By Tania Larson

Building Safer:

How Decades of Earth Science is Helping to Reduce the Biggest Earthquake Vulnerability — Man-Made Structures

Unreinforced masonry buildings are especially vulnerable during strong earthquake shaking. Shaking-hazard maps are used to determine areas where these types of buildings need to be reinforced to make them safe during earthquakes. Photo: J. Dewey

On October 17, 1989, occupants of the Transamerica Pyramid in San Francisco were unnerved as the building started to shake. Sixty miles away, in the forest of Nisene Marks State Park in the Santa Cruz Mountains, the Loma Prieta earthquake had struck with a magnitude of 6.9. The seismic waves were channelled — focused by the geological features of the area — toward San Francisco. USGS instruments installed in the building showed that it shook for more than a minute and that the top floor swayed more than a foot from side to side.

The earthquake caused more than $6 billion in damages and took 63 lives. Yet no lives were lost in the Transamerica Pyramid. Despite the intensity of the shaking, the 49-story building came through undamaged. Having been aware of the area's potential for even larger earthquakes, engineers had designed the Transamerica Pyramid to withstand greater stresses than those from the Loma Prieta earthquake.

The biggest danger during an earthquake is often the failure of man-made structures. Not only are lives lost to falling buildings, collapsed bridges and crumbling facades, but disruption of infrastructure and utilities can cause additional hazards and actually keep emergency crews from life-saving resources. Earth scientists have been working for more than 100 years to improve our understanding of earthquake hazards. One of their most important goals is to provide designers, lawmakers and residents with the information they need to build structures that are better able to withstand the forces of the earthquakes they are likely to face.

Building Codes Help Protect Earthquake-Prone Communities

"The most common cause of damage to a structure (a building or bridge) during an earthquake is strong ground shaking," says E.V. Leyendecker, USGS scientist emeritus. "The first line of defense against such shaking is the design and construction of structures to resist it."

And as USGS scientist David Perkins points out, "Earthquake building codes are the primary means to prevent or limit damage to structures."

Building codes help protect us by requiring that new construction meet certain safety requirements. In many earthquake-prone areas, these codes specify the levels of earthquake forces that structures must be designed to withstand.

"To ensure that the code is adequate without being excessively expensive to implement, engineers have to know the likelihood that certain levels of ground shaking will be experienced during the lifetime of the structure," says Perkins.

But how do they know what conditions a building is likely to face? USGS has developed a number of products to show not only how probable it is that a structure will face small, moderate and large earthquakes, but also how much shaking buildings are likely to experience and how they tend to respond to these varying levels of shaking.

Hazard Maps to Reveal Nationwide Seismic Threats

Since 1948, scientists have been making national earthquake-shaking maps that show the variations in the seismic threat from one area to the next. These maps demonstrate the potential shaking hazard from future earthquakes across the country, and they are frequently updated as scientists learn more about earthquakes and the hazards they pose.

Looking to the Past to "Construct" Models of the Future

Coming up with these estimations can be very complicated. Basically, researchers do everything they can to learn about past events: where earthquakes have occurred, how frequently and at what size; how the vibrations have traveled through the ground; how those vibrations were affected by soil and bedrock; and how all of this affected both the land and the structures we have built. Researchers then combine this information to build models of future earthquakes.

As earth scientists look at historical earthquakes, they are particularly interested in the levels of shaking the earthquakes have caused. "Earth scientists can determine past shaking levels by studying the effects of past earthquakes on people, structures and the landscape," says Perkins. "For more recent earthquakes, instrumentation on the ground and in buildings gives a more direct measure of the shaking experienced."

Scientists have been putting instruments in buildings since the 1940s. From this data, scientists and engineers can directly estimate how earthquake shaking will affect similar buildings in the future. When the information is less direct, researchers use computer models of buildings to indirectly generate the estimated effects.

Digging Deeper

What they don't learn with instrumentation above the ground, researchers can sometimes learn from clues beneath the ground surface. The layers of the earth typically lie flat, but when an earthquake rumbles through these layers, they are disrupted, leaving breaks and folds and other clues scientists can use to learn more about an area's susceptibility to earthquakes.

"Historical seismicity alone does not tell us all we need to know about future earthquake locations and magnitudes," says Perkins. "Accordingly, earth scientists look for faults and signs of earthquake liquefaction or earthquake-induced landslides in the geological past in order to estimate the sizes and dates of these

USGS Earthquake Scientists — A Nationwide Notion of Pride

Heidi Stenner

Title: Geologist

Location: Menlo Park, Calif.

Length of service with the USGS: 7 years

In 1999, a large, magnitude-7.4 earthquake rocked northwestern Turkey. The fault that ruptured is similar in a lot of ways to the San Andreas Fault in California, so it was important to learn all we could about the quake and its effects. As part of a small team, I helped map where and how the fault ruptured the ground. In doing so, we saw multi-story apartment buildings reduced to a single story of rubble, people living in tents outside their homes in the rain and bridges and overpasses rendered useless. And we heard a lot of sad stories.

Seeing firsthand the effects of an earthquake really motivated me to do what I can to keep that from happening again. Understanding the science behind earthquakes is one aspect needed to better prepare and reduce the risk to people from such events. It is my time in Turkey that reminds me most why we need to keep advancing earthquake science.

Thomas Noce

Title: Geologist

Location: Menlo Park, Calif.

Length of service with the USGS: 20 years

I'm most proud to have been working to help quantify the hazards in the greater San Francisco Bay Area, particularly in the areas of man-made land that didn't exist in the 1906 earthquake. These areas are potentially the most vulnerable in a repeat scenario of the 1906 event, and the Loma Prieta earthquake of 1989 provided but a glimpse of their shortcomings. We have learned a great deal about liquefaction and hazard analysis since then, and we have developed methodologies to identify and quantify the liquefaction hazards that will serve us not only here in the Bay Area, but across the country in all seismically-at-risk regions.

Although much work remains to be done in the Bay Area to complete the hazard mapping, what we have begun and hope to finish will serve as an example of how hazard mapping should be done in the future in historically active liquefaction zones across the United States, such as the New Madrid seismic region, Charleston, S.C., the Pacific Northwest and Alaska.

It has been equally exciting to work with the best of the best in their fields, with people who care about their work and their contributions to make the world a safer place.

events. This allows them to extend the 'history' of large events back as much as 10,000 years or more. From this longer history, earth scientists can also determine the rate at which earthquakes of all sizes occur."

However, as Leyendecker points out, this does not tell the entire story. Designing a building requires knowledge not only of the earthquakes it will likely face, but also how those earthquakes will affect the building — the loads it will have to bear and how and to what capacity it will respond to those forces. "Research conducted since the 1906 San Francisco earthquake, particularly over the last 20 to 30 years under the National Earthquake Hazards Reduction Program, has contributed to these three areas of loads, response and capacity," says Leyendecker.

Science Advancements Help Refine and Improve Building Codes

Thanks to increased earth science focus, building codes have seen regular major changes since the 1960s, and according to Perkins, these advancements have paid off.

"Structures built using recent building codes have withstood remarkably large levels of ground motion in the earthquakes that have been experienced since the 1990s," says Perkins.

For example, in 1971, the magnitude-6.6 San Fernando earthquake left the Los Angeles dam badly damaged. This dam, so weakened that a strong aftershock could have caused a collapse, was all that stood between 80,000 people and 15 million tons of water. Residents in an 11-square-mile area were forced to evacuate their homes while the water behind the dam was lowered. With years of ground motion studies and advancements in earthquake studies to turn to, engineers built a new, safer dam. This new structure was tested in 1994 when the magnitude-6.7 Northridge earthquake hit the area. The new dam held, with very little damage.

"In 1996, a major revision of the ground-shaking-hazard maps, developed in collaboration with the earth-science community and design engineers, resulted in major improvement of building codes and design standards," says Leyendecker. The revisions incorporated new descriptions of the hazard, such as the specific soil and rock conditions and how buildings experience vibrations in response to the vibrations of the ground.

"This new way of describing the hazard enables structural engineers to better predict structural response to ground shaking for design purposes. Knowledge of the site condition of the maps also enables engineers to adjust the design to incorporate the actual site condition. In the end, these improvements result in better protection of lives and property," says Leyendecker.

By taking all of this information into account, scientists have created a powerful data set. "With all these forms of earth science information," says Perkins, "researchers can compute the likelihood of future earthquake ground shaking at all locations in the U.S. It is maps of these probabilistic ground motions that are used to determine building code requirements."

More than 20,000 cities, counties and local government agencies use building codes based on these maps, but shaking-hazard maps have many other applications. They are also used by insurance companies to set rates for properties in different areas, civil engineers to estimate the stability of hillsides, the Environmental Protection Agency to set construction standards for waste-disposal facilities, and the Federal Emergency Management Agency to allocate funds for earthquake education and preparedness.

To make sure users understand and get the best value out of the maps, the USGS offers workshops to familiarize users with the shaking-hazard maps and earthquake issues.

While both the Loma Prieta and Northridge earthquakes demonstrated that we can build safer structures that do withstand earthquakes, there were still considerable losses that revealed just how vulnerable major metropolitan areas can be when hit by an earthquake. Awareness of this vulnerability was reinforced by the 1995 Kobe, Japan, earthquake. With magnitudes of 6.7 and 6.9, respectively, both the Northridge and the Kobe events are considered moderate earthquakes, yet even in these areas known for their earthquake preparedness, the losses suffered by the densely populated urban areas were catastrophic.

Houses without adequate connections to foundations can easily shift during even moderate earthquake shaking, causing extensive damage. Pipes and wires may be broken by a slight cripple-wall shift, resulting in fires, water damage or other problems. Much damage of this type can be avoided by using inexpensive bracing techniques, such as those recommended in the seismic design provisions of building codes.

High-Resolution Maps to Help High-Risk Urban Areas

To address this vulnerability, engineers, officials and emergency-response teams needed better, more detailed information. In 1998, the USGS began high-resolution earthquake hazard mapping in three high-risk urban areas: the eastern San Francisco Bay region, Seattle and Memphis. Since then, projects in St. Louis, Mo., and Evansville, Ind., have also been started.

These projects will provide city officials with hazard maps that are more detailed and take local and regional geology into account. As the Loma Prieta earthquake demonstrated, geology can play a big role in how a city is impacted by an earthquake. The assessments are also addressing potential ground failure hazards, such as liquefaction and earthquake-triggered landslides.

This research is being used to create urban hazard maps, scenario earthquake maps and long-term forecasts of earthquake probabilities. These products will provide better details for updating building codes, reducing risks and planning for recovery in high-risk metropolitan areas.

Looking Long Term

The hazard maps that influence today's building codes incorporate more than a century of seismic monitoring and decades of research. In their quest to find ways to protect people from the effects of earthquakes, USGS researchers have come up with many creative ways to expand their understanding of the hazards. They have traveled the globe, comparing notes and historical records with researchers around the world. They have dug through mud and sand and clay. They have bored through layers of rock. They have even learned about earthquakes by examining long-drowned forests and other side effects earthquakes have had on the landscape.

By taking all of these efforts and turning them into products communities can use to protect themselves, USGS researchers have helped save many lives and millions of dollars. But they know their work is not done. In the next 100 years, they will continue to look for new ways to refine and enhance the maps and models that influence building codes, making all of our structures — from our homes, to our hospitals, to the infrastructures that support our resources — better able to withstand the earthquakes they will inevitably face.

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USGS Earthquake Scientists — A Nationwide Notion of Pride

Hal Macbeth

Title: Supervisor of seismic analysis for the Northern California Seismic Network

Location: Menlo Park, Calif.

Length of service with the USGS: 26 years

Public Education: The Earthquake Hazards Team has put a superior effort into providing Web-based information to the public not only about where recent or historical earthquakes have occurred, but also about how the public can use that information to protect themselves and others from earthquake hazards in the future. This effort has brought public awareness and access to disaster crisis information to a level where, in the end result, we hope some lives might be saved.

Through the efforts of public outreach, I have personally fielded calls and e-mails daily on questions about earthquakes, volcanoes, landslides and other hazard/earth science information. Many of these calls are from our nation's youth, who are eager to educate themselves and potentially will be our nation's next generation of scientists. That's much to be proud of.

Emergency Hazards Response: I have seen this as a continually evolving effort to better improve the access of real-time earthquake information for federal, state and local disaster-response teams. I serve as one of five USGS duty seismologists who are on call 24/7 for emergency response to earthquakes occurring in Northern California. ShakeMaps (one of our map products showing calculated ground-shaking intensities) are produced minutes after a moderate-to-large earthquake strikes, alerting rescue/repair crews to focus on the most damaged areas first.

Efforts are also being made to establish an early warning system for ground shaking in a large earthquake, potentially giving a few seconds warning ... more potential lives saved.

I don't think I could be any more proud than being a team member of an organization whose ultimate purpose is to protect lives and property not only here in the United States, but also helping to identify and possibly mitigate hazards in a global crisis, such as tsunamis and other earthquakes occurring around the world.