New design keeps buildings standing and habitable after major earthquakes (w/ Video)

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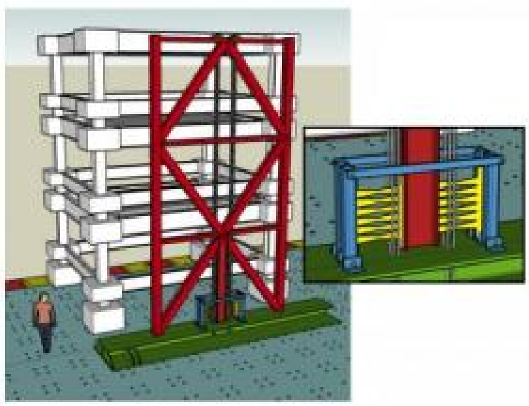

This is a schematic diagram of the rocking frame set up for shake-table testing. The steel-braced frame is shown in red. The white structure behind the frame simulates the weight of a three-story building. The inset shows the replaceable steel fuse, in yellow, at the base of the rocking frame. Behind and in front of the fuse are the vertical steel cables that pull the building back into plumb after an earthquake. During testing, the frame was sandwiched between two of the white structures. Credit: © Stanford University. Illustration by Xiang Ma, Ph.D. candidate in Civil and Environmental Engineering at Stanford

A new earthquake-resistant structural system for buildings, just successfully tested in Japan, will not only help a multi-story building hold itself together during a violent earthquake, but also return it to standing up straight on its foundation afterward, true and plumb, with damage confined to a few easily replaceable parts.

The team that designed the system was led by researchers at Stanford University and the University of Illinois. During testing on a massive shake table, the system survived simulated earthquakes in excess of magnitude 7, bigger than either the 1994 Northridge earthquake or the 1989 Loma Prieta earthquake in California.

"This new structural system has the potential to make buildings far more damage resistant and easier to repair, so people could reoccupy buildings a lot faster after a major earthquake than they can now," said Greg Deierlein, professor of civil and environmental engineering at Stanford, who led the team that designed the new system.

The system dissipates energy through the movement of steel frames that are situated around the building's core or along exterior walls. The frames can be part of a building's initial design or could be incorporated into an existing building undergoing seismic retrofitting. They are economically feasible to build, as all the materials employed are commonly used in construction today and all the parts can be made using existing fabrication methods.

"What is unique about these frames is that, unlike conventional systems, they actually rock off their foundation under large earthquakes," Deierlein said.

The rocking frames are steel braced-frames, the columns of which are free to rock up and down within steel "shoes" secured at their base. To control the rocking and return the frame to vertical when the shaking stops, steel tendons run down the center of the frame from top to bottom. These tendons are made of high-strength steel cable strands twisted together and designed to remain elastic during shaking. When shaking is over, they rebound to their normal length, pulling the building back into proper alignment.

At the bottom of the frame sit steel "fuses" designed keep the rest of the building from sustaining damage.

"The idea of this structural system is that we concentrate the damage in replaceable fuses," Deierlein said. The fuses are built to flex and dissipate the shaking energy induced by the earthquake, thereby confining the damage. Like electrical fuses, the steel fuses are easily replaced when they "blow out."

Deierlein and his colleagues conducted shake testing of the new system in the last few weeks at the Hyogo Earthquake Engineering Research Center in Miki City, Japan. Using different types of fuses and various shaking parameters, they conducted four major tests, the last on Aug. 24. They had previously developed and tested the individual components of the system and performed computational analyses to simulate the system's performance at laboratories at Stanford and the University of Illinois.

"We are really delighted," said Greg Deierlein, who is the principal investigator on the project and oversaw the testing in Japan. "This is the first time we've put this whole system together to see how it would respond dynamically in a building as if it were subjected to an earthquake. It performs well under extreme earthquake shaking."

Deierlein said that while various researchers have been working for 10 or 15 years on some of the ideas and techniques encompassed in the new system, this is the first time anyone has put them all together to demonstrate their performance.

How the tests were done

The tests of the new system were conducted using a three-quarters size model of a standard modern three-story office building with a footprint

120 by 180 feet. The 26-foot tall model sat on a massive vibrating shake table - the largest in the world, measuring over 3,000 square feet in size - that is designed to reproduce the shaking from different earthquakes.

For testing, Deierlein's group constructed a complete three-story steel-braced frame that is sandwiched between two concrete and steel structures in which they concentrated all the mass that would normally be in a building that size. Each of the three stories weighed 100 metric tons.

The researchers subjected their model to ground motions recorded during the 1995 Kobe, Japan, earthquake, magnitude 6.9, and the 1994 Northridge earthquake, magnitude 6.7. The U.S. Geological Survey characterizes the Northridge temblor as the most costly in U.S. history, with losses estimated at more than $40 billion. The Kobe earthquake caused over 6,000 fatalities and economic losses are estimated to have been three to five times greater than Northridge.

System survived even extreme shaking

For some of the shake tests, Deierlein said his group amplified the ground motion shaking from the actual earthquake records to simulate the shaking that would happen during the largest earthquake that each fault is considered likely to generate.

"The rocking frame after that shaking is still virtually undamaged, except that we have these fuses in there that yield and deform, that absorb the energy," Deierlein said.

For the fourth and final test, the group used a motion from the Northridge earthquake and scaled it up 1.75 times greater than the recorded motion, well in excess of the Maximum Considered Earthquake. "The only damage that occurred to the test frame was in the replaceable fuses," said Deierlein. "This final test demonstrated that the rocking frame is a reliable and effective system."

"Most buildings that we design today for large earthquakes are designed such that when there is a large earthquake, the building, in a sense, sacrifices itself to save the occupants," Deierlein said. Buildings that survive earthquakes often have to be torn down because they are too deformed or damaged during the shaking for it to be economical, or even physically possible, to repair them.

"In this design, we are thinking ahead to minimizing the damage that is going to be left in place after the earthquake," Deierlein said. The elastic behavior of the steel tendons, each of which consists of seven steel wires similar to the wire used in modern suspension bridges, is particularly critical to preventing residual deformation of the building by pulling it back into plumb when the shaking stops.

Other economic advantages and sustainability benefits

In addition to saving lives and minimizing repair costs, widespread use of the new techniques could offer other benefits.

"If more buildings are habitable right after an earthquake, you will have less disruption to society," Deierlein said. That could greatly reduce how long economic downturns and social disruptions linger after a major earthquake. And there are potential environmental benefits.

"If you think of the sustainability issues, imagine if you have a city where you have to end up tearing down large numbers of buildings," he said. "In terms of the environmental issues, there are tremendous costs for disposing of construction materials in landfills, coupled with the impacts of manufacturing the materials used for rebuilding.

"We are trying to look at the embodied energy of all of the materials that are used in the building, the things that go into the concrete and steel making, for example," Deierlein said. "By prolonging the longevity of buildings, you have a really positive sustainability impact."

A hoped-for ripple effect

Deierlein said the system he and his colleagues have developed is applicable to steel-framed buildings up to about 15 stories tall, but that the general approach could be modified for other types of buildings.

"We hope that this concept implemented in this braced-frame structure could have much broader applications in terms of spurring the development of these same ideas, but applied to alternate materials and alternate configurations," Deierlein said. "The concept of using this controlled rocking with steel tendons that behave elastically and these energy-dissipating fuses is a general concept that could be applied in different materials and in different forms."

Source: Stanford University (news : web)

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