compartment temperatures ranging between 800°C and 1100°C (four out of six tests exceeding 1000°C).



Photo 5: HOT ROD on the fire side. The intumescent material expands under fire and seals against the ceiling which prevents any smoke from passing to the non-fire side.

The elevated temperature caused significant degradation of interior fire rated gypsum wallboards on sheet steel and plain fire rated gypsum wallboards leading to the loss of some structural strength.

Post-Fire Earthquake Tests: The low-amplitude aftershock significantly attenuated seismic demands in the building because of the elongated period caused by the pre-fire earthquake sequence. However, in the end, the test building resisted collapse due to redistribution of loads and framing action of the Sure-Board® and the Zone 4 tie-down system. Not only did the structure resist collapse, researchers were still able to safely walk through the test building and analyze the structures post-fire/earthquake condition.

"As the nation's largest general contractor that self performs drywall, we at DPR Construction were proud to participate in the seismic performance test of steel stud construction. The test results make a very compelling argument for steel stud framed buildings in lieu of wood and even concrete. Changing the building codes to utilize these construction materials is the first step in building safer, more sustainable communities. DPR will keep leading change in the building industry alongside companies like CEMCO Steel." -Carl Spaete, DPR San Diego

References:

Earthquake and Fire Performance of a Mid-Rise Cold-Formed Steel Framed building – Test Program and Test Results: Rapid Release Report by Xiang Wang, Tara Hutchinson, Gilbert Hegemier, Srikar Gunisetty (UCSD), Praveen Kamath, Brian Meacham (WPI)

After 30 years in the construction industry as a foreman and building consultant, Pilz is now the research and design manager for CEMCO assisting consultants, architects and contractors with interior and exterior performance detailing. He can be reached at (626) 506-3881 or dpilz@cemcosteel.com.

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