STRUCTURAL PERFORMANCE

performance issues relative
to extreme events

The seismically-isolated Ishinomaki Red Cross Hospital, about 75 miles (120 km) from the epicenter of the M9.0 Great Tohoku Earthquake of March 11, 2011, was undamaged, and fully-operational throughout and after the earthquake and subsequent tsunami. Courtesy of SIE, Inc.

What's Happened to Seismic Isolation of Buildings in the U.S.?

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Seismic isolation is the strategy of placing a structure on a flexible foundation to effectively decouple earthquake ground motions from the motion of the building. It is a technically elegant solution to the challenging problem of minimizing or even eliminating earthquake damage in buildings. Yet, despite the substantial benefits offered by seismic isolation and its availability since the mid 1980s, while other countries have readily embraced the technology, the United States has been slow to adopt seismic isolation. In the United States there are only about 125 seismically isolated buildings, whereas in Japan there are more than 6500 and a similar number of bridges. In China there are estimated to be several hundred buildings. After a promising start in the mid-1980s, today seismic isolation of buildings in the U.S. has nearly ground to a halt: presently, only about four or five seismically-isolated buildings are constructed each year. Why have building owners in the U.S. apparently ignored the most effective means available for protecting their investments from earthquake damage? There is no single reason, but rather a host of factors. In this article we explore these factors, and make suggestions for removing some of the barriers to the implementation of seismic isolation in the United States.

The concept of seismic isolation is not new. More than one hundred years ago, in 1885, the Englishman John Milne designed and constructed a seismic isolation system for a building in Tokyo that incorporated ball bearings and dished cast iron plates (Naeim and Kelly, 1999). The first use of rubber for a seismic isolation system was in 1969, when a school in Skopje, Macedonia was constructed on unreinforced rubber blocks. The first modern-era seismically-isolated building was a government building in Wellington, New Zealand, constructed in 1981, which used laminated steel and rubber bearings. These bearings contained a lead core that dissipates energy through plastic deformation during an earthquake, a system that since has become one of the most widely used in the world. Seismic isolation was first introduced to the United States in 1985 with the construction of the Foothill Communities Law and Justice Center, in Rancho Cucamonga, California. This 170,000 square foot facility also uses laminated rubber bearings, called high-damping rubber bearings, with a specially formulated rubber compound to provide the energy dissipation properties to the system. Also developed in the United States in the mid-1980s was a sliding seismic isolation system known as the Friction Pendulum System, which has a sliding surface in the shape of a spherical dish and a low-friction articulated slider to provide an elongated natural period for the supported structure. The first application of this system was the seismic retrofit of a wood frame apartment building in San Francisco that was damaged by the 1989 Loma Prieta earthquake.

The first design provisions for seismic isolation, the *Tentative Seismic Isolation Design Requirements* by the Structural Engineers Association of Northern California, were published in 1986. These evolved into the first formal building code provisions for seismic isolation in the 1991 *Uniform Building Code* (UBC) and are now embodied in the *International Building Code* (IBC), through reference to ASCE/SEI 7, and exist in similar form for seismic isolation retrofit in ASCE/SEI 41.

Thus, by the early 1990s, it appeared that seismic isolation was poised to take off in the United States as the earthquake protection system of choice, particularly for critical facilities such as hospitals, police and fire stations, and emergency operations centers, high-value

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buildings such as museums and data centers, and socially important buildings such as historic city halls. By the late 1990s, though, there were only about 50 seismically-isolated buildings in the U.S., of both new and retrofit construction. This hardly represented the "revolution" in seismic protection technology envisioned by early advocates of seismic isolation; on average, between 1985 and 1997 only about three seismically-isolated building projects were completed each year. In Japan, at the time of the Great Hanshin (Kobe) Earthquake on January 17, 1995, about 85 seismically-isolated buildings had been approved for construction. By the year 2000, there were about 600 (Aiken, et al, 2000). Through the following decade, thousands more seismically-isolated structures were constructed in Japan.

What has accounted for the slow pace of adoption of seismic isolation in the United States? While there certainly are technical challenges to the implementation of seismic isolation, these challenges have mainly been overcome. Today the barriers to implementation in the U.S. are not primarily technical, but rather economic, cultural and regulatory.

Economic Barriers

With few exceptions, building construction in the U.S. is driven by "first-cost" considerations rather than "life-cycle" or "risk management" cost-benefit considerations. When the primary objective of a building project is to keep the initial cost of construction to a minimum, then seismic isolation does not make economic sense. The cost of seismic isolation varies, and the actual costs are a function of the building configuration, total floor area, and seismic design performance objectives. For a typical medium-size data center or laboratory building, a rough estimate of the cost of seismic isolation is 5 to 15 percent of the cost of the structural framing system (*note that this is not the total project cost; depending on the type of facility, seismic isolation often amounts to only a few percent of the total project cost*). When it comes to consideration of seismic isolation, this added cost almost always ends up being a "deal breaker"; why would a building owner add 5 to 15 percent to the structural cost of their project with no clear economic incentive? Why would a developer add seismic isolation as a "feature" when the cost of isolation might make their project un-competitive?

When a life-cycle cost evaluation is performed, considering the full expected life span of a building and assuming the occurrence of a code-based design-level earthquake event during that life span, a far different conclusion is reached. For such an event, a seismically-isolated building can be expected to experience essentially no damage, a far different outcome than for an ordinary building. Furthermore, in the event of a design-level, or even beyond-design-level earthquake, most isolated facilities can be expected to remain fully functional, eliminating losses caused by down-time, lost production, lost data, and lost building contents. An impressive example of this is the fully-operational performance of the Ishinomaki Red Cross Hospital in the M9.0 Great Tohoku Earthquake of March 11, 2011, dramatically demonstrated in this publicly available video: **www.youtube.com/watch?v=Pc1ZO7YwcWc**. Viewed in such a light, seismic isolation almost always shows itself to be economically worthwhile.

Seismic isolation would become more economically attractive to building owners if property insurers recognized the benefits of isolation in reducing earthquake damage. To date, however, insurers have

Overall view of the isolation basement of the Ishinomaki Red Cross Hospital. The isolation system comprises about 100 natural rubber bearings and U-shaped steel dampers. (Photo: SIE, Inc.)

been unwilling to grant premium benefits for seismically-isolated buildings. Whereas insurers routinely offer premium discounts for protection measures such as fire-resistant construction, fire and theft alarms, hurricane resistant windows, and other building features that reduces potential losses, to date they have been unwilling to recognize the benefits of seismic isolation. If insurers were to provide premium incentives to building owners to use advanced protective measures such as seismic isolation, they would help to encourage the use of the technology in the same way that they have encouraged the use of fire-resistant construction.

Cultural Barriers

In the United States earthquakes tend to be viewed as regional hazards, affecting mainly "seismically active" areas such as California, Nevada, Oregon, Washington State, and Alaska. Anyone familiar with seismic hazards in the United States, however, knows that significant seismic hazards actually exist throughout much of the country. Still, the general perception is that earthquakes are not a national problem, but a localized one. In other countries, such as Japan, New Zealand, and Italy, earthquakes are recognized as a threat to the safety and economic well-being of the entire nation. In these countries there is a heightened awareness of earthquake hazards and therefore a willingness to spend resources to mitigate earthquake damage through implementation of seismic isolation.

In the United States there is little interest in devoting time and money to prepare for earthquake events that are viewed (often incorrectly) as having only a small probability of occurrence during the life of a structure. When it is proposed to building developers that they may want to consider designing their building for a seismic performance level above the code-mandated minimum, the authors are consistently met with a blank stare: "Why would I want to do that? Doesn't the building code make my building earthquake-proof?" When it is explained that the building code provides only a minimum level of safety, and that additional design and construction costs are required to provide improved seismic performance, the typical response is "Let's just go with the code." It is human nature to believe that bad things will happen to "the other guy", and in a country the size of the United States, it is even easier to imagine that earthquake damage will happen to someone else in some other place. In other countries, where earthquake hazards exist throughout the nation, it is not as easy to rationalize away the threat of earthquakes.

This cultural difference in the perception of seismic hazards, and the willingness to pay for improved seismic performance, applies not only to developers of commercial buildings, but also to individual home owners. Various estimates have that anywhere from 150,000 to 250,000 people live in seismically-isolated buildings in Japan, and these people have all paid a "premium" to do so. For a typical large condominium building in Japan, the accepted additional cost for seismic isolation is on the order of the price of a small car, about $15,000 or about 5 percent more than a condominium without isolation. In contrast, the number of people in the U.S. who live in isolated buildings is about two dozen.

Countries such as Turkey, Chile and Italy are now experiencing a dramatic upswing in the adoption of seismic isolation for both critical (hospitals, emergency operations centers) and non-essential "commercial" applications (such as multi-unit residential structures). Why? In these countries, recent large earthquakes have caused profound economic and loss-of-life disasters. Seismic isolation has been recognized as the best technology to protect core components of society's infrastructure. It is also interesting to note that in Turkey seismic isolation devices must be imported, due to the lack of local manufacturers, which means the costs to implement seismic isolation are even higher than in the U.S. Even so, this cost premium is not proving to be an impediment to the use of the technology.

Regulatory Barriers

Regulatory impediments to the acceptance and implementation of seismic isolation persist today. Numerous experimental and analytical research programs in the 1980s at many prominent research laboratories worldwide conclusively verified the effectiveness of seismic isolation, and established a strong technical basis for practical design. Building code provisions for seismic isolation, originally established in the 1991 UBC, have systematically evolved since then. It cannot, however, be said that code requirements have been improved in ways to facilitate more straight-forward and widespread use of the technology. In Japan, the 2000 revision of the *Building Standard Law*, the national building code, incorporated new provisions for seismically-isolated buildings that allowed for response spectrum, rather than time-history analyses, along with other simplified design requirements for certain types of isolated structures. These provisions are now used for the design of about one-third of all isolated buildings in Japan. Whilst a number of efforts have been made over time to codify simplified procedures for seismic isolation design in U.S. codes, none have ever been adopted. Instead, seismic isolation design codes have become increasingly complex, and therefore less intuitive and more difficult to use.

In the U.S., the codified performance basis for seismically-isolated structures is higher than that for ordinary structures; that is, the playing field is not level. Clearly, the analysis and design of a seismically isolated building presents greater technical challenges than for an ordinary building, but the building codes place significantly higher requirements on both the seismic performance expectations and on the level of technical review required of the designer. Building owners often do not understand that these additional requirements exist, or why they lead to increased construction costs and design fees. Seismic isolation is a mature technology with a 30-year track record of successful implementation. It's time that onerous code requirements for complex analysis, multi-party peer review, and full preliminary prototype testing of isolation bearings on every project be reduced, as they lead to superfluous costs and schedule delays that inhibit the adoption of seismic isolation.

Summary

In short, the authors believe that the following actions would increase the adoption of seismic isolation of buildings in the U.S.:

- Move away from sole considerations of "first cost" when planning building projects, and give fuller consideration to building life-cycle costs. This is one of the bases of the "green building" movement, where potential increases in first costs are accepted to achieve long-term sustainability objectives.
- Property insurers should be encouraged to recognize the benefits of seismic isolation (and other enhanced seismic protection technologies) in preventing earthquake damage. If reduced insurance premiums were factored into the life-cycle costs of seismically-isolated buildings, the technology would become more economically attractive.
- The design team (engineers, architects, and planners) should not be afraid to promote seismic isolation as a means to reduce or eliminate seismic hazards, increase reliability, and lower total life-cycle costs. While seismic isolation is still a somewhat unusual approach to earthquake protection in the U.S., it has been widely accepted in other countries to the point that elsewhere seismic isolation design and construction are considered routine.
- Regulatory barriers to seismic isolation should be reduced. In particular, better simplified methods for seismic isolation design should be implemented in building codes, and requirements for peer review and project-specific prototype testing should be streamlined.

Readers are invited to submit their own thoughts on why the U.S. has been slow to adopt seismic isolation, while other countries have more readily adopted the technology (**isolationfeedback@live.com**). The authors are particularly interested to hear from those of you who have promoted, but not managed to implement, seismic isolation for a project. These ideas will be collected and will form the basis of a follow up article in a future issue of STRUCTURE magazine.▪

References

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