Title
Performance of Strong-Motion Instrumentation During Fires

Authors
Skolnik, Derek
Saifullah, M Khalid
Emberley, Richard
et al.

Publication Date
2026-07-13

13th National Conference on
EARTHQUAKE ENGINEERING
PORTLAND, OREGON | JULY 13-17, 2026

Resilience Through Community Engagement and Technology

Performance of Strong-Motion Instrumentation During Fires

D.A. Skolnik[1] , M.K. Saifullah[2], R. Emberley[3], S. Sorosh[4], J. Zhang[5], and T.C. Hutchinson[6]

ABSTRACT

Permanent strong-motion instrumentation in buildings provide ground-truth data for advancing the knowledge of real-world dynamic structural behavior to not only improve seismic provisions of building codes but also better inform emergency response and government planning. Owing to the rarity of strong earthquakes, this advancement requires instrumentation of exceptional accuracy and long-term reliability. Publicly funded programs like the California Strong-Motion Instrumentation Program (CSMIP) rely on rigorous instrument specifications to ensure societal benefit with high quality data collection and dissemination. Although these instruments are inherently robust to survive strong shaking, the potential impacts from accompanying extreme and dynamic environmental conditions such as flooding, falling debris, fires, may result in data contaminated with superfluous signals. This paper examines the impact of extreme heat on seismic sensors using post-earthquake fire tests conducted on a full-scale 10-story cold-formed steel building at UC San Diego's outdoor shake table. Two identical high-quality accelerometers commonly used by CSMIP and other public programs, one thermally protected and the other with standard installation, were sacrificed to identify when and how data from the unprotected sensor degraded while also providing potential to detect events like falling debris and localized reductions in structural stiffness.

Introduction

Permanent strong motion instrumentation installed in buildings provide ground-truth data for advancing our understanding of the dynamic structural behavior of real-world buildings, enabling researchers and professionals to improve seismic provisions of building codes as well as better inform emergency response and government planning. Owing to its mission-critical nature, coupled with the fact that strong earthquakes are extremely rare, this advancement requires instrumentation to be both highly accurate and highly reliable. Publicly funded programs, such as the California Strong-Motion Instrumentation Program (CSMIP [1]) and the Advanced National Seismic System (ANSS [2]), that are tasked with obtaining and disseminating these data rely on rigorous instrument specifications to ensure societal benefits and maximize return on public investment. As such, most instruments deployed are extremely robust and are expected to last decades. However, the potential impacts from extreme and dynamic environmental conditions that often accompany damaging earthquakes such as flooding, falling debris, and of course, fire, have remained largely unexplored. Of specific interest is how to confirm data quality and justify use for both typical and forensic investigations.

The work presented here aims to initiate a realistic exploration of these types of impacts by taking advantage of the fire tests performed on a full-scale 10-story cold-formed steel building at UC San Diego's

[1] Program Manager, Earthquake Engineering, Kinemetrics, Inc., Pasadena, CA (email: das@kmi.com)
[2] Project Engineer, Kinemetrics, Inc., Pasadena, CA
[3] Associate Professor, Dept. of Mechanical Eng., Cal Poly San Luis Obispo, CA
[4] PhD Candidate, Dept. of Structural Eng., University of California San Diego, CA
[5] PhD Student, Dept. of Structural Eng., University of California San Diego, CA
[6] Professor, Dept. of Structural Eng., University of California San Diego, CA

Skolnik DA, et. Al. Performance of Strong Motion Instrumentation During Fires. *Proceedings of the 13th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Portland, OR. 2026.

outdoor shake table [3]. Two high quality accelerometers of the same manufacturer and model predominantly used by CSMIP & ANSS were sacrificed in pursuit of this effort. One accelerometer was thermally protected in a way to determine precisely when and how data goes bad in the other "unprotected" sensor.

Setup & Testing

In the summer of 2025, a 10-story cold-formed steel building (CFS10) was built and tested on the six-degree-of-freedom Large High-Performance Outdoor Shake Table at UC San Diego [3]. The building exceeded current ASCE 7-22 [4] height limits for cold-formed steel construction, with a total height of 30.5 m, and was subjected to 18 earthquake motions scaled to multiple risk-targeted hazard levels [5]. An overview of the seismic performance is provided by Hutchinson et al. [6].

Following the seismic test program, two live fire tests were conducted in compartments on Levels 9 and 6. Each compartment was fully sheathed with Type X fire rated gypsum board and exposed to controlled natural fires fueled by stacked wood pallets, see Fig 1. Observations and preliminary thermal modeling results are presented in [7].

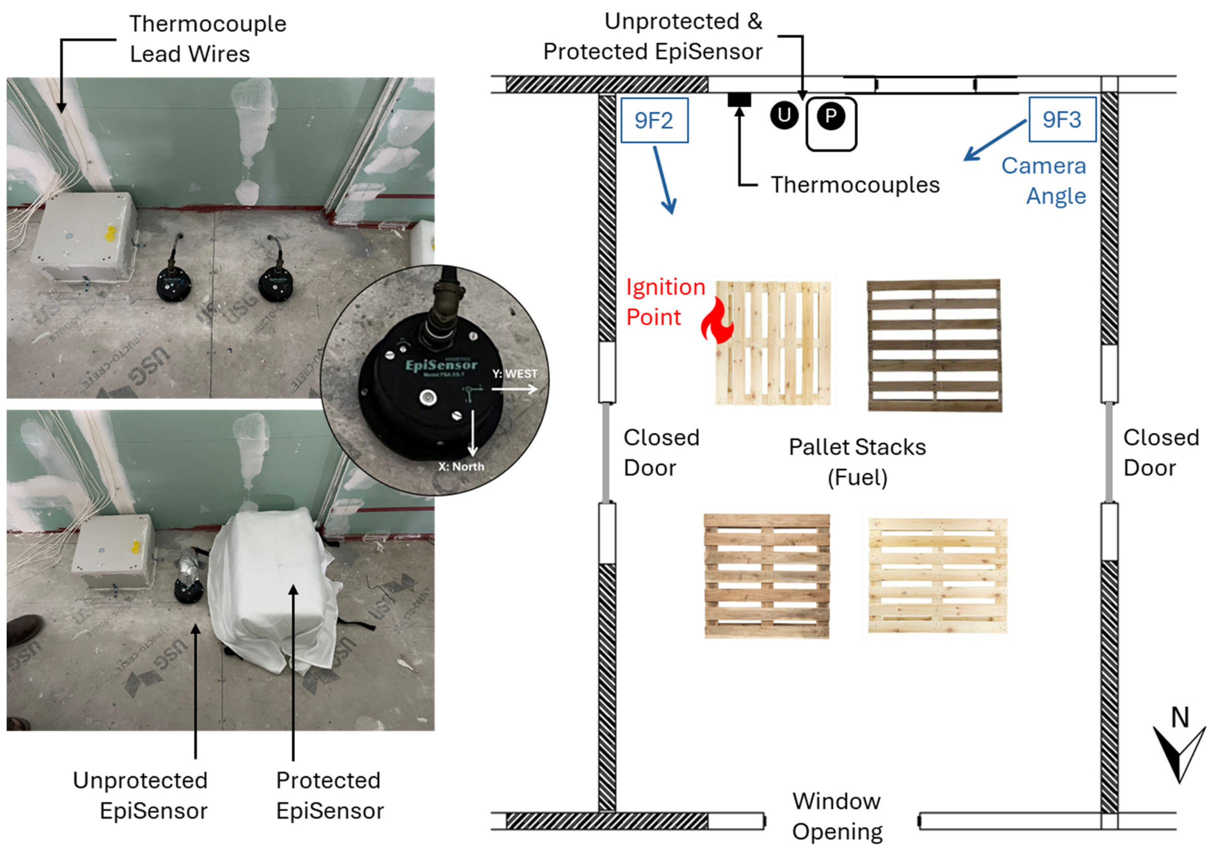

Figure 1. Sensor layout and test setup for Level 9 compartment fire testing.

The photos on the left in Fig. 1 show the identical installation and orientation of the two accelerometers prior to placing a 1-hr rated fire protection box over one of them. The sensor cables, which were routed through holes in the floor to the recorder below, were also protected since the cable was not of the type typically used in real buildings deployments which has a higher fire rating than the sensor. Finally, the 1-hr enclosure was wrapped with several fire-blankets for extra thermal protection. Fig. 1 also shows the locations of two cameras, and the vertical array of thermocouples all along the south wall. For brevity, the technical details of the instrumentation and data acquisition systems used are omitted here. It should be noted that the authors assumed, and verified where possible, that the multiple data sources were synchronized to within a few seconds.

Data & Results

Acceleration and temperature data for both Protected and Unprotected sensors are presented in Fig. 2. Prior to ignition, which is noted at 10:19:40 PDT and shown in left image in Fig. 3, minor vibrations (~0.05g) from the PI performing final checks can be seen. Once the PI departs a few moments later, the compartment floor vibrations settle down with just a few more spikes, most likely due to the PI exiting the building.

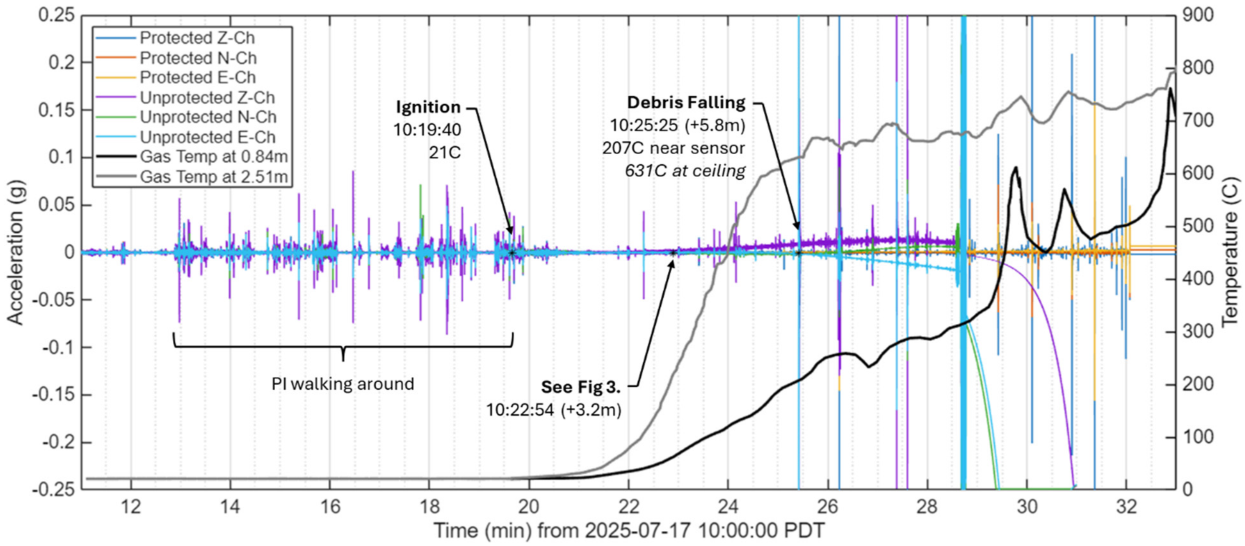

Figure 2. Acceleration data from both Protected and Unprotected triaxial EpiSensor accelerometers (left axis) with gas temperature readings at multiple heights (right axis) superimposed.

Figure 3. Still frames from cameras 9F2 (left) and 9F3(middle), and photo taken immediately post-test.

At approximately 3.2 minutes after ignition, and a temperature over 200C, camera 9F3 fails. The last frame, Fig. 3 middle photo, shows the southeast pallets fully engulfed in flames, the location of the accelerometers (white circle) and the vertical thermocouple array (black circles) with temperature readings. At this point the differential between floor and ceiling temperature is quite large. This is important to note because most accelerometers are typically installed above ceilings. The first noticeable event, observed as large accelerations (>0.25g) occurs at 5.8 minutes and a ceiling temperature over 630C. It is believed that a large piece of gypsum wall fell at this moment which is corroborated in Fig. 3 photo on the right, taken immediately after testing, showing piles of debris including large wall sections.

To compare the effect of extreme heat on the accelerometers, we note the time and temperature when the baseline drift of individual channels exceeds 1% of the sensor's full-scale range (FSR) of measurement (or 2.5mg for the +/-0.25g FSR EpiSensors used), see callouts on Fig 4. For clarity, the term "drift" refers to slow shifting of a signal baseline or offset from zero, and the term "channel" refers to an axis or direction of measurement such as North. Since we are only interested in baselines, smoothed data using one-second moving averages are used in lieu of raw data. As expected, the first observed baseline drift is in the vertical (Z) channel of the unprotected sensor. The exceedance occurs at a temperature of 101C which is considerably higher than the manufacturer's published operational limit of 70C (denoted by the dashed line in Fig. 4). The remaining horizontal channels begin to drift around the same time, but do not exceed the 1% FSR limit for several more minutes and a temperature over 230C. The unprotected sensor finally fails at 310C approximately 9 minutes after ignition. Note the protected sensor did not exceed the 1% limit before it failed several minutes after experiencing temperatures exceeding 500C, although the temperature inside the protective enclosure was certainly lower. The overall smooth nature of the moving averages indicates that the overall effect on the data is not abrupt, which leads to several interesting hypotheses worth further exploration. First, most of the data prior to obvious failure may still be usable after removing the overall drift (e.g., moving average curve). Secondly, the impulses (seen in Fig 2.) are still valid and can be used to determine precise timing of nonstructural events such as large falling debris.

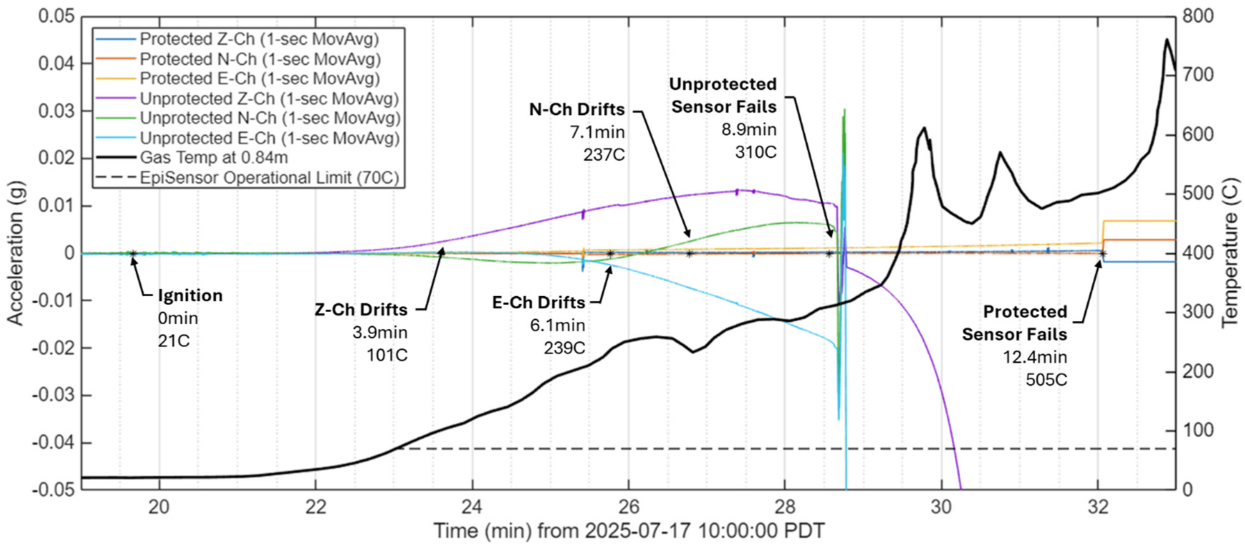

Figure 4. Smoothed acceleration data from both Protected and Unprotected triaxial EpiSensor accelerometers (left axis) with temperature at lowest height (right axis) superimposed.

Conclusions

Data collected from robust strong-motion instrumentation of the type used in large public monitoring programs can retain significant forensic value during post-earthquake fires, even when ambient temperatures exceed specified sensor operational limits. This potential increases substantially when sensors are installed within assemblies providing 2-hr fire-rated protection. Even when sensor functionality is clearly degraded, key features such as the timing of large transient events (e.g., impacts from falling debris) can still be reliably identified. Further evaluation across a range of installation configurations including protective enclosures and mounting locations (above ceiling versus floor-mounted) would improve confidence in the reliability of strong-motion data collected from buildings affected by fire.

Acknowledgments

The CFS10 program is a capstone to the CFS-NHERI project, executed with support of the National Science Foundation (NSF) CMMI 1663569 and 1663348, and numerous federal/state and industry partners, see cfs10.ucsd.edu/sponsors-partners. The efforts of all undergraduate and graduate students, visiting scholars (cfs10.ucsd.edu/people), and the technical support from the UCSD staff (nheri.ucsd.edu/about/personnel) are greatly appreciated. Additionally, the authors are grateful to Kinematics Inc. for donating sacrificial instruments and providing other resources. The opinions and findings of this study are those of the authors and do not necessarily reflect those of the sponsors.

References

1. California Geological Survey, State of California. California Strong Motion Instrumentation Program (CSMIP). Available from: https://www.conservation.ca.gov/cgs/smip [cited 2025 October

2. https://www.usgs.gov/programs/earthquake-hazards/anss-advanced-national-seismic-system

3. McCartney, J. S., Van Den Einde, L., Morrison, M., Palermo, A., Lotfizadeh, K., Lai, C.-T., and Conte, J. P. (2025). Multi-degree of freedom shake table testing of large-scale structural and geotechnical systems with NHERI-UCSD LHPOST6. *Frontiers in the Built Environment*, **11**:1573390. DOI: https://doi.org/10.3389/fbuil.2025.1573390.

4. ASCE. (2022). *Minimum design loads and associated criteria for buildings and other structures* (ASCE/SEI 7-22). Structural Engineering Institute of the American Society of Civil Engineers. Reston, VA.

5. Zhang, J., Sorosh, S., Ji, R., Schafer, B. W., and Hutchinson, T. C. (2026). “Full-scale 10-story cold-formed steel building shake table test: Protocol development and shake table performance.” In *Proceedings of the 13th National Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, Portland, OR. (In review).

6. Hutchinson, T. C., Eladly, M., Ji, R., Rivera, D., Cyizere Rukundo, F., Singh, A., Sorosh, S., Zhang, J., Zhang, X., Padgett, L., Jones, H., Karns, J., and Schafer, B. W. (2026). “Advancing use of cold-formed steel framing systems for mid-rise residential construction in seismic zones via full-scale shake table testing.” In *Proceedings of the 8th Residential Building Design & Construction Conference*, State College, PA. (In review).

7. Niu, Y. Emberley, R., Hutchinson, T.C., Schafer, B.W., Meacham, B., Gernay, T. (2026). Thermal modeling of post-earthquake fire tests on a 10-story cold-formed steel building. *International Association of Fire Safety Science* (IAFSS) *Symposium*. In Review.