Designing for Resilience

Part 1

By SEI Board of Governors Resilience Committee

This two-part series discusses resilience for engineering design practice. Part 1 includes an overview of the ASCE Code of Ethics, resilience concepts for design practice, and how the ASCE Report Card addresses resilience.

ASCE Code of Ethics and Resilience

The first statement of the new American Society of Civil Engineers (ASCE) *Code of Ethics* (ASCE 2022) reads, "Engineers govern their professional careers on the following fundamental principles:

- Create safe, resilient, and sustainable infrastructure.
- Treat all persons with respect, dignity, and fairness in a manner that fosters equitable participation without regard to personal identity.
- Consider the current and anticipated needs of society.
- Utilize their knowledge and skills to enhance the quality of life for humanity."

Also, the *Code of Ethics* requires that "Engineers adhere to the principles of sustainable development…". These principles are further developed in ASCE Policy Statement 500, *Resilient Infrastructure Initiatives*, which states that "...an all-hazard, comprehensive risk assessment that considers event likelihood and consequence, encourages mitigation strategies, monitors outcomes, and addresses recovery and return to service should be routinely included in the planning/design process for infrastructure at all government levels." Although these notions are permeating calls to action by our professional society, concepts of resilience and sustainability are still new to structural engineers, including how to incorporate these concepts into their projects.

The *Code of Ethics* has a footnote that states: "This Code does not establish a standard of care, nor should it be interpreted as such." While this caveat provides an exemption for litigation purposes, the principles established in the *Code of Ethics* do govern engineering practice and licensure requirements.

The *Code of Ethics* addresses the responsibilities of five stakeholders: Society, Natural and Built Environment, Profession, Clients and Employers, and Peers. In the case of a conflict between ethical responsibilities, the stakeholders are listed in the order of priority. The following responsibilities for each stakeholder apply to resilience in engineering practice:

SOCIETY
- First and foremost, protect the health, safety, and welfare of the public.
- Enhance the quality of life for humanity.

NATURAL AND BUILT ENVIRONMENT
- Consider and balance societal, environmental, and economic impacts, along with opportunities for improvement, in their work.
- Mitigate or minimize adverse societal, environmental, and economic effects.

PROFESSION
- Educate the public on the role of civil engineering in society.
- Encourage and enable the education and development of other engineers and prospective members of the profession.

CLIENTS AND EMPLOYERS
- Communicate in a timely manner to clients and employers any risks and limitations related to their work.
- Present clearly and promptly the consequences to clients and employers if their engineering judgment is overruled where health, safety, and welfare of the public may be endangered.

PEERS
- Encourage and enable the education and development of other engineers and prospective members of the profession.

Note that the current language for Natural and Built Environment uses sustainability concepts that can also be applied or extended to resilience.

Sustainability refers to maintaining and improving the quality of life without degrading the quantity, quality, or availability of natural,

Figure 1. Social functions and institutions should inform the performance requirements for buildings and infrastructure (NIST 2016).

economic, and social resources; sustainability focuses on infrastructure materials and methods for construction, operation, and maintenance. Resilience refers to maintaining and improving societal functions by designing and preparing for rapid infrastructure recovery following damaging events; resilience focuses on discrete hazard events and chronic conditions (e.g., sea level rise) that reduce or impair infrastructure functionality. Project goals for both concepts require the development of integrated or compatible design criteria.

Community resilience addresses societal needs, among other factors, such as safety and performance. For the built environment, community resilience relies upon the ability of infrastructure to enable functions and services, such as housing, commerce, water, power, communication, and transportation services, under daily operational conditions and severe stressors due to hazard events. Community resilience goals inform performance objectives for the built environment before, during, and after hazard events.

Engineers have a key role in educating stakeholders about the benefits of resilience in designing new buildings and infrastructure systems and monitoring, maintaining, and upgrading existing infrastructure.

When Should Engineers Be Involved?

Engineers need to be involved earlier in project planning, where societal needs are established regarding minimum or acceptable outcomes following hazard impacts. Early involvement allows engineers to hear the performance requirements identified by planners and designers and help them determine if the performance of existing building stock is adequate or if new requirements are needed. The structural engineers' involvement can give a unique perspective and identify opportunities others may not see.

What Are the Ethical Trigger Points?

Suppose a designer is requested to consider a building as part of a community resilience plan (regardless of occupancy/function). In that case, the designer needs to discuss the expected performance of the facility with the client. Based on the client's needs, this may be beyond what is prescribed in current codes and standards and may require the use of Performance-Based Design (PBD) to address recovery of function and other considerations.

With Whom Should We Be Talking?

Typically, discussions about projects are limited to potential clients. However, if the architect is excluded during these discussions, the potential ramifications of exclusive focus on structural optimization may reduce the long-term business benefit. Structural engineers must talk to architects and owners (the architect's client) in an educational capacity at the onset of project inception. These discussions should include a planning group that includes key community stakeholders and considers the project's contribution to maintaining community functions and lessening recovery time following a disruptive hazard event.

What Knowledge Informs Design Decisions?

Specific occupancies should always target higher performance levels (e.g., Risk Category III and IV), but, in some cases, large and multiple-purpose buildings may be identified as essential to community functions. For example, imagine a situation where a municipality identifies which critical facilities are needed for its functional recovery and determines they have gaps (e.g., they need a large shelter). Then, a development plan to build a multi-purpose facility can address the social needs that serve the community now and into the future.

> *…new construction built to the latest codes and standards is still subject to damage that may impair their use or intended functions, as codes and standards primarily focus on life safety.*

Community and Infrastructure Resilience

According to the literature and policy statements, the common aspects of resilience are "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions" (Koliou et al., 2018). The performance of the built environment, and its support of social, economic, and public institutions, is essential for a community's immediate response and long-term recovery after a disruptive natural hazard event.

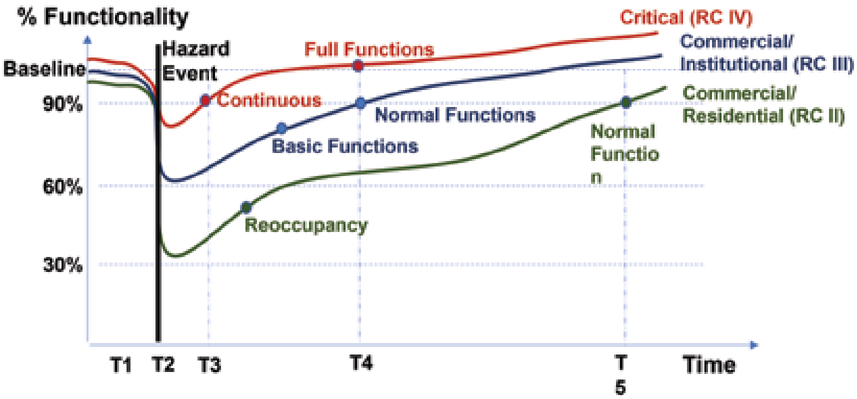
Why Resilience?

Civil infrastructure, on which any community's economic and social well-being depends, is susceptible to damage and/or disruptions to functionality due to natural hazards. While new buildings and infrastructure tend to perform as expected for design-level events, existing buildings and infrastructure are typically more susceptible to damage during the same events. Furthermore, engineers are challenged to design for nonstationary hazard conditions due to climate change; for example, when environmental conditions (e.g., sea level, rainfall intensity, wind speed, etc.) associated with a design-level event are expected to increase over a project's design life.

Upgrading and constructing buildings and infrastructure to the latest codes and standards improve their performance and community resilience for hazard events. However, new construction built to the latest codes and standards is still subject to damage that may impair their use or intended functions, as codes and standards primarily focus on life safety. Damage to existing infrastructure often produces disproportionate economic and social losses, especially for lower-income households and other vulnerable segments of society. How we choose to construct our infrastructure opens the door to future disasters, as design choices have an impact on society. Regardless of wealth or political capital, communities expect and deserve infrastructure investments that meet community needs.

How Is the Design Tied to Community Resilience?

The needs of community members and social institutions – including government, industry, business, education, and health – help define functional requirements for community buildings and infrastructure (*Figure 1*). For instance, can residents remain in their homes after a significant event? Can governments communicate with residents



T1 Pre-event condition due to maintenance, degradation, retrofits
T2 Disruptive hazard event causing structural and nonstructural damage
T3 RC IV critical facility - continuous functions achieved at 90% of functionality (hours)
T4 RC III commercial/institutional building - basic functions achieved at 75% functionality
T5 RC II commercial/residential building - reoccupancy achieved at 50% functionality

- Initial functionality may be achieved with temporary measures to provide power, water, or other services.

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to inform them and support recovery efforts? Can businesses and factories resume operations within a reasonable period? These social needs determine the performance expected from buildings and infrastructure (NIST, 2016).

Resilient design concepts for individual building or infrastructure projects may include 1) location considerations to mitigate hazard exposure, 2) design or mitigation features to withstand and minimize load effects (e.g., limiting structural drift impacts on nonstructural systems), 3) limiting member failure to a specified location and manner (e.g., local ductile failure without structural instability), 4) design adaptation for future anticipated conditions and events, and 5) design or mitigation features to improve the time to recovery of function after a hazard event.

Recovery of function, or functional recovery, after a damaging event, depends on the extent of damage and repairs and the ability to obtain operational supplies and resume organizational operations. A building may have reduced functionality because of structural or nonstructural damage or service loss from external infrastructure systems. A building's functional recovery may involve temporary solutions while repairs to internal or external systems are underway. *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (FEMA/NIST 2021) provides additional guidance that focuses on the recovery of individual buildings and infrastructure systems.

Functionality is measured relative to a baseline level, often defined by pre-event conditions. *Functional recovery* measures the time to achieve distinct performance states, such as *re-occupancy* (safe re-entry for shelter or protecting contents), *basic functions/operability* (system provides its regular pre-event services, with temporary solutions as needed), and *full function* (all functions restored to pre-event levels and all repairs completed). *Figure 2* depicts how the percentage of facility functionality versus recovery time can help specify performance states for buildings and infrastructure based on their Risk Category (RC) (McAllister 2022).

The ASCE Report Card and Resilience

Resilience needs are articulated by the ASCE (2021a) Report Card as follows: "We must utilize new approaches, materials, and technologies to ensure our infrastructure can withstand or quickly recover from natural or man-made hazards."

Advancements in resilience across all infrastructure sectors can be made by:

1) Incentivizing and enforcing the use of codes and standards to mitigate the risks of major climate events such as hurricanes, fires, sea level rise, manmade events, and more.
2) Understanding that our infrastructure is a system of systems encouraging a dynamic, big-picture perspective that weighs tradeoffs across infrastructure sectors while keeping resilience as the chief goal.
3) Prioritizing projects that improve the safety and security of systems and communities to ensure continued reliability and enhanced resilience.
4) Improving land use planning across all decision-making levels to strike a balance between the built and natural environments while meeting community needs, now and into the future.
5) Incorporating natural or "green" infrastructure to enhance the resilience of various infrastructure sectors. Leveraging natural infrastructure in engineering design can mitigate the effects of natural and manufactured hazards while improving environmental assets and social capital. In addition, such designs can extend the design life of existing infrastructure by lessening environmental loadings or serving as a "first line of defense" in innovative designs that consider non-static load conditions under future climate scenarios.

Engineers can support community resilience goals by incorporating them into building and infrastructure design practice. For example, community goals can be addressed by a project with specific resilience requirements to guide its performance, damage states, and functional recovery for design hazard events.

Closing Thoughts

The needs of community members and social institutions – including government, industry, business, education, and health – help define functional requirements for community buildings and infrastructure. Functionality and functional recovery measures, such as re-occupancy, basic functions/operability, and full functions, need to be assessed relative to the role of the building or infrastructure system in the community.

Engineers have a key role in educating stakeholders about the benefits of resilience in new and existing buildings and infrastructure systems. Being involved in project planning when societal needs are established allows for consideration of options such as increasing the Risk Category or using PBD for performance objectives beyond those achieved with codes and standards. Such decisions and design choices set the stage for future hazards and societal impacts. All communities expect and deserve infrastructure investments that meet community needs.▪

References are included in the PDF version of the online article at **STRUCTUREmag.org**.

The mission of the SEI Resilience Committee is to advance structural engineering professional practice by developing programs and resources to support engineering professionals working toward enhancing resilience.

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