IMPROVING RESILIENCY BY DESIGNING FOR COMMUNITY NEEDS

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Abstract

The fundamental purpose of civil engineering—to meet community needs—can help the profession frame the discussion around resiliency and in particular, help answer questions such as, "What performance targets are appropriate for buildings and infrastructure in a given community?" Ultimately, the built environment is a means to an end—buildings and infrastructure enable services, provide shelter, facilitate transportation, and ultimately, enable and sustain society. Community needs are particularly important following a disaster—it is these needs that need to drive performance criteria and design.

There have been various recent efforts to highlight the need to design around community needs. This paper pulls from key aspects and recommendations from various efforts; principally the ATC-126 Project, which developed the NIST GCR 16-917-39 Report, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery* (NIST, 2016). That NIST Report addresses overarching societal considerations, lifeline interdependencies, lessons from past disasters, gaps and deficits, and the current state of U.S. standards, guidelines, and performance criteria for the following key lifelines: electric power, natural gas and liquid fuel, telecommunication, transportation, and water and wastewater systems. Findings, conclusions and recommendations that are general, as well as specific to each lifeline, are provided in full in the Report and only a selection of them are covered in this paper.

Introduction

Civil engineering is one of the oldest engineering practices and emerged to both meet the basic needs of society and improve quality of life, whether it involved building a bridge to connect communities or designing houses that provide better protection from the elements. As our civilizations have evolved and become increasingly complex and interconnected, the civil engineering profession has become less connected with the communities they serve.

This fundamental purpose of civil engineering—to meet community needs—can help the profession frame the discussion around resiliency and in particular, help answer questions such as, "What performance targets are appropriate for buildings and infrastructure in a given community?" Ultimately, the built environment is a means to an end—buildings and infrastructure enable services, provide shelter, facilitate transportation, and ultimately, enable and sustain society. Community needs are particularly important following a disaster—it is these needs that need to drive performance criteria and design.

There have been various recent efforts to highlight the need to design around community needs. For example, the NIST *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (NIST, 2015) was developed on the following fundamental premise: "social functions and needs of a community should drive the requirements of the built environment for a community to be resilient." The NIST *Guide* (2015) points out that buildings and lifelines exist to support social functions and institutions, including family and kinship, education, health, government, economy, media, and other community-based organizations. The NIST *Guide* also stresses that critical buildings and infrastructure systems are particularly important in supporting recovery following a hazard event.

This paper pulls from key aspects and recommendations from various efforts, including the NIST *Guide* and principally the ATC-126 Project, which developed the NIST GCR 16-917-39 Report, *Critical*

Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery (NIST, 2016). That NIST Report addresses overarching societal considerations, lifeline interdependencies, lessons from past disasters, gaps and deficits, and the current state of U.S. standards, guidelines, and performance criteria for the following key lifelines: electric power, natural gas and liquid fuel, telecommunication, transportation, and water and wastewater systems. Findings, conclusions and recommendations that are general, as well as specific to each lifeline, are provided in full in the Report and only a selection of them are covered in this paper.

Societal Needs and Expectations

As our world becomes more urbanized and more interconnected, community needs and expectations are changing at an increasingly fast rate. Here, the term "societal expectations" is defined as in the NIST GCR 16-917-39 Report—it refers "to what different groups within the population want or hope for with respect to lifeline performance and post-disaster restoration time" (NIST, 2016). The ATC-126 Project that developed that Report aimed to investigate what is currently known about societal expectations—with a focus on communities in the United States—and how these expectations vary within and across communities. Some of the major findings are described in the following subsections.

Community Expectations and Needs are Highly Diverse and Dynamic. Society's exposure, sensitivity, and adaptability to hazard events varies widely across communities, within communities, and over time. In general, because resilience varies as a function of exposure, sensitivity, and adaptability, it is usually those of lower socio-economic status that bear the most severe impacts (NIST, 2016). Community needs and expectations are also highly influenced by the frequency of lifeline disruptions. As an example, people in communities where water service disruptions are a regular occurrence will be better able to cope with water service disruptions following a disaster—in many cases, households and businesses in these types of communities store significant amounts of water to deal with the regular, expected disruptions. As communities develop over time, these needs and expectations change along with them. Globalization, interconnected supply chains, and the growth of cloud-based information technology are some examples of the many factors that shape and influence evolving community expectations and needs.

Community's expectations also vary over the different stages of a disaster—defined in the NIST *Guide* (2015) as short-term recovery (typically lasts days), intermediate-term recovery (typically lasts weeks to months), and long-term recovery (typically lasts months, and possibly years). For example, the public's response regarding a lack of water following the 1995 Kobe earthquake went from "request for information" in week 1, to "anxiety, impatience" in weeks 3 and 4, to "anger" in week 5 (Matsushita, 1999). The availability of alternatives and substitutes that provide similar services to the ones that were disrupted (e.g., backup generator providing emergency power, or bottled water for drinking) also highly influence the community's response.

Lack of Empirical Data on Community Expectations and Potential Indicators. One of the major conclusions of the study around community expectations was that there is a lack of empirical data around societal expectations following disasters. However, it can be said that some community needs are fundamental and that there are overriding values for all communities—these include life safety and health. The NIST Report (NIST, 2016), in particular, focused on human health and safety, the functionality of health-care systems, and economic well-being as priority issues to assess and characterize societal expectations for lifeline performance. Emphasis was also given to the short-term recovery phase (measured in days) following a major hazard event or other lifeline disruptions because the most severe societal impacts, such as deaths, injuries, and business interruption losses, generally occur during this time frame. This is consistent with the NIST *Guide* (NIST, 2015), which notes that some needs are more fundamental than others.

Because there is very little empirical data on community expectations, the ATC-126 Project team investigated potential indicators of those expectations. These potential indicators included major programs, investigations, and regulatory changes triggered by performance during disasters. The overriding support for many of these programs, investigations, and regulatory changes indicate that building and infrastructure performance did not meet community expectations. A good example of this kind of indicator is the nonstructural program to seismically brace all the suspended ceilings and light fixtures in every Los Angeles County school building following the 1994 M6.7 Northridge earthquake. This program was initiated because both FEMA and the State of California realized that the amount of damage from heavy nonstructural components, and the corresponding impact had the earthquake occurred during school hours, was completely unacceptable. The damage vividly demonstrated the potential risk to students, and sparked quick action to mitigate this risk that otherwise might have not been supported.

Community expectations of post-disaster restoration times are also likely to be influenced by emergency preparedness information provided by emergency management organizations. Most emergency management organizations recommend for people to be prepared to be without services for three days following a major hazard event (NIST, 2016). These advisories are likely to have an influence on what society expects from lifeline performance and how they prepare. If members of the public act on the information they receive from emergency management organizations, it is important to ensure that these organizations fully understand the performance targets of lifelines in their community. This would be helpful in ensuring that community residents are properly preparing for disruptions.

Communities Need Reliable Electric Power to Function. As mentioned earlier, we live in a dynamic world that is becoming increasingly urbanized and in particular, is highly dependent on electric power. Almost all other types of infrastructure systems are dependent on electric power and the demand for reliable electric power is continuing to increase. The importance of electric power has been stressed in business and household surveys that were conducted in the 1990s. As an example, a survey in Tennessee found that 59% of randomly selected businesses would have to shut down immediately if they lost power (Tierney and Dahlhamer, 1997). Given that businesses, in general, are now even more dependent on information technology (and therefore, electric power), it is expected that this has only increased since these surveys were conducted. The National Renewable Energy Laboratory (NREL, 2003) also points out that economies are "increasingly based on the real-time flow of information and increasingly dependent on machines controlled by digital components" and therefore, are increasingly vulnerable, making power outages exorbitantly expensive and unacceptable for many businesses. Additionally, there are indications that businesses are considering power quality and reliability in facility siting decisions (e.g., LA Times, 2001), signifying that electric power is viewed as a fundamental need.

Selected Key Points and Recommendations

The ATC-126 Project highlighted an extensive list of needs and recommendations associated with lifelines to improve the understanding of societal considerations that influence the resiliency of communities. A selection of key points and recommendations from relevant reports, but mostly from the NIST Report (NIST, 2016), are described in the following subsections.

Learn from Other Lifelines and Different Types of Events. As mentioned earlier, there is very little empirical data on societal expectations of performance of lifelines and even when data is available, much of it might be outdated as community expectations are constantly evolving. Coupled with this is the fact that many hazards of significant magnitude, in particular earthquakes and tsunamis, rarely occur and therefore, there are limited opportunities to "test" the resiliency of systems. Because of this, it is important to learn as much as possible from other lifelines and other disruptive events.

Successful lifeline frameworks, programs and practices to improve resiliency should be assessed for applicability to other lifeline systems. The mapping application developed for natural and liquid gas pipeline safety is a good example of one framework that could be considered for other lifelines. The Pipeline and Hazardous Materials Safety Administration (PHMSA) identified five areas for local governments to improve protection of pipelines and increase the resiliency of the gas and liquid fuel transmission system, which included pipeline awareness, pipeline mapping, excavation damage prevention, land use and development planning near transmission pipelines, and emergency response to pipeline accidents (NIST, 2015). In an effort to address these needs, the PHMSA developed the Pipeline Information Management Mapping Application, which allows the identification of high consequence areas, where hazardous pipelines are located in close proximity to other underground facilities, including electric power and telecommunication cables (PHMSA, 2013). In particular, the National Pipeline Mapping System Public Viewer allows users to access pipeline maps without disclosing sensitive pipeline information. This application, where the community can access information that is important for building resiliency, should be assessed to determine if it provides a good framework for other lifeline systems, including multiple systems and collocated facilities (NIST, 2016).

Another interesting approach to consider is the "Chaos Monkey" approach pioneered by Netflix, in which testing is regularly conducted to ensure that applications continue to work under a variety of failures and disruptions (NIST, 2016). This approach helps test the resilience and recoverability of cloud computing services. This is particularly important given that many post-disaster reports indicate that telecommunication system backup plans did not work as anticipated or that presumed redundancy either never existed or no longer existed due to engineering changes, leading to a false sense of resiliency (NIST, 2016). Similar to the mapping application for pipelines, this approach should be assessed to determine if a similar approach could be used to test the resilience of other lifeline systems.

It is also important to learn as much as possible from any relevant event, even if it is not the hazard of interest or if it is outside the country of interest. This is particularly important for earthquake engineering because the occurrence of this hazard in a particular location is rare and therefore, our evolving systems do not get "tested" regularly. The electric power failures and corresponding cascading effects during the Northeastern U.S. Blackout in 2003 is a good example. This event, which is estimated to have caused $7-10 billion in losses (ICF Consulting, 2003), demonstrated some of the widespread impacts that electric power disruption can have on communities. Similarly, Hurricane Katrina provided important lessons regarding the long-term impacts that wide-scale school closure can have on communities. These lessons are applicable to hazards that have the potential to damage large numbers of schools at a time. Hurricane Katrina highlighted that it is not just school damage and collapse, but also long-term school closure that is detrimental to children and communities. A seven-year study of students that were impacted or displaced by Hurricane Katrina found that many of them had declining educational trajectories and many never recovered the former stability in their lives (Gothergill and Peek, 2015). Many of the students' personal, family, and social lives were significantly impacted and led to higher levels of anxiety and more behavioral problems. The ongoing ATC-122-1 Project, which is currently developing a school safety guide on natural hazards, is finding that schools should probably be considered critical infrastructure, given the diverse functions and critical needs that they serve for communities. For example, school buildings are often the sites for aid distribution and shelters for displaced families following a disaster. Even when school buildings are not designated a shelter, school policy in the U.S. is that if children cannot return home safely, they must be sheltered in place at the school until parents are able to pick them up.

Think in Systems and Interdependencies. Most design is focused at the component level, and consideration of system behavior is not frequently included. In particular, there is currently no direct link between the design of system components dictated in codes and standards to intended systematic targets. To address this, NIST (2016) recommends developing a methodology to link component-based design criteria into system level performance targets.

Additionally, most professions work in silos, whether in research, in design, or in operation of infrastructure and lifelines. Past disasters have demonstrated the importance of understanding how failures in one system can have cascading effects in another. To address this, NIST (2016) recommends that operators share information among each other, systematically think through their dependencies on other infrastructure and coordinate post-disaster repair to avoid causing further problems. For example, power restoration should be coordinated with natural gas system repair to prevent sparking fires (NIST, 2016).

Consider Potential Societal Impacts. Siting and design decisions should consider potential negative impacts that they could have on society, especially following hazard events, as that is when many of these systems will be particularly needed. In particular, as designs and systems become more efficient, it might also mean lack of redundancy and concentration of vulnerability. Collocation of lifelines is a great example of this—it provides for enhanced efficiency, but also increases the risk for cascading failures, entails complex interactions in restoration, and requires post-event collaboration and coordination among various systems and organizations (NIST, 2016). Decisions to collocate lifelines should take these impacts into consideration.

Most existing models do not typically link back to societal impact; most of them focus on technical aspects and corresponding impacts on the specific components and systems being modeled. To address this need, NIST (2016) recommends developing models that reflect societal impacts. These types of models can help improve the understanding of how engineering decisions ultimately impact society and can help lead to informed decisions that improve resiliency in communities.

Conclusion

Addressing evolving community needs is not a new concept for civil engineering—it is the very reason that this engineering practice emerged in the first place. Framing discussions about resilience around this basic concept will help the profession make more conscious engineering decisions that ultimately link back to societal impacts.

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