GEOSTRATA

FEBRUARY/MARCH 2024

EARTHQUAKE GEOTECHNICS

Proudly published by the Geo-Institute of ASCE

THE FUTURE OF SEISMIC CODES

Functional Recovery and Geotechnical Engineering

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Sunrise over Anchorage, Alaska, following the 2018 earthquake. (Photo source: NIST.)

A paradigm shift in seismic code provisions for design against earthquake hazards is a much needed and exciting engineering frontier. Current seismic codes primarily target life-safety performance objectives, but future design standards will aim to move beyond life safety, targeting improved post-earthquake performance to support reoccupancy and recovery of functions within a reasonable time. This new performance state, which moves beyond life safety, is called "functional recovery." Initial efforts in functional recovery frameworks have focused primarily on buildings and structural engineering considerations. To be effective in implementing functional recovery goals, however, significant efforts to address geotechnical engineering aspects will also be required for buildings, lifelines, geostructures, and critical infrastructure.

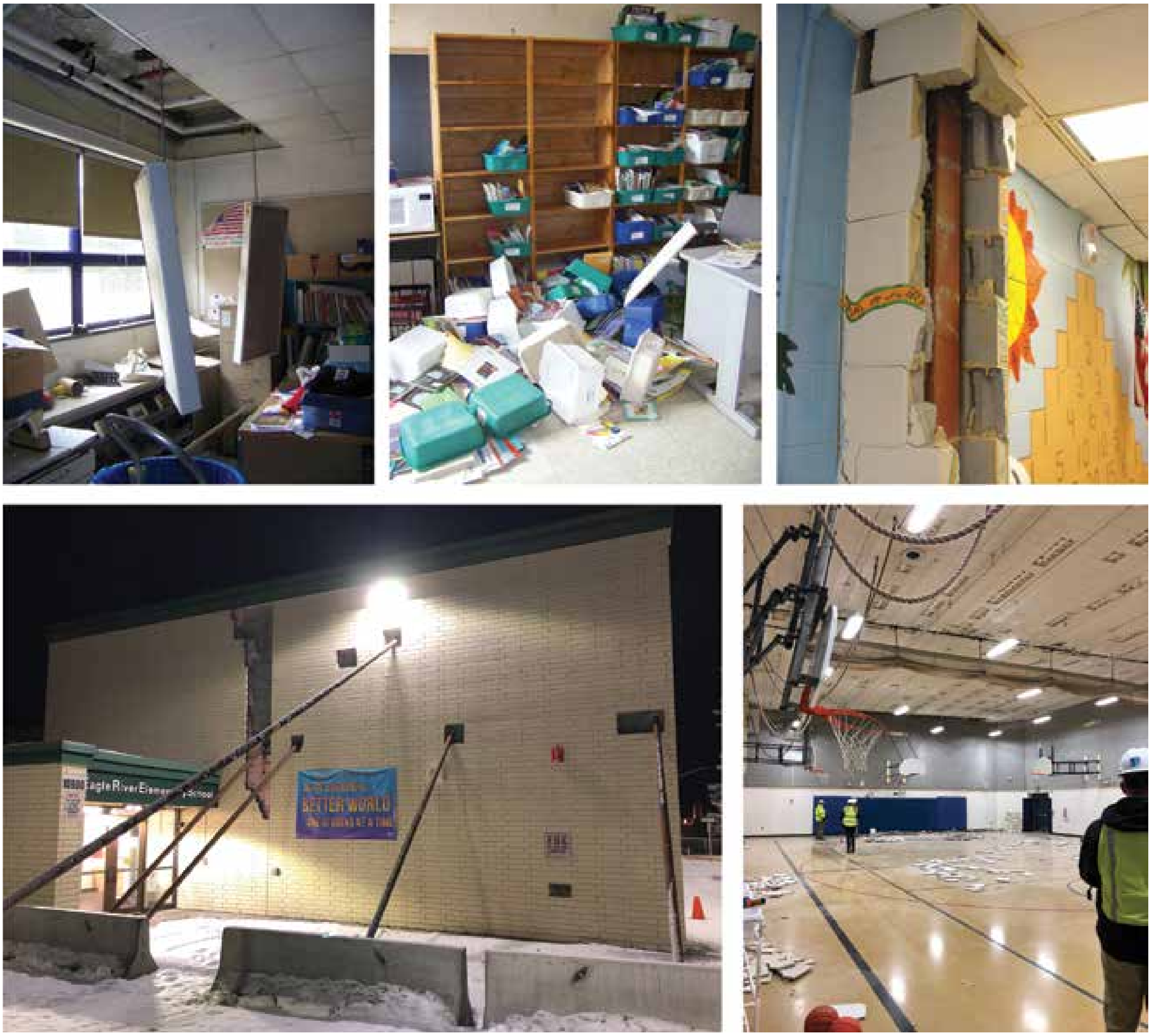

Figure 1. **Earthquake damage at schools following the 2011 M5.8 earthquake in Mineral, Va. (top row) and the 2018 M7.1 earthquake in Anchorage, Alaska (bottom row). Life safety was preserved, but damage resulted in loss of function. (Photo sources: NIST and FEMA.)**

Moving Beyond Life Safety

As scientific and engineering knowledge advances, seismic building codes and design standards evolve to reflect our improved understanding of earthquakes and seismic performance, as well as growing societal expectations for the performance of the built environment, such as buildings, lifelines, and other infrastructure. U.S. building code developments over the last few decades incorporate and update geotechnical aspects, like site classes and amplification factors, design ground motion levels, and time history analysis procedures. However, with all these changes, the overarching philosophy has remained the same: the primary design objective for most buildings is *life safety*. This goal ensures that a structure remains stable enough so that people can evacuate, regardless of the post-event state or eventual potential collapse or need for demolition. This focus on life safety has resulted in advances in seismic safety and reduction in lives lost from earthquakes for communities across the U.S., but can still leave people and communities devastated after an earthquake event. Engineering design has evolved such that life safety is achievable for significant events, given sufficient resources and proper implementation. But is that enough?

Communities cannot operate without shelter and other infrastructure that enable socioeconomic functions. Recovery after an earthquake depends on how quickly the emergency, medical, commercial, educational, and cultural services resume after an event. Performance-based engineering was introduced decades ago and allows individual structures or assets to perform better than life safety, but recent earthquake events have shown that even when life-safety criteria are met, a paradigm shift for codes and standards is needed to ensure post-earthquake resilience and viability of communities at the municipal and regional levels. Figure 1 shows photos from the 2011 M5.8 earthquake in Mineral, Va., and the 2018 M7.1 earthquake in Anchorage, Alaska, where life safety was preserved, but damage resulted in loss of function. In addition, the compounding effects from multi-hazards and the economic and environmental impacts of post-earthquake demolition and rebuild have also underscored the need for a fundamental change in the approach to earthquake engineering and seismic design.

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A Congressional Mandate

In 2018, Congress tasked NEHRP, the National Earthquake Hazards Reduction Program, with convening a committee of experts to develop a report providing options for improving post-earthquake performance of buildings and lifelines infrastructure for the American people. While earthquake risk mitigation has been a federal priority since the 1970s with the establishment of the Earthquake Hazards Reduction Act, this novel effort requested that two NEHRP agencies — NIST, the National Institute of Standards and Technology, and FEMA, the Federal Emergency Management Agency — explicitly focus on *improving time to reoccupancy and recovery of building functions and lifelines services*. In January 2021, NIST and FEMA issued a joint report (*FEMA P-2090/NIST SP-1254*) that discusses options and priorities for achieving enhanced recovery, termed "functional recovery." This report is herein referred to as the NIST-FEMA Functional Recovery Report, or the FR Report. The report defines functional recovery as "a post-earthquake performance state in which a building or lifeline infrastructure system is maintained, or restored, to safely and adequately support the basic intended functions associated with the pre-earthquake use or occupancy of a building, or the pre-earthquake service level of a lifeline infrastructure system."

The FR Report presents seven recommendations regarding key areas of development for functional recovery performance (Figure 2). The report was informed by input gathered from expert stakeholders during several workshops across the nation, collectively published in *NIST SP-1269*. The experts strongly emphasized that functional recovery goals will need a *well-defined framework* and significant development for application to *new buildings*, *existing buildings*, and *lifelines infrastructure*. They also defined three areas of necessary supporting actions outside of application in codes, standards, and guidelines: *pre-disaster recovery planning*, *education and awareness*, and *access to financial resources*. Each of these recommendations is discussed in a dedicated chapter in the FR Report. Significant efforts are ongoing at federal, academic, research, and nonprofit organizations (such as NIST, FEMA, the Earthquake Engineering Research Institute, the National Institute of Building Sciences, and the International Code Council, among others) to further define and advance the approaches needed to achieve functional recovery goals.

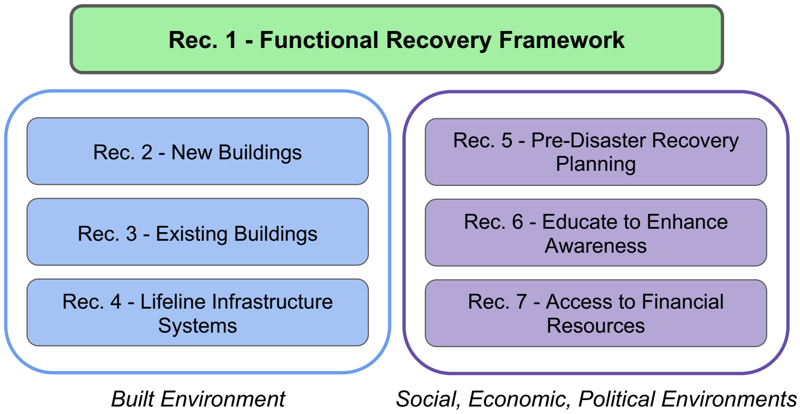

Figure 2. **Recommendations for developing Functional Recovery goals for improving the functional recovery of the built environment and the social, economic, and political environments (modified from the *FR Report*).**

The performance objective of functional recovery would fill an important gap for asset-level design, positioned between life safety (with the goal to minimize fatalities) and immediate occupancy (with the goal to minimize damage). The FR Report prioritizes the development of a framework for the application of functional recovery to establish minimum performance standards for buildings and lifeline infrastructure in communities across the U.S. The development of a framework and the consistent application of functional recovery goals is intended to *work toward more equitable distribution of risk for communities across the U.S.*

Because functional recovery is envisioned for application at the asset level via codes, standards, and guidance documents, it won't require time consuming asset-by-asset planning processes, but instead will aim to provide *protections for occupants or users based on the importance of the function or service provided by that asset*. In this sense, functional recovery can contribute to meeting overall community resilience goals. Likewise, functional recovery is envisioned to enable wide-scale achievement of recovery performance that doesn't necessarily require the expense and complexity of performance-based design, targeting outcomes based on the needs of users. Improving the time to reoccupancy and recovery of basic functions and services, however, will still demand significant coordination among engineers and others, such as social scientists, planners, emergency managers, and anyone involved with risk mitigation and recovery efforts and planning.

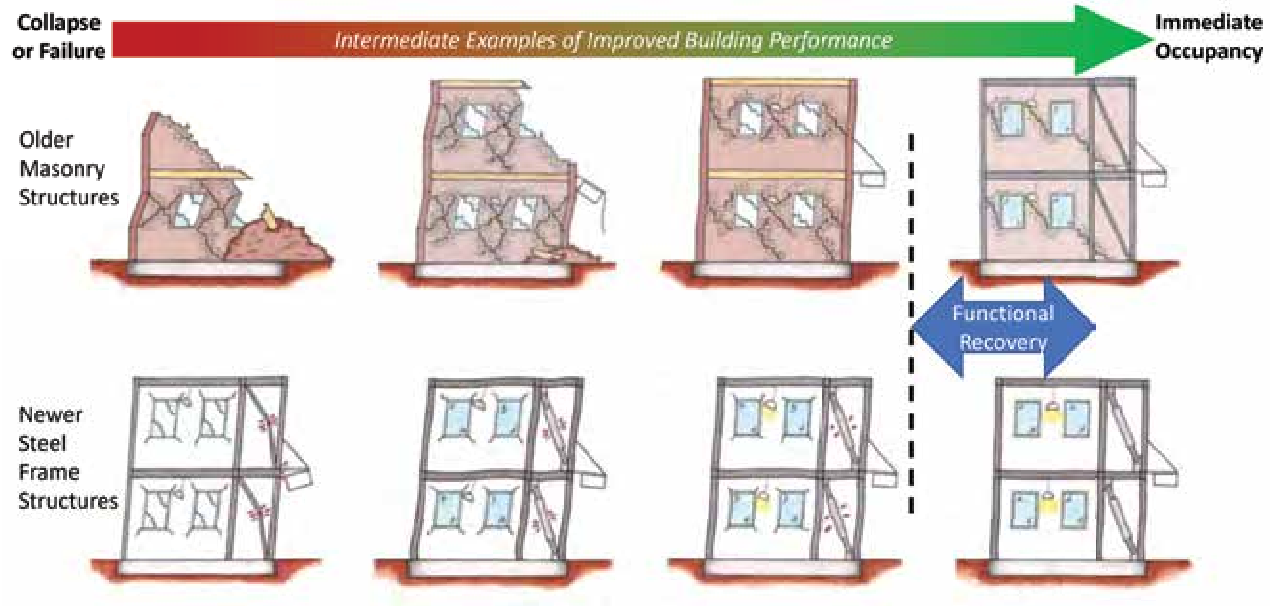

Figure 3. **Conceptual spectrum of building performance states and relative placement of functional recovery-based goals (modified from FEMA P-58-7).**

Communicating the New Performance Objective

As with many engineering concepts, communicating the message and meaning of functional recovery within technical communities and to the public can be challenging. For example, how does functional recovery differ from existing performance objectives of life safety and immediate occupancy, in terms of what the post-earthquake damage state looks like for a given asset? Figure 3 illustrates the potential spectrum visually, using various post-earthquake damage states of a given building. But this type of graphic is heavily geared toward technical audiences with a specialty in building structures and doesn't necessarily communicate the many embedded societal considerations that implicitly go into developing design standards.

It's precisely these embedded societal considerations that are most meaningful for the owners, occupants, and users of the built environment in terms of understanding what a given performance objective will mean for them. The purpose of a seismic performance objective is to achieve a desired post-earthquake asset state for a given shaking intensity, but how do these performance states work to address the range of potential human impacts (e.g., death and injury, loss of shelter, loss of functions or services, psychological trauma or distress, costs, and interruptions to daily life)? Moving beyond life safety requires more explicit consideration of these human impacts in determining and achieving functional recovery performance goals.

The definition of "functional recovery" states that function should be "maintained, or restored," which implies that some damage may occur, but would be repairable quickly enough to achieve the desired state. Beyond engineering aspects, the time to achieve this state will depend on many factors, such as the inspection process and evaluation time; decision-making of the asset owner (or insurance company) for repairs; supply, labor and financial capacities; damage to associated structures and lifelines; and occurrence of subsequent earthquakes or aftershocks before making the repairs. Additionally, even for a design-level earthquake, the post-earthquake damage state of an asset may not align with the intended design performance target due to many factors outside engineering design, such as construction quality or deferred maintenance. Adequately communicating these concepts to the public and other stakeholders will have a major impact on expectations for the built environment and how performance of the built environment is perceived following earthquakes. Addressing these topics to develop effective functional recovery performance goals that can be incorporated into future codes and standards will require collaboration between engineers, social scientists, and other stakeholders.

Connecting the Dots

To date, advances in functional recovery efforts have focused more heavily on buildings as a more straightforward application as compared to lifelines (e.g., due to building codes, property ownership structures, interdependencies, and ability to use representative typologies). However, the issue of lifelines such as water, electricity, gas, sewage, and telecommunication looms large as they're integral to the emergency response and recovery of a community. The functionality of transportation systems (also considered under lifelines in the FR Report) will be critical for a community in both the short- and long-term timeframes following an earthquake. A building's functionality will typically require that connections with lifelines are maintained and operable, with the lifelines themselves having many interdependencies (e.g., a water distribution system that relies on electrical power for operations).

For functional recovery to be achieved, lifelines will need to maintain some level of operation and service, and the connections between lifelines and other components of the built environment will need to remain intact. The need is clear, but the challenge is significant. Lifelines are typically designed for operational levels rather than life safety, and the broad range of systems covered under "lifelines" are not guided by any single design code, governing body, or ownership and management structure. The systems can also

RECOMMENDATION	FEDERAL GOVERNMENT (NEHRP AGENCIES)	STATE, LOCAL, TRIBAL, AND TERRITORIAL GOVERNMENTS	CODES AND STANDARDS DEVELOPMENT ORGANIZATIONS	PLANNING, DESIGN, AND CONSTRUCTION PROFESSIONALS, AND INDUSTRY ASSOCIATIONS	BUILDING AND LIFELINE SYSTEM OWNERS, DEVELOPERS, TENANTS, USERS, AND GENERAL PUBLIC
Rec 1: Develop a framework for post-earthquake reoccupancy and functional recovery objectives	Lead or strongly support	Participate in national; Lead state and local	Strongly support, or lead	Participate	Participate
Rec 2: Design new buildings to meet recovery-based objectives	Support	Participate in national; Lead state and local	Lead technical development	Participate in development; Lead implementation	Participate in development; Lead implementation
Rec 3: Retrofit existing buildings to meet recovery-based objectives	Support	Lead state and local development and implementation	Lead technical development	Participate in development; Lead implementation	Participate in development; Lead implementation
Rec 4: Design, upgrade, and maintain lifeline infrastructure systems to meet recovery-based objectives	Lead or strongly support development and implementation	Participate in national; Lead state and local development and implementation	Strongly support, or lead technical development	Participate in development; Lead implementation	Lead development; Lead implementation
Rec 5: Develop and implement pre-disaster recovery planning focused on recovery-based objectives	Strongly support, or lead	Lead state and local development and implementation	Support development	Participate in development; Lead implementation	Participate in development; Lead implementation
Rec 6: Provide education and outreach to enhance awareness and understanding of earthquake risk and recovery-based objectives	Lead	Lead or strongly support	Strongly support	Strongly support	Participate
Rec 7: Facilitate access to financial resources needed to achieve recovery-based objectives	Strongly support, or lead	Strongly support, or lead	Support	Support	Participate

Table 1. Roles of different stakeholders for implementing functional recovery recommendations (from the *FR Report*).

span multiple municipalities, counties, and even states – adding to the complexity of determining and implementing necessary post-earthquake operations levels to meet functional recovery goals. There are several ongoing efforts, with much work remaining, to address Recommendations 1 and 4 of the FR Report to enhance the functional recovery of lifelines.

Geotechnical Engineering and Functional Recovery

So, what does functional recovery mean for the geotechnical engineering community? There are many aspects of functional recovery where geotechnical input is needed or where geotechnical aspects are decisive, such as the impacts of geohazards on the built environment, foundations, lifelines, connections between buildings and lifelines, development of metrics, regional considerations, and the intersection with social/economic factors. Motivation for engagement by the geoprofessional community could arise in three key areas, for functional recovery as a:

- *New frontier* for risk-informed decisions for major challenges facing the built environment
- *Societal demand* that will be requested by clients and stakeholders explicitly, or expected from them implicitly
- *Leadership opportunity* for the geoprofession

Geotechnical engineering, by nature, is not prescriptive and requires multidisciplinary collaboration and understanding. Geotechnical engineers are thus uniquely positioned to provide leadership and guidance on practical, innovative goals and strategies for developing and implementing functional recovery as the future of seismic codes. Whether the motivation is technical, societal, or business-oriented, there's a role for geoprofessionals to play in this paradigm shift on the horizon for seismic codes.

Table 1 depicts the envisioned roles of stakeholders for developing and implementing functional recovery recommendations across several sectors and groups. Table 2 shows an example of conceptual functional recovery categories and target functional recovery times for buildings and lifeline systems. Current seismic codes already imply a target recovery time of hours or less to achieve near-full functionality (if not continuous operation) in building facilities that are deemed to provide essential services (i.e., *ASCE 7-22* Risk Category IV). Economic analysis, other benefit-cost-considerations, community-specific needs, and differences in existing

RECOVERY CATEGORY	RECOVERY PHASE	COMMUNITY FUNCTIONS OR SERVICES	TARGET RECOVERY TIME	EXAMPLE BUILDINGS AND INFRASTRUCTURE ENABLING FUNCTION OR SERVICE
A	Immediate	■ Public health and safety ■ Telecommunications and cyberinfrastructure ■ Acute healthcare ■ Shelter	< 24 hrs	Cell phone towers, emergency operations center, fire stations, hospitals, lifelines, police stations, designated shelters
B	Near Term	■ Key transportation services ■ Banking and finance ■ Energy and electricity ■ Food and water resources ■ Outpatient healthcare ■ Housing	1-6 days	Critical retail (grocery, home improvement), nursing homes, outpatient medical, pharmacies, residential water, transportation (roads, bridges, ports, runways)
C	Short term	■ Education ■ Governance ■ Housing ■ Local economy (jobs) ■ Social support ■ Cultural identity (religious)	1-4 wks	Courthouses, daycares, government buildings, lifeline infrastructure, major regional employers, schools and rec centers, single- and multifamily residential
D	Long Term	■ Cultural identity (landmark) ■ Entertainment ■ Recreation	1 month+	Buildings not assigned to other categories, historic buildings, landmarks, museums, night clubs, religious centers, stadiums, restaurants, other commercial buildings, theaters, country clubs

Table 2. **Conceptual functional recovery categories for a Design Hazard Level (modified from the *FR Report* and Sattar, et al., 2022).**

building inventory versus new building planning, are just a few of the considerations that may go into developing these target recovery categories and times.

Looking at both the envisioned roles of stakeholders and the delineation of target recovery categories and times, there are many instances where geotechnical engineering input would be needed, whether for buildings, lifelines infrastructure, or another component of the built environment. Valuable input from geotechnical engineers would include a broad range of topics, such as:

- Practical experience with foundation repair times (and availability of qualified contractors) after earthquake events
- Technical criteria for evaluating seismic performance of buried utilities or retaining walls and cut slopes
- Addressing hazards that may cross property boundaries (e.g., landslides)
- Innovating by creating foundation solutions that can provide — together with the superstructure — redundancy in an infrastructure network
- Considering geo-capacity challenges in aged systems due to compounded seismic hazards and climate effects
- Developing code language that effectively conveys the performance objective, yet allows for engineering judgement and adapting to site-specific and project-specific conditions

What thoughts come to mind as you read through Tables 1 and 2? What information would you, the geoprofessional, expect to see in a seismic design code or guidance document to enable efficient and consistent design and construction that meets the functional recovery performance objective?

Looking Ahead

The functional recovery performance objective represents a new engineering frontier and an exciting paradigm shift for seismic codes to advance beyond the goal of life safety. The concepts and framework developed under this work can also be extended to other hazards, such as wind and storm events, and to multihazard considerations. Much work remains for developing and implementing the overall functional recovery framework and specific objectives in design codes and guidance documents. The motivating factors for functional recovery developments and the unique positioning of geoprofessionals to play leadership roles in shaping this endeavor, will hopefully engage our community and encourage big-picture considerations of technical innovation, socioeconomic impacts, and clear communication of post-earthquake performance goals to stakeholders and the public. GS

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