New report shows how earthquake damage can impact building fire safety performance

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Damage to building structural elements, elevators, stairs, and fire protection systems caused by the shaking from a major earthquake can play a critical role in the spread of fire, hamper the ability of occupants to evacuate, and impede fire departments in their emergency response operations. These are among the conclusions of a groundbreaking study of post-earthquake building fire performance conducted in 2012 by researchers in the Department of Fire Protection Engineering at Worcester Polytechnic Institute (WPI).

"When the ground stops shaking after a major earthquake, the damage may have just begun," said Brian Meacham, associate professor of fire protection engineering at WPI and principal investigator for the post-earthquake fire study. "Historically, post-earthquake fires have been as devastating if not more devastating, than the seismic events that preceded them. In fact, the largest peacetime urban conflagrations (in San Francisco in 1906 and in Tokyo in 1923) were post-earthquake fires. More recently, fire caused significant damage following the 1995 Kobe, Japan, earthquake."

While the danger of widespread quake-related fires is well-known, much less is known about how earthquakes affect the ability of individual buildings to withstand fire or how building fires evolve and spread in the minutes and hours after a quake strikes, Meacham said. "Although considerable research has been undertaken with respect to the performance of structural systems in quakes, research aimed at understanding and quantifying the performance of nonstructural systems and post-earthquake fire performance of buildings has been severely lacking."

To help close that knowledge gap, WPI spent last year participating in an unprecedented study of the effects of earthquakes and post-earthquake fires on a full-scale building. Sponsored by the National Science Foundation and a host of industrial partners, and led by researchers at the University of California, San Diego (UCSD), the study centered on a five-story building constructed atop the world's first large outdoor, high-performance shake table, located at the Englekirk Structural Engineering Center at UCSD. A principal focus of the study was the performance of critical facilities, including hospitals and data centers.

The building was outfitted with a working elevator, a full-size interior staircase, heating, ventilating and air conditioning system components, electrical equipment, fire protection systems, and a mock medical suite, intensive care unit, medical storage room, server room, and residential space. The third floor was configured for fire testing, including complete partition walls and ceiling systems, firestop materials at joints and through partitions, a fire door, a fire sprinkler system, and a smoke detection system.

The researchers subjected the building to a series of simulated earthquakes, ranging from 6.7 on the Richter scale (the magnitude of the 1994 quake in Northridge, Calif.) to 7.9 (representing the 2002 earthquake in Denali, Alaska), while a team of engineers from UC San Diego monitored the building's performance through more than 500 channels of data from a wide range of sensors.

After each simulated earthquake, Meacham and his student researchers entered the building to document the state of the active and passive fire systems and to conduct pressure tests to determine if the shaking compromised the integrity of the third-floor rooms, possibly creating openings that could allow smoke and flames to move between compartments.

After the seismic testing was complete, the WPI team conducted a series of six live fire tests in four spaces on the third floor. They ignited pans of heptane, a liquid fuel that burns hot enough to simulate a fully engaged compartment fire. Using temperature probes and video cameras, the researchers assessed how damage from the simulated earthquakes affected the ability of the active and passive fire protection systems to contain fires and prevent the spread of smoke.

Here are some of the impacts on fire and life safety systems that Meacham and his team documented following the largest earthquake motion and post-earthquake fire tests:

- Structural damage on the second and third levels was significant; while the building didn't collapse, it had to be shored up to support gravity loading prior to the fire testing.
- Damage to the building's interior and exterior wall and ceiling systems created openings through which smoke and flames could spread; debris from the walls and ceilings became obstacles that would have hampered the evacuation of occupants or the movements of firefighters.
- A number of doors were unable to be opened or closed (open doors allow fire to spread; stuck doors can cut off escape routes or hinder the movements of first responders).
- Access to the upper floors was cut off when the staircase became detached from the landing and distortion of the elevator doors and frame on some levels made the elevator unusable. During the fire tests, smoke and hot gasses entered the elevator shaft through the open doors, spreading smoke to other floors and raising temperatures to dangerous levels.

- Most of the active and passive fire protection systems, including the sprinkler system, the heat-activated fire door, fire dampers, and fire stop materials, performed well.

"We are pleased with what we were able to learn in this initial full-scale test of post-earthquake fires," Meacham said. "Through this research, we have begun to build a base of knowledge that will allow us to design more resilient buildings and building systems, and provide better protection to people, property, and mission. But there is much more to do and a lot more we can learn in subsequent studies."

Meacham said he would like to conduct additional laboratory and large-scale studies that will broaden the base of knowledge, encompassing, for example, different construction techniques and different glazing systems; that will gather additional types of information, including heat flux, flow velocity, and visual records of smoke movement and fire growth; and that will compare fire performance before and after earthquake damage.

More information: To read the complete report on the post-earthquake fire tests and learn more about this research project, visit www.wpi.edu/academics/fpe/poli … ering-framework.html

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