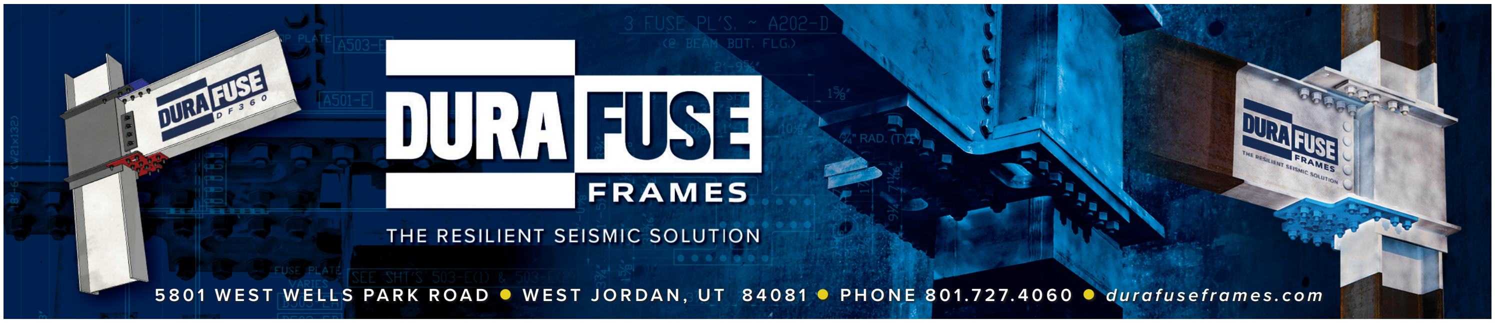


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# TECHNICAL BULLETIN 25

# Shake Table Testing of DuraFuse Frames

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**Abstract:** The large high performance outdoor shake table (LHPOST) at the University of California San Diego was upgraded between 2018 and 2022. As part of the upgrade, an accessory frame was added that can be used for non-structural component testing. The accessory frame, called the Modular Testbed Building (MTB2), uses DuraFuse Frames® for lateral resistance since it must be able to withstand repeated severe earthquake shaking. In April 2022, the first system characterization tests were performed on the MTB2. The building was subjected to twenty earthquake ground motions of varying intensity. At least ten of the earthquakes would be characterized as strong. Under the design-level shaking, the building experienced story drifts around 2% and the fuse plates experienced minor yielding. The same fuse plates were used for multiple design-level records without requiring replacement. No damage was observed in the beams or columns. At the conclusion of testing, the fuse plates were removed without difficulty, and the MTB2 was switched to its buckling-restrained brace configuration.

## Background

Historically, the United States has lagged behind Japan and Taiwan when it comes to large shake table facilities and testing. The biggest shake table in the US is the NHERI Large High Performance Outdoor Shake Table (LHPOST) at UC San Diego. The table opened in 2004, and between 2005 and 2018, more than thirty structural and geotechnical tests were performed on the table (http://nheri.ucsd.edu).

Limitations of the LHPOST made it difficult to investigate some aspects of seismic design. The table was only capable of single-direction movement, so bi-directional effects and the influence of vertical accelerations could not be investigated. It was also difficult to test non-structural components of buildings under design level-earthquakes, because only one test could be performed at design-level shaking and then the underlying building structure would be damaged and the stiffness characteristics could not be maintained for subsequent tests

## Table Upgrades and Modular Testbed Building (MTB2)

To address these shortcomings, the table was upgraded between 2018 and 2022 with a $16.3 million grant from the National Science Foundation (https://ucsdnews.ucsd.edu, Oct 18, 2018). In addition to adding multi-degree of freedom capabilities to the table, an accessory frame was proposed by Tara Hutchinson (UC San Diego) and Chris Pantilides (University of Utah) that could be used as a structural frame for various types of projects on non-structural components. They called it the Modular Testbed Building (MTB2), and one requirement was that it could easily be repaired following severe earthquake shaking. Figure 1 shows the table and MTB2 when the upgrades were completed in April 2022.

**Fig. 1.** *The upgraded shake table at UCSD with the modular testbed building.*

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The MTB2 is one-bay by two-bays in plan, and three stories tall (Fig. 2). In the one-bay direction, the building has buckling-restrained braces (BRB). In the two-bay direction, the frames can be configured as either moment frames or as buckling-restrained braced frames. This allows the MTB2 to simulate a variety of structural systems. The moment frame configuration employs DuraFuse Frames®, since the DuraFuse connection is the only prequalified fully-restrained connection that is easily repairable.

**Fig. 2.** *Modular testbed building (MTB2).*

## MTB2 Moment Frame Design

Member sizes were selected for the MTB2 so that the stiffness and natural frequencies of the MTB2 would reasonably represent actual three-story steel structures. The columns were W12×96 and the beams were W14×34. The W14x beams were used to be in proper proportion to the bay length. Figure 3 shows the fuse plates at one of the beam-to-column connections. The fuse plates were ½ inch, A572 Gr. 50 steel.

**Fig. 3.** *DuraFuse connection in the MTB2.*

The corner columns in the MTB2 were used for the braced frame in one direction and moment frame in the other. A special DuraFuse connection detail was used for this bi-axial condition (Fig. 4 shows a column prior to erection). A similar detail has been used on other building projects that involve both DuraFuse Frames and buckling-restrained braced frames.

**Fig. 4.** *Bi-axial column detail for the MTB2.*

## Shake Table Testing

The MTB2 was the first structure to be tested on the UCSD shake table after the upgrades were completed. In April 2022, the MTB2 was erected on the table over the course of three days and then instrumented by the research team from UCSD and the U of U. The purpose of the tests was to get baseline performance characteristics for the bare-frame MTB2, so that for future studies that include non-structural components like cladding or stairs, there will be bare-steel data for comparison.

The building was subjected to a variety of historical earthquake records, scaled to represent various levels of severity (Table 1). White-noise testing was used in-between earthquakes to check natural frequencies (indirect characterization of damage). The Northridge record used for much of the testing was recorded at the Rinaldi Receiving station and is classified as a near-fault record. The building was subjected to twenty earthquake motions in the moment frame configuration, at least ten of which would be characterized as strong. The same fuse plates were used for all of the tests.

**Table 1.** *Earthquake records used for shake table testing.*

| Event | Record | No. of Tests | Scale Factors |
|---|---|---|---|
| Chi-Chi Taiwain, 1999 | TCU065 | 3 | 0.35-0.45 |
| Kobe Japan, 1994 | Takatori | 5 | 0.175-0.375 |
| Northridge CA, 1994 | Rinaldi | 12 | 0.175-1.0 |

The DuraFuse Frames performed as expected during the earthquake shaking. The maximum drift experienced by the MTB2 frame was almost 2%, which is similar to the design story drift for many moment frame buildings. There was no yielding in the beams, columns, or panel zones and there was no damage to welds. The fuse plates experienced yielding, as evidenced by flaking of the mill-scale, but had more-than-sufficient capacity to resist multiple severe events (Fig. 5).

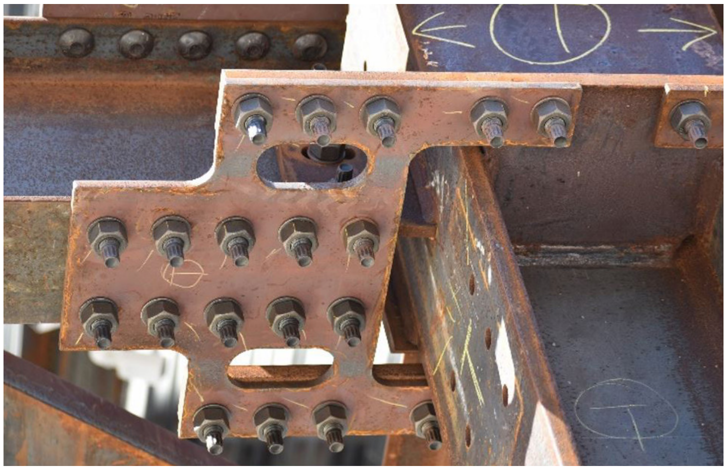

**Fig. 5.** *Fuse plate yielding during severe earthquake shaking.*

After the twenty earthquakes, the fuse plates were removed so the MTB2 could be prepared for the all-BRB configuration. There was no difficulty in removing the fuse plates. The bolts were loosened with a torque wrench and then removed by hand (Fig. 6). The fuse plates were replaced with bolted gusset plates to receive the BRBs. The bolted gusset plates used the same beam holes as the fuse plates. The frame was able to accommodate the installation of the bolted gussets and BRBs without the need of cables for replumbing.

**Fig. 6.** *Fuse plate removal after testing.*

These tests were the first-of-their-kind in several ways. They were the first time a large-scale special moment frame had been tested under 3-D shaking in the US. They were the first time a prequalified US moment connection had been tested under design level earthquake shaking. They were the first time a US steel special moment frame had been repaired after inelastic response.

## Summary

The large high performance outdoor shake table at the University of California San Diego was upgraded between 2018 and 2022. As part of the upgrades, an accessory frame was added that can be used for non-structural component testing. The accessory frame, called the Modular Testbed Building (MTB2), uses DuraFuse Frames® for lateral resistance since it must be able to withstand repeated severe earthquake shaking. In April 2022, the first system characterization tests were performed on the MTB2. The building was subjected to twenty earthquake ground motions of varying intensity. At least ten of the earthquakes would be characterized as strong. Under the design-level shaking, the building experienced story drifts around 2% and the fuse plates experienced minor yielding. The same fuse plates were used for multiple design-level records without requiring replacement. No damage was observed in the beams or columns. At the conclusion of testing, the fuse plates were removed without difficulty, and the MTB2 was switched to its buckling-restrained brace configuration.