ENGINEERS: THE FORGOTTEN STAKEHOLDER IN THE RESILIENCE CONVERSATION

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Abstract

Resilience is a broadly defined concept that involves political, economic, and social issues as well as engineering issues. The concept of resilience, that is, the ability to prepare for, adapt to, and rapidly recover from the effects of natural disasters is a notion that is appealing to political, business, and individual interests across all levels of society. As a result, the resilience buzzword has taken over the national and international conversation related to preparedness, mitigation, design, and construction.

The concept of community resilience involves social, political, cultural, and human considerations along with building and infrastructure considerations. Understanding community needs, assessing the hazards in a region, evaluating the vulnerabilities and functional interdependencies of the built environment, and prioritizing the investment of limited resources, is a monumental challenge. Deciding what to do is a complex problem that involves interactions between a large number of disparate stakeholders, with potentially competing interests, and varying levels of technical knowledge or decision-making capabilities.

Measuring community resilience involves technologies that are in their infancy and information that is incomplete. Millions of dollars are being invested in researching the problem, but practical solutions and reliable information will be a long time in coming. As Federal, State, and Local governments invest in long-term research, and community stakeholders attempt to develop resilience plans based on available information, engineers are the stakeholders with the ability to bridge the gap between new theoretical ideas and practical implementation. Engineering issues, however, are only one consideration, and conversations at the local and national levels are dominated by the other stakeholders involved. Fundamentally, resilience is an engineering concept and engineers need to take a leadership role in the resilience conversation to facilitate the implementation of resilience concepts in the near term.

Introduction

The idea that stakeholders should be involved in decision-making is not new. In the case of design against the effects of natural hazards, performance-based seismic design in its current form originated in the 1990s. With its unprecedented economic impacts, the 1994 Northridge earthquake demonstrated that current building codes were generally adequate to protect lives, but they were not adequate (or intended) to protect against the economic disaster that a major earthquake could cause (SSC, 1995). As a result, performance-based design concepts permeated the seismic design and construction industry, and engineers began involving sophisticated clients in decisions related to seismic risk in the form of hazard levels and performance objectives. Stakeholders were introduced to the idea that code compliance was not "earthquake-proof," and that there was a menu of performance-based design options that could be used to reward additional investment with improved performance (or to achieve equivalent performance with reduced investment).

Since then, performance-based seismic design concepts have become more sophisticated, and performance-based design concepts are being applied in other hazard areas. Based on a probabilistic framework developed by the Pacific Earthquake Engineering Research Center (PEER) in the 1990s, the

Federal Emergency Management Agency (FEMA) funded the ATC-58 series of projects to develop a probabilistic performance-based seismic design methodology intended to provide stakeholders with quantitative information on which to base design decisions. The current phase of work is intended to develop a procedure for practical use of this information in performance-based design of buildings. To date, stakeholder interactions on this project have shown that communication of hazard and performance information to non-technical audiences has not gotten any easier, and communication of probabilistic information is even more difficult, if not impossible.

Community resilience concepts are the latest evolution of stakeholder involvement in performance-based decision making. Because communities are complex combinations of social, political, cultural, and human needs combined with complex building and infrastructure interdependencies, the resilience conversation involves interactions between a large number of disparate stakeholders, with some competing interests, and varying levels of technical knowledge or decision-making capabilities. These stakeholders need information on which to base important decisions on preparedness, emergency response, and how to prioritize the investment of limited resources. This information, if available, is incomplete, highly uncertain, and likely probabilistic. Communication of this highly technical information in actionable ways will be extremely difficult, and use of this information by disparate stakeholders will be a challenge. The technical community needs to think about what type of information will be provided, how we intend it to be used, how it will be communicated by engineers, and what actions can and should be taken based on this information to meet community objectives for resilience.

Lessons from Performance-Based Seismic Design

Present-generation procedures are based on FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA, 1997), and are currently embodied in ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014). These documents outline concepts of performance levels related to damageability and varying levels of seismic hazard. Inherent in the concept of performance-based engineering is the selection of *performance objectives* (i.e., an expression of desired performance at a specified seismic hazard level) by informed and knowledgeable stakeholders. Although present-generation procedures establish a vocabulary and a means by which engineers could quantify and communicate seismic performance to clients and other stakeholders, implementation in practice has uncovered certain important limitations in their use. Probabilistic expressions of seismic hazard (in terms of return periods on the order of hundreds or thousands of years) are difficult to explain in the context of the average design life of a building, performance level characterizations (e.g., life safety or immediate occupancy) are difficult to factor into financial models, and few clients fully comprehend the ramifications of the trade-offs that were being made in performance-based design decisions.

The FEMA-funded ATC-58 series of projects is intended to develop a next-generation performance-based design methodology that addresses the problems encountered with present-generation procedures. The technical engine for this methodology was published in 2012, as the FEMA P-58, *Seismic Performance Assessment of Buildings, Methodology and Implementation* (FEMA, 2012). In this methodology, performance is characterized in probabilistic terms as the potential for incurring damage or losses in the form of casualties, repair costs, repair time, and unsafe placarding (see Figure 1).

The current phase of work (ATC-58-2 Project) includes utilizing the assessment methodology to develop practical performance-based design guidance. Recognizing that stakeholder input is key to development of design guidance, the ATC-58-2 Project has included significant interactions with stakeholders to identify their decision-making needs. In spite of advancements that have been made, results from a FEMA-sponsored workshop on communicating seismic performance metrics in design decision-making (ATC, 2014) showed that there is still a gap between what stakeholders know and understand, and what engineers are trying to provide.

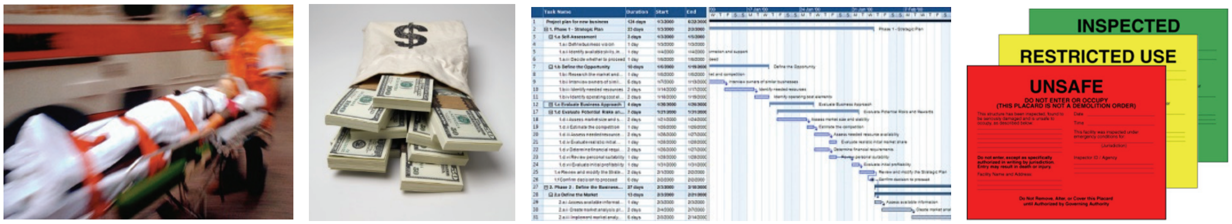

Figure 1. Earthquake consequences in terms of casualties, repair costs, repair time, and unsafe placarding, which are expressed probabilistically in the FEMA P-58 next-generation seismic performance assessment methodology.

The workshop also showed that probabilistic measures of performance are not understandable by most stakeholders. Most importantly, it showed that just because we can calculate a loss quantity, such as the potential for casualties, it does not mean that information is useful, desirable, or even actionable. Stakeholder participants in the workshop expressed a strong preference for not receiving information on performance related to casualties. Although they could imagine making a financial decision based on an acceptable level of expected repair costs, they were uncomfortable dealing with the potential for casualties or the notion of an acceptable number of casualties. Lessons from stakeholder interactions related to performance-based seismic design should be brought to the resilience conversation.

Resilience Concepts

Resilience is a broadly defined concept that involves political, economic, and social issues as well as engineering issues. It is also an evolving concept. In 2013, the Community and Regional Resilience Institute (CARRI) published an analysis of more than 40 definitions of resilience (CARRI, 2013). In general, most definitions of resilience include the concepts of preparing for anticipated hazards, adapting to changing conditions, and rapidly recovering from the effects of natural disasters.

Resilience is an appealing notion that seems to embody the concepts of preparedness, mitigation, response, and sustainability that came before it. Perhaps because of its broad-based definition, it has the potential to be all things to all people, which makes it politically palatable and acceptable to the public across many different social dimensions. As a result, the resilience buzzword seems to have taken over the conversation related to preparedness, mitigation, design, and construction like no other national imperative that came before it.

In 2015, the National Institute of Standards and Technology (NIST) published the *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (NIST, 2015) defining resilience, and outlining a six-step process for resilience planning. The recommended planning process is necessarily comprehensive (see Figure 2). It defines the notion of communities as an assembly of political, social, human, and cultural needs along with financial considerations and a built environment containing many interdependencies (see Figure 3). It outlines a logical process of: (1) assembling relevant stakeholders in a collaborative team; (2) understanding the problem through assessment of social dimensions and the built environment; (3) determining goals and objectives; (4) initial plan development through analysis of gaps and solution strategies; (5) preparation, review and approval of a resilience plan; and finally (6) implementation.

The *Community Resilience Planning Guide* correctly explains that the effects of a natural disaster on a community will be a complex interrelationship between how the hazard is distributed throughout the region, the vulnerability of buildings and infrastructure to that hazard, the functional interdependencies between buildings and systems, and how different segments of the community are able to withstand (or not withstand) the loss of infrastructure or services over a period of time. It also points out that planning for resilience involves elected and appointed government officials, representatives from various civic departments and services, emergency planners, business interests, and community groups, as well as the design and construction industry. Although resilience is a shared goal, many of these groups might have competing interests that affect resilience planning. For example, funding mitigation activities could undesirably raise taxes, or increases in construction costs could adversely affect businesses or availability of affordable housing.

Figure 2. The community resilience planning process (from NIST, 2015).

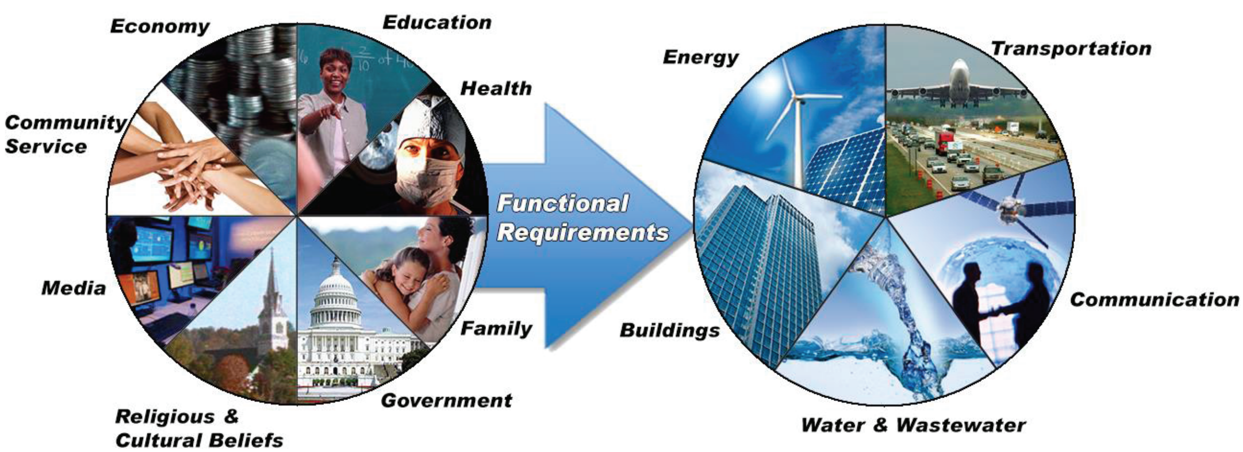

Figure 3. Interdependencies between community social functions and the built environment (from NIST, 2015).

Resilience Technologies

Measuring the current resilience capability in a community is a monumental technical challenge. It has captured the attention of Federal, State, and Local governments in the Unites States, and millions of dollars are being invested in researching the problem. Research organizations have been set up to receive funding for advancing the technology, and countless resilience institutes have been formed with proprietary tools or services intended to assist communities in becoming more resilient.

One such organization is the NIST-funded Community Resilience Center of Excellence, headed by Colorado State University and 10 partner research institutions. This $20 million, five-year program is intended to accelerate NIST's long-term goal to develop system-level models and associated databases to provide quantitative, scientific-based information for community resilience decision-making. The centerpiece of this effort is the NIST-Community Resilience Modeling Environment (NIST-CORE). NIST-CORE is an impressive undertaking that promises to model the hazard throughout a region and geospatially predict potential damage in the built environment. Early results indicate that the technology exists to simulate regional hazard and vulnerability, and there is every expectation that this research effort will eventually be successful. How long will it take to achieve this long-term goal? What kind of information will be generated, what are its limitations, and will it be understandable and actionable by stakeholders?

Although logically explained and theoretically defined, measurement of community resilience today is based on technologies that are in their infancy, information that is largely incomplete or imperfect, and results that are highly uncertain and complex to interpret. We need to make sure community resilience stakeholders understand the limitations in available information, and how best to use it.

Are We Avoiding What We Already Know?

Measuring resilience is a logical objective, and investing in research for the development of new design and construction technologies is necessary for the future viability of the built environment. But no amount of analysis is going to tell us that we are not at risk for damage to key buildings and infrastructure or loss of key community functions or services.

There is a notion that our technologically dependent society has made us more brittle, rather than more resilient (McAslan, 2010). In the past, access to information was possible if you had a book and a candle. Today, any number of occurrences can limit access to information, from a power outage, to a telecommunications failure, to a bookshelf falling over and damaging a computer. Edwards (2009) notes that critical services such as food supply chains, sewer systems, electrical power grids, and transportation networks are progressively more interconnected and reliant on information and communication systems. Nothing operates without power, and modern conveniences associated with technological advancements of the information age have created a just-in-time lifestyle in which goods, services, and information are obtained on-demand. The system is a fragile connection of interdependencies that leaves society vulnerable to even small disturbances.

Is trying to analyze whether or not the power (or other) distribution system will remain intact a reliable community resilience planning activity, or is it wishful thinking? We could invest a lot of time an effort in determining that the system is likely to be functioning, but even this best case scenario means there is a possibility that service will be interrupted, at least to a portion of the community. Looking at it another way, it is a virtual certainty that a major natural disaster is likely to cause a power outage somewhere within a community. If power is critical to functionality, steps should be taken to avoid being without power.

Similarly, we know even code conforming buildings are likely to become damaged, liquefiable soils are likely to liquefy, and any other distributed system (e.g., sewer, water, transportation) are likely to become interrupted. We don't need complex analytical platforms to tell us this. That is not to say that analyzing vulnerabilities and interdependencies to understand the possible extent of damage would not be useful information. The point is not to wait until our developing technologies have matured, or until our incomplete information becomes complete. We should not allow imperfect knowledge of our resilience situation to keep us from acting on what we know to be true now. We should also remain cognizant of what actions can and should be taken based on information available now as well as information that is likely to be available in the future.

What Can Engineers Do Now?

Before the advent of performance-based design, engineers made performance decisions on behalf of society. Implicitly, engineers knew that society expected structures to be safe and not fall down under the loads anticipated during the service life of the structure, and codes were developed accordingly. More recently, societal expectations have been evolving, and emphasis on functionality (in addition to safety) is increasing.

It is safe to say that communities now want to be resilient. Definitions of what constitutes resilience might vary, but we implicitly know that resilience translates to the built environment in terms of improved performance, decreased vulnerability, more redundancy, and less reliance on interdependencies with potentially vulnerable infrastructure. In the performance-based design paradigm, we can keep asking stakeholders if they want buildings to be occupiable (yes), systems to be functional (yes), communities to be livable (yes), and whether they want to pay for it (many do, but a large percentage say no), but we know these answers. The complexity associated with quantifying the resilience problem, the large number of disparate stakeholders, and the potentially competing interests of different community groups will allow the conversation to continue, and might allow society to avoid asking and answering the hard question which is: if we really want resilience, are we willing to take the steps necessary to achieve it?

NIST GCR 16-917-39, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery* (NIST, 2016), identified improvement of codes, standards, and guidelines as the first of four key recommendations for improving resilience. Of course, changes to building design and construction practice must be done in ways that are socially and economically feasible, but the best way that engineers can influence the future built environment is through the code development process. We need to develop a functional performance objective for buildings and infrastructure in our building codes.

Engineering is eliminating variables, bounding solutions, enveloping scenarios, and controlling responses to obtain a desired outcome. Engineers can help simplify the resilience conversation by using engineering principles to help reduce complex interactions into simple and actionable steps that can be taken in the near term. We also need to be honest about what we know to be true now, even if the answers are difficult for stakeholders to hear. For example:

- If electrical power (or other service) is absolutely critical, provide for emergency power (or other on-site services).
- If critical services are located in one building, build more than one. If they are located in vulnerable buildings, relocate them.
- Land-use planning affects resilience. Building in flood zones, liquefaction zones, and landslide hazard areas should be avoided if at all possible.

- No amount of analysis will provide perfect information. We must communicate uncertainty, not promise that we know the answer, and help communities with practical contingency planning for buildings and infrastructure.

Conclusion

As community leaders seek to develop long-term resilience plans that satisfy all interest groups, and researchers continue to advance our analysis and design technologies, engineers should use engineering principles (although not necessarily engineering language) to simply the design challenges and help implement near-term steps leading to resilience. Since we know the desired outcome, it is time for engineers to take a leadership role, and once again make decisions on behalf of society to help it achieve what we know it wants.

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