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

Part 1

By S. K. Ghosh, Ph.D.

Articles recently appearing in major newspapers and features run on other media outlets have called into question the seismic performance of buildings designed using U.S. seismic codes and standards. The primary criticism appears to be that, while the codes and standards prevent the collapse of buildings in strong earthquakes and even provide life safety by allowing people to evacuate safely, they do not ensure the continued functioning of the buildings or the community.

The following is a sampling of relevant comments:

> *NY Times, April 17, 2018: San Francisco's Big Seismic Gamble*
>
> The article quotes seismologist Dr. Lucy Jones, formerly of the U.S. Geological Survey, as saying: "When I tell people what the current building code gives them, most people are shocked… Enough buildings will be so badly damaged that people are going to find it too hard to live in L.A. or San Francisco."
>
> *ABC7 Los Angeles, June 7, 2018: Dr. Lucy Jones pushes for Safer Buildings*
>
> "What we have are buildings that won't kill you. But if it's a total financial loss, well that was your financial choice to make. We're creating disposable buildings. So when you go into the engineering analysis, we can make it 50 percent stronger by adding 1 percent to the cost of construction, which is not very much. There may be even better, more cost-effective ways.
>
> What we're creating right now is such a huge financial vulnerability. It really impairs the economic future of the state [California]. I think it's something that needs to be done at the state level so that the cities aren't competing with each other on this type of thing."

If a useful discussion is to occur regarding seismic performance and functionality of buildings following earthquakes, several additional essential aspects need to be brought into the discussion. These include: the performance impact of the large existing stock of vulnerable buildings, the many aspects beyond building design that would impact building functionality, the likely performance of new buildings designed to current building codes, the earthquake performance successes of Japan that might provide guidance, and the already existing process by which seismic design provisions are developed, vetted, and adopted into U.S. building codes. This article discusses these items with the hope that they will be contemplated together, allowing for the development of well-considered and beneficial improvements in seismic design, where needed.

Anticipated Performance of Existing Vulnerable Buildings

The existing building stock in this country includes a large proportion of vulnerable buildings that were either not designed by a structural engineer at all or designed by older codes with no or inadequate consideration of resistance to lateral (sideways) forces due to wind or earthquakes. In California, there is more knowledge of the existing building stock than in many other parts of the country.

According to California Assembly Bill (AB) 2681, which was vetoed by then-Governor Brown in September 2018, "Potentially vulnerable building" means a building that meets one of the following criteria:

1) The design and construction of the building were approved by the city or county before the adoption of the 1976 edition of the *Uniform Building Code* and had one or more of the following characteristics:
   a) Unreinforced masonry lateral force-resisting systems or unreinforced masonry infill walls that interact with the lateral-force-resisting system.
   b) Concrete buildings with a nonductile lateral-force-resisting system.
   c) Soft, weak, or open front walls at the ground floor level of multistory light framed buildings.
2) The design and construction of the building were approved by the city or county under the 1995 or earlier edition of the *California Building Code* and consisted of any of the following structural systems:
   a) Steel frame buildings with moment frame connections.
   b) Concrete or masonry buildings with flexible diaphragms.
   c) Buildings with precast, prestressed, or post-tensioned concrete.

The significance of the 1976 *Uniform Building Code* (UBC) is that there were significant changes made in the 1973 UBC following observations of structural performance and damage in the 1971 San Fernando earthquake. These changes were enhanced and refined in the 1976 UBC. The significance of the 1995 *California Building Code* (CBC) is that it is based on the 1994 UBC and the prequalified moment connections at beam-column joints of steel special moment frames of the 1994 and earlier editions of the UBC were found to be deficient (many of them failed) in the 1994 Northridge, CA, earthquake.

Much of the risk to human life and property in earthquakes stems from the existence of the vulnerable buildings listed above.

Effective mitigation of the risk to vulnerable buildings would require widespread retrofitting measures which can be mandated or facilitated only by local (city, county, or state) ordinances. This does not fit into the conventional scope of building codes. If the decision is made to retrofit a building – either because it is required or voluntary – the *International Existing Building Code* (IEBC), which makes extensive references to ASCE 41, *Seismic Evaluation and Retrofit of Existing Buildings*, can be utilized for that purpose.

Survival of Cities Raises Diverse Challenges

To quote again from the NY Times article cited above, "The goal of the code, say proponents of a stronger one, should be the survival of cities – strengthening water systems, electrical grids, and cellular networks – not just individual buildings." The items mentioned are referred to as lifeline infrastructure and are critical to the resiliency of communities, but they are also clearly outside the scope of the nation's building codes as they are currently constituted and accepted.

Exterior cladding (such as walls, windows, doors, and roofs) and interior non-structural systems (such as suspended ceilings, partitions, fire sprinklers, and communication systems) or components (such as HVAC equipment) may sustain damage in an earthquake, which leads to a partial or total loss of building function. The lack of integration between performance goals for structural, exterior, and interior systems means that even if the structural system performs well, damage to these non-structural systems and components may mean the building would not be available for its intended use. It ought to be noted that satisfactory seismic performance of exterior and interior nonstructural systems is already within the purview of the building code. The problem is that these non-structural systems and components often do not benefit from the same level of engineering attention and inspection as the structure itself.

Reasonable Level of Safety

2018 IBC Section 101.3 states: "The purpose of this code is to establish the minimum requirements to provide a reasonable level of safety…" *A reasonable level of safety* has been interpreted to mean that we expect some level of damage, but less than what would be expected to put lives at appreciable risk when loads are so large (such as in an earthquake) that society has determined it to be economically unjustifiable to prevent *all* damage.

Two Initiatives

Given concerns raised about inadequacies of U.S. seismic codes and standards, two significant initiatives that were recently undertaken merit brief discussion.

California Assembly Bill 1857

Assembly Bill (AB) 1857 was passed by the California legislature but vetoed by then-Governor Brown in September 2018.

This bill would have required the California Building Standards Commission to assemble a *functional recovery working group*. The bill would have required the working group, by July 1, 2022, to consider whether a "functional recovery" standard is warranted for all or some building occupancy classifications and to investigate the practical means of implementing that standard.

The bill would have required the working group to advise appropriate state agencies to propose appropriate building standards. If it were determined that a functional recovery standard was not warranted, the bill would have required the working group to assist with the development of a document providing guidance to, among others, building owners and local jurisdictions regarding function recovery after a seismic event. The bill would have authorized the commission to issue regulations based upon the recommendations from the working group. According to the bill, "functional recovery standard" meant a set of enforceable building code provisions and regulations that provide specific design and construction requirements intended to result in 1) a building for which post-earthquake structural and nonstructural capacity is maintained, or 2) can be restored. The restoration was to support the basic intended functions of the building's pre-earthquake use and occupancy within a maximum acceptable time, where the maximum acceptable time might differ for various uses or occupancies.

The shortcomings of California AB 1857 were that it moved towards requiring that more resources go into construction of new buildings 1) for California only, not making use of the national forums already used for the development of seismic design requirements, 2) without recognizing the broad and complex infrastructure and community aspects to be addressed to achieve continued function of buildings, and 3) without specific discussion of the much larger, likely impact of existing vulnerable buildings.

continued on next page

U.S. Senate – NIST Initiative

In May 2017, the U.S. Senate tasked the National Institute of Standards and Technology (NIST) with 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. This led to the release, in August 2018, of NIST Special Publication 1224, *Research Needs to Support Immediate Occupancy Building Performance Objective following Natural Hazard Events*.

To quote from NIST's announcement of the report: "After an earthquake, hurricane, tornado or other natural hazard, it's considered a win if no one gets hurt and buildings stay standing. But an even bigger victory is possible: keeping those structures operational. This outcome could become more likely with improved standards and codes for the construction of residential and commercial buildings, …" It is important to note that NIST's scope extends beyond earthquakes to all natural hazards.

According to Steven McCabe, Director of the National Earthquake Hazards Reduction Program (NEHRP) at NIST, "Current standards and codes focus on preserving lives by reducing the likelihood of significant building damage or structural collapse from hazards. …But they generally don't address the additional need to preserve quality of life by keeping buildings habitable and functioning as normally as possible, what we call 'immediate occupancy.' The goal of our report is to put the nation on track to achieve this performance outcome."

The NIST report is organized around four topic areas: building design issues; community considerations; economic and social considerations; and, acceptance and adoption considerations. The report concluded: "New engineering design approaches and construction techniques, combined with considerations of community, social, economic, and acceptance and adoption issues, are needed to improve the performance of commercial and residential buildings and community resilience."

The report went on to state: "In exploring the research and implementation needs for IO building design and adoption, it has become clear that enhanced building performance is more than a technical problem of how to design and construct buildings that are more resilient to natural hazards. There are multiple complex social, economic, and policy challenges that should also be addressed to ensure that adoption of IO performance objectives is not only viable but would also be successful in meeting goals for increased community resilience to natural hazard events. …The challenge of achieving IO performance is just as much a social and economic matter as it is a technical one."

Current Codes and Standards Provide More than Life Safety

Seismic design for basically all buildings in the United States is done by a standard that is adopted by the *International Building Code* (IBC). The standard is ASCE/SEI 7, *Minimum Design Loads, and Associated Criteria for Buildings and Other Structures*. It assigns every structure to one of four Risk Categories (RCs):

- RC I – buildings that pose a low risk to human life in the event of failure (e.g., unoccupied storage facilities and barns).
- RC II – all buildings except those classified as Risk Categories I, III, and IV. (e.g., most commercial and residential buildings).
- RC III – buildings designed to accommodate a large number of occupants (e.g., schools and theatres) or that contain hazardous materials or processes, potentially posing a substantial risk to human life in the event of failure.
- RC IV – buildings classified as essential facilities or that contain hazardous materials or processes, the failure of which could pose a substantial risk to the community.

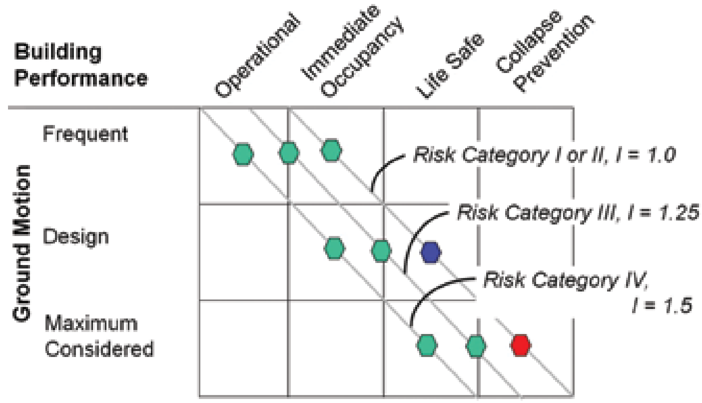

Figure 1. Expected seismic performance of buildings assigned to different seismic design categories. Courtesy of FEMA P-1050-1.

RC I and II buildings are designed for earthquakes using an Importance Factor, I_e, of 1.0; RC III buildings are designed using an I_e of 1.25, and RC IV buildings are designed using an I_e of 1.5. This means that RC III buildings (schools) are designed using seismic forces that are 25% higher than those for RC I or II buildings. Moreover, RC IV structures (hospitals, fire stations, police stations) are designed for 50% higher seismic forces than RC I or II buildings. Thus, RC III buildings have 25% more strength to resist lateral forces due to earthquakes than RC I or II buildings, and RC IV structures have 50% more strength.

Seismic design is different in another critical respect for higher risk category structures. ASCE/SEI 7 imposes acceptable limits on interstory drift. Interstory drift is the difference between the lateral deflection expected in the design earthquake at the top of a story minus the same deflection at the bottom of the same story. RC I and II structures are typically permitted an interstory drift up to 2% of story height, RC III structures up to 1.5%, and RC IV structures only up to 1%. This is primarily to minimize damage to nonstructural (architectural, mechanical, and electrical) components.

The combination of the higher importance factor and the tighter drift limit results in a higher level of performance for RC III buildings than for RC I and II buildings, and an even higher level of performance for RC IV buildings (*Figure 1*). RC I and II buildings can be immediately occupied following frequent earthquakes (ones that are likely to occur once every 50 years or so), provide for life safety (an opportunity for occupants to safely evacuate the building) in the design earthquake (simplistically, an earthquake that is likely to occur once every 500 years), and prevent collapse in the maximum considered earthquake (again, simplistically, an earthquake that is likely to occur once in 2500 years). An RC IV structure (hospitals, fire stations, police stations), on the other hand, remains operational following frequent earthquakes, can be occupied immediately following the design earthquake, and provides for life safety even in the maximum considered earthquake. The performance of an RC III structure is in between the performances of an RC I or II structure and an RC IV structure.

The critics of current seismic codes and standards are primarily looking for seismic performance for RC II buildings (commercial, residential occupancies) that would be equivalent to, or at least comparable to, the seismic performance of RC IV buildings.▪

Part 2 of this series will be published in an upcoming issue of STRUCTURE and will discuss earthquake performance successes and opportunities within already existing code processes.

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**)