Is Seismic Design by U.S. Codes and Standards Deficient?

Part 2

By S. K. Ghosh, Ph.D.

Part 1 of this series discussed background information relative to the issues, including an overview of current codes and standards (STRUCTURE, July 2019).

A Success Story

The Disaster Prevention Research Institute (DPRI) of Kyoto University issued some revealing statistics following the January 17, 1995, earthquake that hit the Japanese port city of Kobe and surrounding areas (the Great Hanshin earthquake). *Figure 2* is drawn based on those statistics. The figure clearly shows that the strongest correlation of damage was with the age of the structure.

The correlation can be attributed largely, if not entirely, to important revisions over the past 50 years to the Japanese national building code and related national standards. The Japanese national code, the *Building Standard Law of Japan* (BSLJ), specifies design loads, allowable stresses, and other requirements. The details of structural design are specified in standards issued by the Architectural Institute of Japan (AIJ). These AIJ standards, prepared separately for each structural material, are supplements to the BSLJ.

The 1968 Tokachi-Oki earthquake caused significant damage to buildings, and a revision to the BSLJ reduced the spacing of steel ties in reinforced concrete columns to 4 inches. In 1971, a major revision of the AIJ standard for reinforced concrete incorporated ultimate strength design of beams and columns for shear, including more stringent shear reinforcement requirements. These changes are comparable to significant code changes in the United States following the 1971 San Fernando earthquake in California. Post-1971 reinforced concrete structures performed much better in the 1995 Kobe earthquake than their pre-1971 counterparts, primarily because of the improved shear design of columns, as can be seen in *Figure 2*.

The 1978 Miyagi-ken-Oki earthquake caused significant damage to buildings and led to a 1981 revision of the BSLJ, which introduced a two-phase earthquake-resistant design. The first-phase design (essentially the allowable stress design from the previous BSLJ) is intended to protect a building against loss of function in ground motions expected to occur several times during its lifetime, with peak ground accelerations in the range of 0.08g to 0.10g. The second-phase design is intended to ensure safety under a ground motion expected to occur once in the lifetime of a building, with peak ground accelerations in the range of 0.3g to 0.4g. Post-1981 structures designed by the two-phase procedure performed well in the 1995 Kobe earthquake, as can be seen in *Figure 2*.

There was a remarkable lack of widespread significant structural damage to buildings from ground motions associated with the magnitude 9.0 Tohoku earthquake of March 11, 2011, which caused tsunamis that unleashed major devastation. Significant structural damage was observed only in older buildings predating the 1971 and 1981 code changes mentioned above.

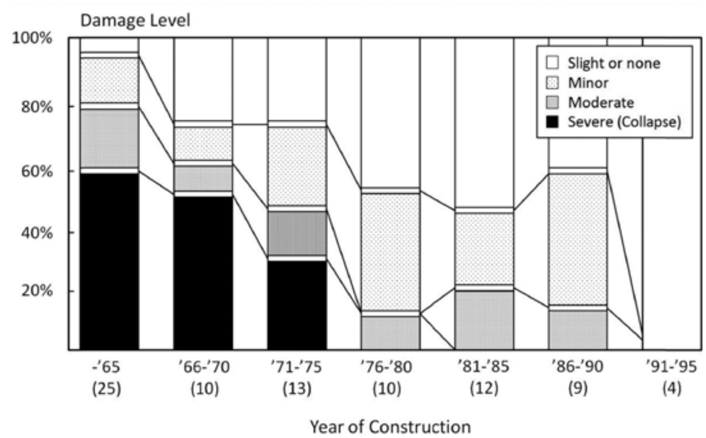

Figure 2. Correlation of damage observed in the 1995 Kobe earthquake with age of structures.

Although precise definitions of the various damage states are not available, it appears the two-stage design introduced in the BSLJ in 1981 may have the potential to bring designers close to attaining a functional recovery performance objective. Examining this potential in the context of U.S. seismic codes and standards is likely to be beneficial.

Improvements Are Desirable; Simplistic Solutions Are Not the Answer

The U.S. Geological Survey (USGS) has issued Fact Sheet 2018-3016: *The HayWired Earthquake Scenario – We Can Outsmart Disaster*. The scenario anticipates the impacts of a hypothetical magnitude-7.0 earthquake on the Hayward Fault. The fault is along the east side of California's San Francisco Bay and is among the most active and dangerous in the United States because it runs through a densely urbanized and interconnected region.

Studies done for the HayWired scenario showed that:

- Even if all buildings in the bay region met current building code, 0.4 percent could collapse, 5 percent could be unsafe to occupy, and 19 percent could have restricted use.
- For only a small percentage cost increase, more resilient buildings constructed to more stringent building codes could allow 95 percent of the bay region's population to remain in their homes and workplaces following such an earthquake.

Although many assumptions form the basis of a study such as the above and the numbers are not to be taken literally, the importance attached to building codes and the impact of improvements in building codes should be noted.

Governor Brown's message accompanying his veto of California Assembly Bill 1857 read in part:

"The National Institute of Building Science and Technology is in the initial stages of developing an immediate occupancy standard for buildings following a natural disaster. This federal agency is consulting engineers, scientists, and other experts to understand the changes needed to ensure that a building can be used immediately after a natural disaster.

Instead of duplicating this federal process at the state level, it would be wise to let the Institute finish its work."

As noted in Part 1 of this article, NIST's charge was "the development of a plan detailing the basic research, applied research, and implementation activities necessary to develop a new immediate occupancy (IO) building performance objective for commercial and residential buildings." Despite Governor Brown's claim, NIST is not "in the initial stages of developing an immediate occupancy standard for buildings."

While the needed research detailed in the NIST report will take much time and resources to carry out, if the objective is narrowed down to functional recovery or immediate occupancy of commercial and residential buildings following the design earthquake of ASCE/SEI 7 (note that these are not identical objectives; immediate occupancy is somewhat more stringent), that may indeed be attainable with the knowledge and the information that is already available. This will doubtless contribute to community resiliency. However, a few things are going to be essential to keep in mind.

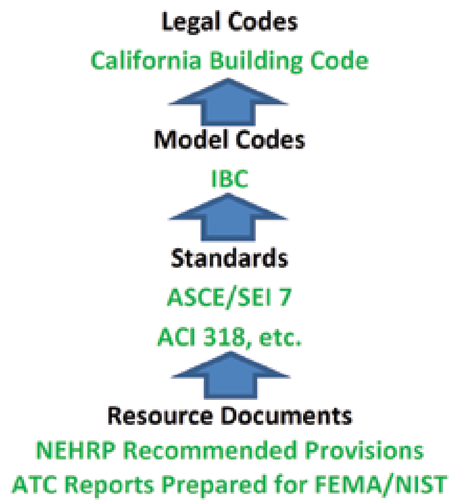

Figure 3. The codes and standards system in the United States.

First, it has been suggested that the use of an importance factor I_e of 1.5 for all buildings will take us to, or at least close to, functional recovery or immediate occupancy (see Lucy Jones' ABC7 interview cited in Part 1). The approach was proposed in a document issued by the National Institute of Building Sciences, *Natural Hazard Mitigation Saves – 2017 Interim Report*. This kind of an approach is unlikely to be sufficient, as evidenced from the fact that California's Office of Statewide Health Planning and Development (OSHPD), the state agency charged with the safety of healthcare facilities, has found it necessary to make dozens of significant modifications to the seismic design provisions of the IBC and ASCE/SEI 7 for the design of healthcare facilities in California. The use of a higher I_e-value in design does not change the risk category of a building. The risk category, along with the anticipated intensity of seismic ground motion at the site, determines the Seismic Design Category (SDC) of a building, which dictates many important aspects of design and detailing. If one is looking for a simplistic solution, assign all buildings to RC IV. That would be like being forced to buy expensive insurance, difficult to afford and often of questionable benefit, for every building.

Second, it must be understood that there is always a cost associated with enhanced performance. The challenge is going to be to attain the objective while keeping the total cost increase to a minimum. The basis of a 1% increase in construction cost for a 50% increase in lateral strength, as claimed in the Lucy Jones interview, is far from clear. In any case, this would only address the primary structure and not all of the non-structural items that keep a building functional.

Third, the best way of accomplishing the outlined objective may not be by passing a bill in a state legislature. Such a measure is preemptive, cannot have a national consensus behind it, and also bypasses long-established procedures for making changes in U.S. building codes and standards.

Regular Order

There is an established building code development and adoption process in the United States (*Figure 3, page 19*). State and local building codes, which are the legal codes that must be followed for design and construction, are typically based on a model code. The model code of choice in virtually the entire country today is the IBC, seven editions of which, dated from 2000 to 2018, have been published.

A model code organization such as the International Code Council (ICC), the publisher of the IBC, does not have resources to develop code provisions on every aspect of design and construction covered by the building code. Thus, it is common for the model codes to adopt national consensus-based (or ANSI-approved) standards. ASCE/SEI 7 – *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* and material standards such as ACI 318 – *Building Code Requirements for Structural Concrete*, TMS 402/602 – *Building Code Requirements and Specification for Structural Masonry*, AISC 360 – *Specification for Structural Steel Buildings,* and the *National Design Specification®* (NDS) *for Wood Construction* are important standards that are adopted by the IBC for design loads on structures and design and construction provisions for structures made of different materials. ACI 318 and TMS 402 are standards and not codes, even though the word *Code* appears in their titles. The various standards published by ASTM International are also widely adopted by the model code as well as by many other standards.

The seismic design provisions of ASCE/SEI 7 are drawn mostly from a resource document called the NEHRP *Recommended Seismic Provisions for New Buildings and Other Structures*, funded and published by the Federal Emergency Management Agency (FEMA). Enhancements to the seismic provisions are often based on reports prepared by the Applied Technology Council (ATC). That organization prepares its reports following research or studies sponsored by entities such as NIST or FEMA on particular topics of interest (*Figure 3*). These reports are then published by FEMA, NIST, or ATC itself.

If a functional recovery or an immediate occupancy (IO) objective is to be added to U.S. seismic design requirements, the document in which it needs to be added is ASCE 7. Work leading to such an addition can be done through a coordinated study, such as an ATC or NIST project, or by some other similar means. Some funding is going to be necessary.

Conclusion

To claim that the current U.S. seismic codes and standards are deficient is unwarranted. Codes and standards implement decisions made by the structural engineering community a long time ago given perceived societal needs, including economic considerations. Structures designed by these codes and standards are expected (see *Recommended Lateral Force Requirements and Commentary*, 1996 Edition, by the Seismology Committee of the Structural Engineers Association of California), in general, to be able to:

1) Resist a minor level of earthquake motion without damage.
2) Resist a moderate level of earthquake ground motion without structural damage but possibly with some nonstructural damage.
3) Resist a major level of earthquake ground motion – of an intensity equal to the strongest earthquake either experienced or forecast for the building site – without collapse but possibly with some structural as well as nonstructural damage.

It is expected that structural damage, even in a major design level earthquake, will be limited to a repairable level for most structures. In some instances, repair may not be economical. The level of damage depends upon several factors, including the intensity and the duration of ground shaking, age of the structure, structural configuration, type of lateral force-resisting system, materials used in the construction, and construction workmanship. Damage to nonstructural systems and building contents can be much higher than the damage to the building structure.

Although the performance expectations are now being stated differently in recognition of the importance of community resiliency, and some advances have been made in this arena, structural and nonstructural damage is still expected in the design earthquake, except possibly in essential facilities. Whether this is still an acceptable basis for a building code is a question that is increasingly raised. A decision, and ways of implementing that decision, should preferably be developed utilizing the established consensus process.▪

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*S. K. Ghosh is President, S. K. Ghosh Associates Inc., Palatine, IL and Aliso Viejo, CA. He is a long-standing member of ASCE Committee 7, Minimum Design Loads for Buildings and Other Structures, and ACI Committee 318, Structural Concrete Building Code. (**skghoshinc@gmail.com**)*