

Seismic Risk - Why It Should Be Considered and Impediments to Implementation - An Earthquake Center Perspective

Michel Bruneau¹

¹ Director, Multidisciplinary Center for Earthquake Engineering Research, Professor, Dept. of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, NY 14260. Ph: (716) 645-3391x104; Fax: (716) 645-3399; email:

bruneau@mceermail.buffalo.edu

Abstract

Selection of acceptable seismic risk revolves around significant societal and engineering concerns. One approach relies on cost-effective quantitative enhancement of seismic resilience for critical structures and systems. A Center perspective can provide a coordinated research framework to develop the advanced knowledge and technologies needed to develop the integrated engineering tools, decision-support systems, and related techniques, and procedures needed for that purpose.

Introduction

Recent changes to the seismic hazard return period and corresponding force level that should be considered in design, and the progressive adoption of mandatory seismic design requirements by some jurisdictions in the middle and eastern parts of the US, has caused considerable discussions as to whether seismic risk should be considered, and, if so, what level of seismic resilience is desirable for society.

There are both significant societal and engineering concerns related to this issue. On one hand, financial, political, or societal arguments are often advanced to argue against the adoption of such seismic design requirements, generally underlying a general skepticism towards the proposed design levels corresponding to the credible earthquake at any given location; on the other hand, few are openly willing to condense responsibility for (say) 50,000 death and \$100 billion in losses in any natural disaster, recognizing that what is often perceived as a reasonable assumption of risk and cost-saving measure prior to such an event is unavoidably treated as a lack of responsible duty in lawsuits after the fact (note that the overwhelming accumulated engineering knowledge that exist on how to mitigate risk makes reliance on the “act of god” theory practically indefensible). Therefore, unless a legal entity (e.g. an agency, a state, or an owner) develops the confidence to affirm that it has willingly elected to ignore the seismic risk and openly acknowledge that it is willing to deal with the aftermath of a disaster rather than invest into planning and preparedness, consideration of seismic risk is unavoidable. The challenge (and arguments) of

course, lies in the level of risk to consider, and the trade-offs required as the considered scenarios remain credible but correspond to longer return periods.

In addition, although providing new infrastructure with a satisfactory level of seismic protection is achievable at reasonable cost, past earthquakes have demonstrated that the most significant risk and exposure lies in the existing infrastructure never designed considering seismic hazards. This creates a significant challenge as it is not fiscally possible to seismically retrofit the entire existing infrastructure. A responsible goal however is to focus available resources on enhancing the seismic resiliency of communities, by focusing on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. These critical facilities consist of water and power lifelines, acute-care facilities (hospitals), and organizations that have the responsibility for emergency management at the local community level. The highway network connecting critical facilities is also key following an earthquake. Recent research showed that residents of high-risk communities assign great importance to these particular infrastructural elements, ranking water pipelines, major hospitals, and electrical power systems as the three most important elements in the built environment that they believe must remain operational in the event of a major earthquake. Survey respondents also expressed a greater willingness to contribute financially to the seismic upgrading for hospitals and other public safety buildings and for utility and transportation lifelines than they would for other types of structures.

A Center perspective makes it possible to view and address the above issues through coordinated and integrated research activities, by develop the advanced knowledge and technologies needed to achieve integrated engineering tools, decision-support systems, and related techniques, and procedures that can provide cost-effective quantitative enhancement of seismic resilience of these highly critical structures and systems, as described in the following.

Definition of Resilience

As part of the conceptualization of a framework to enhance the seismic resilience of communities (Bruneau et. al 2003), seismic resilience has been defined as the ability of a system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance) and to recover quickly after a shock (re-establish normal performance). More specifically, a resilient system is one that shows:

1. Reduced failure probabilities,
2. Reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences,
3. Reduced time to recovery (restoration of a specific system or set of systems to their “normal” level of performance)

A broad measure of resilience that captures these key features can be expressed, in general terms, by the concepts illustrated in Figure 1, based on the notion that a measure, $Q(t)$, which varies with time, can be defined to represent the quality of the infrastructure of a community. Specifically, performance can range from 0% to 100%, where 100% means no degradation in quality and 0% means total loss. If an earthquake occurs at time t_0 , it could cause sufficient damage to the infrastructure such that the quality is immediately reduced (from 100% to 50%, as an example, in Figure 1). Restoration of the infrastructure is expected to occur over time, as indicated in that figure, until time t_1 when it is completely repaired (indicated by a quality of 100%). Hence, community earthquake loss of resilience, R , with respect to that specific earthquake, can be measured by the size of the expected degradation in quality (probability of failure), over time (that is, time to recovery). Mathematically, it is defined by:

$$R = \int_{t_0}^{t_1} [100 - Q(t)] dt \quad [1]$$

Much research is needed to quantify resilience, particularly for some type of critical facilities. For a geographically distributed system designed to provide a standardized service, such as a power grid, or a water distribution network, the problem is simpler, as the vertical axis in Figure 1 could be a quantifiable value, such as kilowatts, gallons, or households provided with service. However, for critical systems for which the deliverable is not a simple engineering unit, such as for the case of acute care facilities, the vertical axis is harder to define.

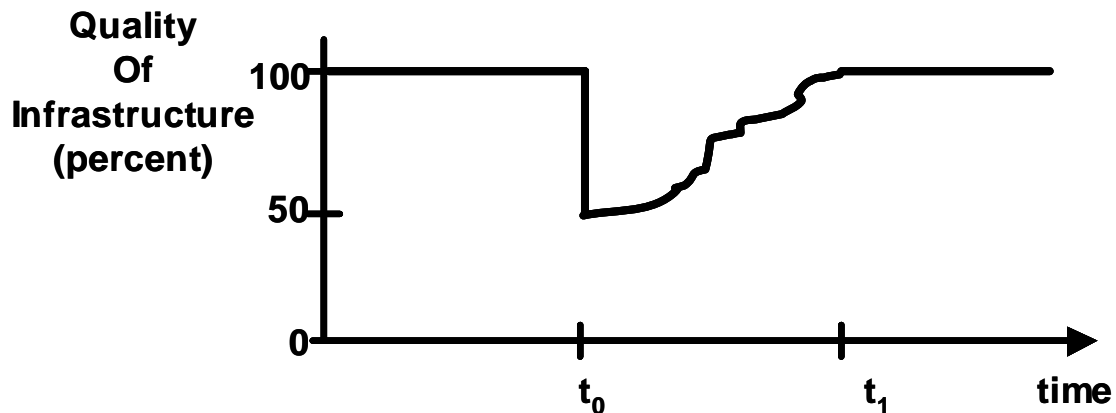


Figure 1: Schematic representation of seismic resilience concept (Bruneau et al. 2003)

Due to the complexity of acute care facilities, and depending on the extent of seismic deficiencies in any specific hospital, considerable investment may be required to ensure that an acute care facility remains operational following an earthquake. The extensive resources that would be required to achieve such a level of resilience would likely not be available at the onset, and activities to upgrade the facilities would have to be staggered over many years. Ideally, using the limited resources available at any

time along this multi-year upgrading process, the objective would be to first make the investments that provide the largest enhancements to seismic resilience, and to sequence all subsequent investments following the same logic. This approach presents a significant challenge to decision makers and their specialist consultants, as there is no integrated tool that could support such a decision on factual engineering data. Integrated coordinated research is needed to investigate how such integration could be achieved.

A research program can be structured such that efforts aimed at the development of seismic response modification technologies provide data that can be used in integrated decision engines. Such a program can also address research needs for seismic retrofit technologies to provide effective solutions for acute care facilities, and complement the research needed to formulate the integrated decision systems that would be required to identify the most appropriate seismic actions, taking into account both engineering issues and organizational constraints (technical and organizational dimensions of resilience).

Data from past earthquakes as well as engineering experience demonstrates that functionality of a building can be lost due to structural failure, geotechnical failure, or damage to nonstructural building components (i.e., medical equipment). Furthermore, these are closely inter-related as damage to nonstructural building components, for example, is directly tied to structural response. In other words, modifying structural response solely for the purpose of reducing damage to the structure may have positive or negative impacts on the seismic performance of nonstructural building components. Therefore, a coordinated research program on that topic must also focus on the integrated issues of performance, including both structural and nonstructural systems and components and their functionality.

An example of “roadmap” needed to quantify and enhance the seismic resilience of acute care facilities is shown in Fig. 2. This roadmap can serve as the backbone of the needed research activities and as a primary tool to focus and integrate research activities in this perspective, listing the steps toward the objective, and the essential dependencies. The roadmap emphasizes that seismic resilience may be compromised by failure of both engineered and non-engineered systems. It also conceptually illustrates the probabilistic fragility framework that must be integrated to quantify seismic resilience of acute care facilities, and where interventions can be made to enhance this resilience.

As shown in Fig. 2, a first interim quantification of resilience is possible at the physical dimension level. From there, social science research input is needed to generate the knowledge to elevate the resilience quantification to the organizational dimension level by translating the physical system resilience into operational consequences. The research funding environment germane to a research Center, with a focus on system-level research, makes it possible to allow the development of the coordinated and integrated research efforts needed to tackle such major problem.

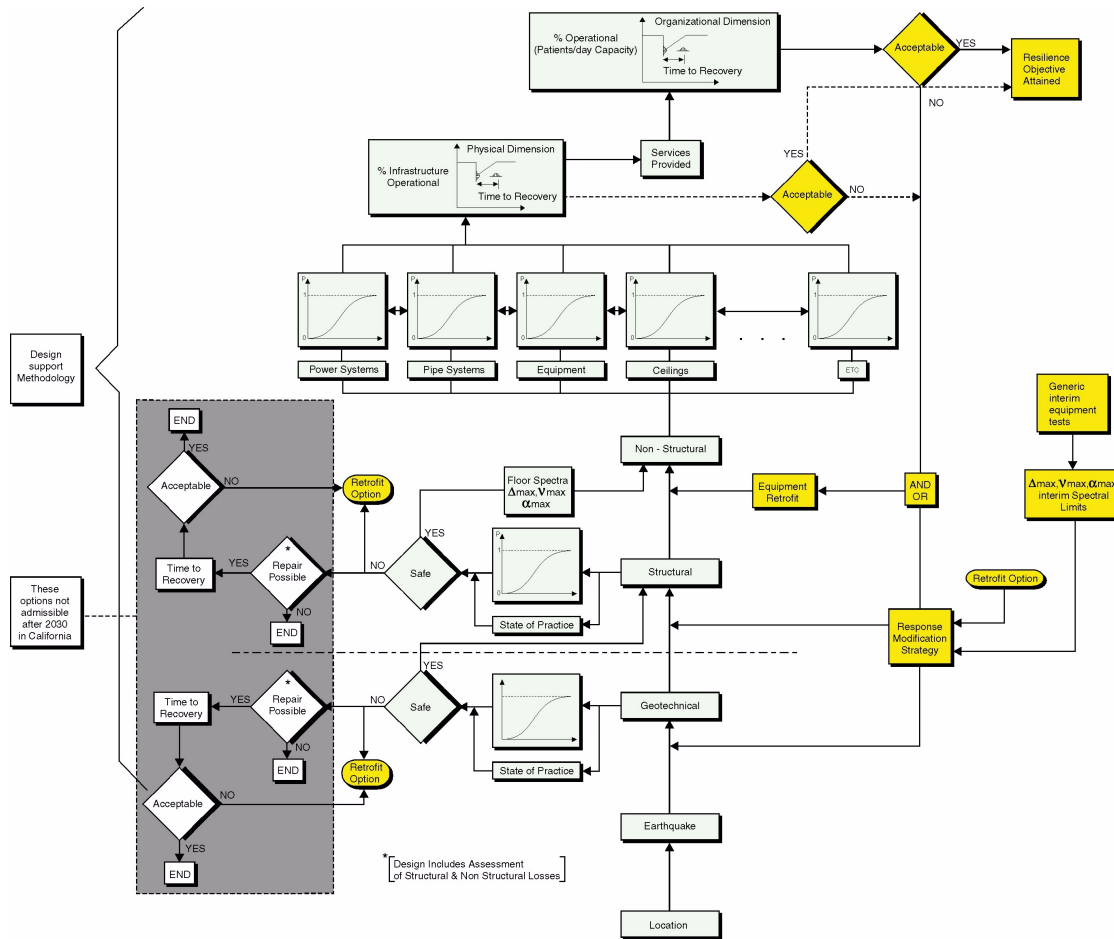


Figure 2: Flow-chart of procedure to achieve seismic resilience for a single hospital

Conclusions

Considerable challenges and trade-offs exist in defining the seismic risk to consider, particularly in the design of critical facilities. While much effort can be expanded on a pure risk definition, an alternative approach can focus on the development of decision support methodologies to manage the trade-offs and best utilize the available resources. Focusing on the objective of enhancing seismic resilience can provide a responsible goal to expend such available resources, by focusing on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. Centers can contribute toward this objective by formulating and coordinating integrated research programs.

References

Bruneau, M., Chang, S., Eguchi, R., Lee, G., O'Rourke, T., Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., von Winterfelt, D., (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities", EERI Spectra Journal, Vol.19, No.4, pp.733-752.