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Functional Recovery: A Conceptual Framework with Policy Options

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Executive Summary

Earthquake-resistant design, especially as required by building codes, has always been primarily about safety. Over the last few years, policymakers and advocates have begun calling for “better than code” seismic design (Federal Register, 2016; San Francisco, 2016; NIST, 2017).

A productive way to think about this goal is to envision codes and standards written to achieve not only safety, but also acceptable recovery times. The recent NEHRP reauthorization, which EERI supported and helped to draft, does this. It calls for FEMA and NIST to convene experts to recommend “options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake reoccupancy and functional recovery time” (42 U.S.C. 7705(b); Senate Bill 1768, 2018).

The NEHRP reauthorization cites two milestones on the post-earthquake timeline: reoccupancy and functional recovery. For a building, the first milestone, reoccupancy, is the ability to re-enter, take shelter, and begin the recovery phase safely (SPUR, 2012). Functional recovery is the next milestone; it marks the restoration of building services as needed to support a significant measure of the building’s intended preearthquake use (Bonowitz, 2011). Similarly, for infrastructure systems functional recovery marks the restoration of the system’s services as needed to allow users to resume most of their pre-earthquake activities (Davis, 2019a; 2019b).

A working definition, suitable for both buildings and lifeline infrastructure, is presented in the paper, as follows: *Functional recovery is a post-earthquake state in which capacity is sufficiently maintained or restored to support pre-earthquake functionality.*

Thus, design for functional recovery means considering both safety *and* recovery time in design. Where current reoccupancy or recovery times are unacceptable, higher performance goals might be set, resulting in changes to what and how we build. But in many cases, expected reoccupancy or recovery times might already be adequate, in which cases “better than code” performance would mean only that the recovery goals and expectations are better understood and more clearly conveyed.

We recognize that a design shift for functional recovery will need to consider interdependencies between at least five physical systems that comprise the built environment and will involve four sets of linked but largely independent issues.

The systems are:

- Buildings, new and existing, serving all occupancies and uses
- Water and wastewater systems
- Energy systems
- Communication systems

- Transportation systems

The issue areas, for each building or infrastructure system, are:

- Definitional: What needs to be functional to achieve “functional recovery”? Which internal components or external resources are needed to ensure functionality?
- Policy: What is an acceptable functional recovery time?
- Technical: What strategies and criteria will provide high probability that functional recovery will be achieved within the acceptable time? In what cases will planning strategies be needed to supplement design strategies?
- Implementation: What aspects of our current practices might need to change in order to apply the technical standards to achieve the policy goals? How will interdependency effects be coordinated between responsible stakeholders? If planning strategies are needed to supplement traditional design strategies, who will be responsible for setting criteria and implementing them?

Functional recovery concepts can be applied to the design or retrofit of individual buildings and infrastructure systems. From the public policy perspective, however, design focused on realizing functional recovery for individual buildings and infrastructure systems is a mechanism for achieving community-wide goals. With the NEHRP reauthorization, increasing community resilience is now a stated purpose of the program (42 U.S.C. 7702), and NIST is charged with conducting research “to improve community resilience through building codes and standards” (42 U.S.C. 7704(b)(5)). The NIST *Community Resilience Planning Guide* (2016a) describes community resilience as a set of recovery time goals for different community services. For a community-wide service to recover in an acceptable time, the buildings and lifeline infrastructure that support it must recover their own basic functionality in time as well. Thus, functional recovery is the link between design provisions – which are technical and applied to individual buildings or lifeline infrastructure components – and community resilience – which is holistic and measured at a broader scale.

Functional recovery is also closely related to community resilience in part because of the unavoidable interdependencies between buildings and lifeline infrastructure systems. Thus, the development of functional recovery as a meaningful and robust concept will need to acknowledge these interdependencies, while also recognizing the unique characteristics and conditions inherent to each system.

It is critical to explore the types of public policy actions that legislatures and government agencies at the federal, state, and local levels might take to facilitate the implementation of functional recovery-based seismic design. EERI recognizes that the normal processes for developing design standards can and should be used, and that there are also interim options available to policymakers. In this paper, EERI explores a diverse suite of policy possibilities organized into the following four categories:

1. Legislation and regulations that require designing and planning for functional recovery, in addition to safety.
2. Interim programs that encourage designing and planning for functional recovery.
3. The development of technical consensus, specifically in the form of standards that set objective design criteria and planning strategies for achieving specified functional recovery times.
4. The development of policy consensus, specifically in the form of building code provisions and infrastructure regulations that assign, with local customization, acceptable functional recovery times to buildings and lifeline infrastructure systems based on their role in supporting various community functions.

Part 1: Conceptual Framework

This updates a version first published on July 24, 2019

Why Functional Recovery?

Communities should be explicit about the time it will take to recover functionality after an earthquake. Buildings and lifeline infrastructure can be designed or retrofitted for timely restoration of service. Stating these goals and implementing regulations to support them is what it means to design for functional recovery.

Design for functional recovery does not necessarily mean an increase in construction cost or even a change in performance relative to current practice. Rather, design for functional recovery means considering both safety *and* recovery time in design. With functional recovery times better understood and more clearly conveyed, higher performance goals might then be selected where needed.

Design for functional recovery is a necessary tool for assessing and improving community resilience. As such, functional recovery concepts and design provisions should be developed with the whole community in mind, considering interdependencies between buildings and lifeline infrastructure systems and accounting for existing conditions, which vary from community to community. Due to these complexities, efforts are needed by multiple stakeholder groups to develop consensus definitions, design strategies, policies, and practices regarding post-earthquake functional recovery of:

- Buildings, new and existing, serving all occupancies and uses
- Lifeline infrastructure systems, starting with those prioritized by NEHRP:
 - Water and wastewater systems
 - Energy systems
 - Communication systems
 - Transportation systems.

EERI supports such efforts and intends to contribute to them. Indeed, functional recovery is related to the topics of other EERI policy statements, including lifeline infrastructure (EERI, 2016a), building code adoption (in development), and community resilience (EERI, 2019). This paper starts this effort to reach consensus by clarifying the concept of functional recovery and describing how it relates to current practice.

In addition, EERI is also exploring public policy actions that government agencies might take to facilitate the implementation of functional recovery-based seismic design as described in part two of this paper.

Rethinking Codes for Safety

Earthquake-resistant design, especially as required by building codes, has always been primarily about safety. Over the last few years, policymakers and advocates have begun calling for “better than code” seismic design (Federal Register, 2016; San Francisco, 2016; NIST, 2017).

A productive way to think about this goal is to envision codes and standards written to achieve not only safety, but also acceptable recovery times. The recent NEHRP reauthorization, which EERI supported and helped to draft, does this. It calls for FEMA and NIST to convene experts to recommend “options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of

post-earthquake reoccupancy and functional recovery time” (42 U.S.C. § 7705(b); Senate Bill 1768, 2018). Where current reoccupancy or recovery times are unacceptable, higher performance goals might be set, resulting in changes to what and how we build. But in many cases, expected reoccupancy or recovery times might already be adequate, in which cases “better than code” performance would mean only that the recovery goals and expectations are better understood and more clearly conveyed.

Understanding Functional Recovery

The NEHRP reauthorization cites two milestones on the post-earthquake timeline: reoccupancy and functional recovery. For a building, the first milestone, reoccupancy, is the ability to re-enter, take shelter, and begin the recovery phase safely (SPUR, 2012). Functional recovery is the next milestone; it marks the restoration of building services as needed to support a significant measure of the building’s intended pre-earthquake use (Bonowitz, 2011). Similarly, for infrastructure systems functional recovery marks the restoration of the system’s services as needed to allow users to resume most of their pre-earthquake activities (Davis, 2019a; 2019b).

Functional recovery is different from performance in the emergency or response phase that immediately follows a damaging earthquake. Certain buildings (designated “essential facilities” by the building code) and parts of all lifeline infrastructure systems have pre-assigned roles to play in the response phase, so for them, functional recovery will include the ability to handle those response-related demands. In general, however, functional recovery is about what’s needed under normal conditions, not the performance under extreme or emergency conditions.

A consensus formal definition of functional recovery has not yet been established, though the key concepts are widely accepted (PUC, 2019). A working definition, suitable for both buildings and lifeline infrastructure, can be derived from the text of proposed California Assembly Bill 393 (2019):

*Functional recovery is a post-earthquake state
in which capacity is sufficiently maintained or restored
to support pre-earthquake functionality.*

For a building, “capacity” traditionally refers to the structural and nonstructural systems whose design is regulated by building codes. When considering a building’s “functionality,” one should also consider building contents and even the ground itself, as well as the availability of certain external services delivered by lifeline infrastructure systems. For lifeline infrastructure systems, functional recovery is likely to be measured as the maintenance or restoration of some substantial percentage of pre-earthquake network capacity.

But which functions are necessary, how much of each are needed, and how soon must they be restored? These are among the obvious next questions (discussed in four categories below), and they anticipate the development of a design code or standard for functional recovery. Assembly Bill 393 envisions such a document, defining a “functional recovery standard” as:

[A] set of enforceable building code provisions and regulations that provide specific design and construction requirements intended to result in a building for which post-earthquake structural and nonstructural capacity are maintained or can be restored to support the basic intended functions of the building’s pre-earthquake use within an acceptable time, where the maximum acceptable time may differ for various uses or occupancies.

This definition presumes the working definition of functional recovery as a measurable state, then adds the element of time. Functional recovery need not be immediate, but it should be achieved “within [the] acceptable time” established by policy. By linking functional recovery to a “set of enforceable ... regulations,” the definition also suggests that certain design strategies might or might not be needed depending on the desired recovery time (Bonowitz, 2018; PUC, 2019). Traditional design strategies to ensure the damage resistance of physical components are likely to be supplemented by planning strategies as needed to meet the prescribed recovery time. Planning strategies might include land-use planning, business resumption and continuity planning, pre-planned inspection or repair protocols, infrastructure substitutions or back-ups, strategies to reduce impeding factors, or other risk reduction, restorative or adaptive strategies (Almufti, 2013).

A functional recovery code or standard would have benefits even if the substantive design criteria, and the resulting buildings, do not change. Just the explicit assignment of buildings and infrastructure systems to expected or acceptable functional recovery times would inform stakeholders and support broader planning efforts.

Relation to Community Resilience

Functional recovery concepts can be applied to the design or retrofit of individual buildings and infrastructure systems. From the perspective of public policy, however, design focused on realizing functional recovery for individual buildings and infrastructure systems is a mechanism for achieving community-wide goals. With the NEHRP reauthorization, increasing community resilience is now a stated purpose of the program (42 U.S.C. § 7702), and NIST is charged with conducting research “to improve community resilience through building codes and standards” (42 U.S.C. § 7704(b)(5)).

NEHRP, like other government and non-government groups, defines community resilience largely in terms of the capacity of a community to recover from natural hazards effects (42 U.S.C. § 7703; PUC, 2019). The emphasis is on the community as an organization of people, not just physical objects. Yet the services people rely on – housing, education, commerce, government – are in the modern world closely related to the built environment.

The NIST *Community Resilience Planning Guide* (2016a) describes community resilience as a set of recovery time goals for these various community services. For a community-wide service to recover in an acceptable time, the buildings and lifeline infrastructure that support it must recover their own basic functionality in time as well. Thus, functional recovery is the link between design provisions – which are technical and applied to individual buildings or lifeline infrastructure components – and community resilience – which is holistic and measured at a broader scale.

Because a community’s built environment can contain both new and old buildings and infrastructure, its potential resilience is a function of more than just the regulations adopted for new construction. For example, housing as a community-wide service comprises recent buildings, non-conforming buildings, and possibly even collapse-prone buildings of every size and construction type. Therefore, in setting recovery goals, it is rational that communities with an older or more vulnerable housing stock might set more aggressive goals for its new housing to ensure a larger portion will provide reliable fast recovery (SPUR, 2009a; SPUR, 2009c; Mieler, et al., 2015). This might pose a challenge where communities within a state or region are committed to using a uniform model code. Retrofit programs serve community-wide resilience goals if they close gaps between current and desired recovery times for a given community service (SPUR, 2009b; City and County of San Francisco, 2016). Even if a retrofit cannot achieve the same functional recovery time as new construction, the aggregate effect of a citywide

program might effectively close the resilience gap. From a community resilience perspective, functional recovery concepts and design provisions should be developed with the whole community in mind.

System Interdependencies

Functional recovery is closely related to community resilience in part because of the unavoidable interdependencies between buildings and lifeline infrastructure systems. Individual buildings are often dependent on other buildings due to geographic proximity, or commonality of functional purpose (e.g. a university campus, or buildings within a community that support healthcare delivery). Additionally, buildings are connected to dispersed and overlapping infrastructure networks. Water and wastewater systems rely on the energy system, communication systems need water and energy, all rely on goods and services delivered over transportation networks and, increasingly, on wireless communications, and each infrastructure system includes building structures among its physical components (San Francisco, 2014). Earthquake damage or slow recovery of one system is likely to affect the others. In effect, the modern built environment is a system of systems.

Development of functional recovery as a meaningful and robust concept will obviously need to acknowledge these interdependencies. Even so, any near term development will just as obviously need to start from existing conditions recognizing that each system is already organized around its own stakeholder groups, its own policies and procedures, its own terminology and knowledge base, its own body of law, and even its own history and culture. Independent development within each system is inevitable, but it can perhaps be better coordinated through adoption of common ideas, vocabulary, and goals. Coordination and collaboration among the leading stakeholder groups could be facilitated by the establishment of regional “lifelines councils,” as previously recommended by EERI (EERI, 2016a; NZLC, 2016).

Developing the Concept of Functional Recovery

In the short term design that emphasizes functional recovery objectives is likely to draw on existing tools and policies already applied to essential facilities and infrastructure systems (NIST, 2017; Bonowitz, 2018; PUC, 2019). As the concept develops, these tools will be enhanced by research and practice in four issue areas: Definitional, Policy, Technical, and Implementation. The issue areas necessarily overlap, but they are distinct enough that EERI recommends using them as a way of framing efforts to develop the concept of functional recovery.

Progress within each issue area can be – and is likely to be – largely independent of the others, with some issues reaching consensus while others are still being debated. EERI advises that this reality should be embraced as essential. Speculation about implementation or policy feasibility should not rule out technical options, and the lack of a technical standard should not inhibit interim policies and experimental implementations.

Definitional

For a given building or lifeline infrastructure system, what needs to be functional to achieve “functional recovery”? Which internal components or external resources are needed to ensure functionality? This question is addressed by analytical research (NIST, 2018; Center for Risk-Based Community Resilience Planning; Soga et al, 2019; Davis, 2008) and by new approaches to earthquake reconnaissance that reveal recovery-critical issues (Davis, 2014a; Davis, 2014b; EERI, 2016b; Tremayne et al, 2017).

Policy

For a given building or lifeline infrastructure system, considering its use and the needs of its users, what is an acceptable functional recovery time? This question is addressed by established policy-making practices informed, ideally, by scientific research to quantify the benefits and costs to communities. This will require data, models and other evidence to understand community preferences and benefit-cost considerations (NIST, 2016a).

Technical

For a given building or lifeline infrastructure system, what strategies and criteria will provide high probability that functional recovery will be achieved within the acceptable time? In what cases will planning strategies be needed to supplement design strategies? These questions are addressed by analytical research and testing, together with established practices for developing consensus-based codes and standards (RRMC, 2019; PUC, 2019; NIST, 2014).

Implementation

What aspects of our current practices might need to change in order to apply the technical standards to achieve the policy goals? How will interdependency effects be coordinated between responsible stakeholders? If planning strategies are needed to supplement traditional design strategies, who will be responsible for setting criteria and implementing them? These questions can be anticipated by the same groups that address the other three issue areas, but progress is generally made only through experiment by innovative stakeholders, followed by promotion by professional organizations (including EERI), and in some cases by eventual codification or regulation.

State of Practice

To develop the concept of functional recovery, and to identify options for implementing functional recovery-based design and improving community resilience, it is useful to review the state of practice regarding each of the five systems identified above: How do current practices and leading documents in each field think about post-earthquake functional recovery?

For the purposes of this discussion, it is acknowledged that the infrastructure systems described consist of buildings to support their functions, non-building structures, and many other subsystems and components, that are explicitly stated in each section. In most cases, building structures that serve these systems are designed to the building codes described in the buildings sections, while other non-building structures are designed to standards described in each specific section.

Buildings

Current building codes already acknowledge that some facilities, like hospitals and fire stations, are “essential” for public safety and need to be functional immediately after a damaging earthquake. The code therefore assigns these buildings to the highest of four “risk categories” and sets design criteria to ensure quick recovery. Buildings that are components of lifeline infrastructure systems that serve essential facilities (such as water pump enclosures, power generating stations, or emergency communications offices) are also assigned to the highest risk category. For other buildings – including schools, housing, workplaces, and public accommodations – the code focuses on safety. Nearly all well-designed but non-essential buildings are expected to recover functionality over time, but the code states no specific goals and makes no specific requirements.

Building code provisions for essential facilities assigned to the highest risk category thus offer a basic version of a functional recovery-based code. These provisions address the definitional question by setting the scope of design to ensure the desired building use will be maintained (including both the basic structural elements and nonstructural components), and identifying, for example, which nonstructural components must be braced or have their ruggedness verified by testing. They address the technical question by providing enforceable design and acceptability criteria. They address the implementation question by ensuring quality of construction through robust inspection and enforcement, and clearly delineating jurisdictional lines of authority and responsibility. And they address the policy question by specifying which building uses are assigned to the highest risk category in the first place.

Design criteria are provided in a separate standard known as ASCE 7 (ASCE, 2016). ASCE 7 expects buildings assigned to the highest risk category, Risk Category IV, to perform in ways that “would not prevent function of the facility immediately following” a design-level earthquake. The ASCE 7 commentary adds that a Risk Category IV facility should be “operational” immediately following a more frequent event. The term “operational” is defined in the performance-based ASCE standard for seismic retrofit to mean “[t]he building is suitable for its normal occupancy and use, although possibly in a slightly impaired mode, with power, water, and other required utilities provided from emergency sources, and possibly with some non essential systems not functioning” (ASCE, 2017).

The terminology of ASCE 7 and ASCE 41 is very close to the definition of functional recovery suggested above, but neither of these standards accommodates the idea that different building uses should have different acceptable recovery times. A relatively new document, FEMA P-58 (ATC, 2012), covers a full time range, but it only addresses *repair* time and impeding factors (e.g. forcible closure and long procurement times), which are easier to calculate but different from functional recovery. In any case, each of these performance-based documents represents a step toward an eventual functional recovery standard.

A more complete functional recovery code would address all building uses, not just those deemed essential. It could then extend the current Risk Category IV concepts in two ways. First, addressing the policy question, a functional recovery code would set acceptable functional recovery times for each intended building use. As suggested by NIST (2018), these could reasonably be on the order of days, weeks, or even months. Second, addressing the definitional and technical questions, this new code would provide the scope and criteria necessary to achieve the specified functional recovery time with high reliability. Such a code would be consistent with the definition of functional recovery standard discussed above.

Water and Wastewater Systems

Water and wastewater systems comprise water supply, treatment, transmission and distribution subsystems and wastewater collection, conveyance, treatment and disposal subsystems. Major operating components include treatment plants, pipes, tunnels, dams, reservoirs, tanks, and pumping stations. These subsystems and components suggest the functions necessary for functional recovery, and serve as a starting point to address the definitional question.

Performance objectives for water and wastewater systems focus on safety, public health, and fire protection (AWWA, 1994; ALA, 2004, 2005a, 2005b; ASCE, 1999, 2002; NIST, 1997). NIST (2016b) and ASCE’s Risk and Resilience Measurement Committee (RRMC, 2019) summarize the existing guidelines, standards, and codes applicable to the design of water and wastewater systems. Most do not address seismic design, though some address particular components, such as ductile piping.

A relatively new voluntary standard by the American Water Works Association, AWWA J100, addresses recovery time (AWWA, 2010). For the most part, however, the industry does not address the policy question with recommended restoration times. ASCE is currently developing a manual of practice for the seismic design of water and wastewater pipelines which incorporates four performance levels, but it does not address functional recovery times (ASCE, 2019).

Work by the Los Angeles Department of Water and Power might lead to a functional recovery standard or policy of greater applicability. LADWP implemented a performance-based seismic design procedure for its Water System addressing the hierarchy of system, subsystem, and component design with a focus on providing post-earthquake services (LADWP, 2019). The procedure estimates the time needed to restore operability in a way that could accommodate functional recovery goals as described here (Davis, 2014a; 2014b; 2019a; 2019b).

Energy Systems

Energy systems comprise power plants, transmission, and distribution systems for electricity, oil, and natural gas. Non-petroleum systems include dams and hydro-electric plants, solar plants, and individual solar systems, wind farms, and nuclear reactors.

The electricity, oil, and gas industries are highly regulated, with emphasis on “low consumer costs, safe delivery and use, and reliable service” (NIST, 2016a). None of the federal regulatory bodies, including the Federal Energy Regulatory Commission (FERC) and the Nuclear Regulatory Commission (NRC), or state regulatory commissions adopt specific seismic design criteria that establish desired or acceptable post-earthquake recovery times, and in general the performance goals are not well defined. At the state and local levels, regulators may adopt codes or standards for design and construction, but “there is wide variation in the level of design guidance” (NIST, 2016a).

Communication Systems

Communication systems comprise landlines, satellite, and wireless transmission systems, as well as the internet network, for both emergency and non-emergency uses. Current emergency and non-emergency systems overlap, using the same network nodes and links, as well as the same hardware and software.

Emergency call service (9-1-1) is a mandatory function supported by all service providers. Dedicated sites and circuits with redundancy and interoperability are installed to handle the high volumes expected immediately after an earthquake. FirstNet, the First Responder Network Authority, is expected to improve the emergency communication system as states implement it (FirstNet, 2019).

Power is the most critical element of a functioning communication system. Most systems use an uninterruptible power supply with backup batteries, but newer technologies are also available. After the 1971 San Fernando earthquake, Bell Communications Research created the Network Equipment Building System (NEBS), which called for at least eight hours of backup power for communication equipment. NEBS GR-63 (2017) remains the only guideline for earthquake protection of communication equipment.

Most wireless service providers have chosen not to follow NEBS. In 2014, the FCC attempted to establish a standard for backup power to cell sites but was unsuccessful. Backup power equipment can sometimes be infeasible to install for cell sites on building roofs, so these sites typically have no backup power. In some cases, a small solar panel and rechargeable battery is sufficient. In any case, functional recovery of cell sites installed on or within buildings can be limited by damage to the building itself. Planning strategies, as opposed to design strategies, are therefore likely to be part of a functional recovery standard

for communication systems. Strategies already in use for routine outages within wireless systems include substitute services (landline or internet) and mobile units.

An earthquake recovery issue perhaps unique to communication systems involves the expected demand surge that can result in a lack of service even when the system components are undamaged. Demand after the 2011 Canterbury Earthquake Sequence was ten times normal (ASCE/TCLEE, 2013); demand after Hurricane Sandy in 2012 was 13 times normal. Communication systems are designed assuming only a fraction of all potential users will be active at any time, so a demand surge exceeds the system's capacity even in the absence of damage. This demand surge is perhaps analogous to traffic jams during a pre-hurricane evacuation or planned power shutdowns during heatwaves. While perceived as a loss of function by the end user, these situations are more a result of heightened demand under rare conditions, than a failure to return to normal. To design for these rare cases is often costly and impractical so creative planning and response strategies are especially need, along with consideration of how routine upgrades could be designed or implemented to better accommodate temporary scalability.

Transportation Systems

Transportation systems comprise highways and roads (with associated bridges, tubes and tunnels), mass transit (with control facilities and stations), ports, and airports. Intermodal transportation systems, combining individual systems with often complicated transitions and intersections, are increasingly a feature of the modern built environment.

Performance-based seismic design criteria have been developed for highways, railways, ports, and airports. These address the policy question by classifying system components in terms of the importance of the facility. Typically, the criteria are intended to protect the structures and accept damage to roadways, runways, and rails on the assumption that these components can be quickly repaired.

The following discussion provides examples of existing design guidelines, illustrating the variety of transportation systems and established design approaches.

The California Department of Transportation's Seismic Design Criteria (Caltrans, 2019) are explicit about expected recovery times for two classes of bridge structures. Presuming a 975-year earthquake hazard, "Important" bridges are expected to provide limited service within days of the event, and "Recovery" bridges are expected to provide limited service within weeks. For a third class, "Ordinary" bridges, no post-earthquake recovery expectations are stated.

Outside of California, some other states also have their own criteria for bridge design, but some adopt the basic criteria developed by AASHTO (2014). Even for areas of high seismicity, the AASHTO criteria use safety-based objectives only, similar to the Caltrans criteria for Ordinary bridges. Operational objectives are left to the discretion of the bridge owner.

Seismic design criteria by the American Railway Engineering and Maintenance-of-Way Association (AREMA) specify a three-point performance objective intended to provide for train safety, "structural integrity," and collapse prevention at three different hazard levels. The specified hazard levels vary with the importance of the bridge, a classification based on damage implications, commercial value, replacement value, occupancy factors, and hazardous material factors. Any consideration of functional recovery time is merely implicit in the importance classification.

For ports, ASCE (2014) provides seismic design criteria for three categories of pile-supported piers and wharves, with the categories related to the structure's importance. As with the AREMA criteria,

consideration of functional loss is implicit in the importance classification. The Port of Long Beach (2009) has developed its own criteria that are more explicit about functional recovery time, intending no interruption in service following a 72-year shaking, and perhaps a few months to recover function after a 475-year event.

The Federal Aviation Administration (FAA) has written a number of documents for airport design, but they say little about expected seismic performance, referring instead to ASCE 7, the standard for design of new building structures. Airports in areas of high seismicity often write their own design criteria. For example, San Francisco International Airport developed criteria for its new air traffic control tower intended to keep the tower fully operational through a code-level design earthquake (Structure, 2017). This is consistent with performance expectations for new buildings assigned to Risk Category IV, discussed above.

Part 2: Functional Recovery Policy Options

Purpose & Scope

The concept of functional recovery represents a welcome shift in seismic design philosophy that will lead to new technical tools and more transparent public policy. With functional recovery-based codes and standards, communities can be more explicit and more intentional about the time it will take to recover basic functions after an earthquake. EERI recognizes that the normal processes for developing design standards can and should be used to implement functional recovery concepts, and that there are also interim options available to policymakers.

Some communities will prefer to wait until new consensus standards are available. Where a community estimates its current expected recovery to be unacceptably slow, however, they would do well to apply existing tools now, however imprecise or incomplete. The policy question can be addressed and acted upon even as the technical questions are debated. (In engineering, as in any complex field, there is almost never a single, complete, and final answer.)

This section explores potential policies that could be developed or implemented by legislatures and government agencies at the federal, state, and local level. The policy options vary in scale and focus, however an attempt was made to consider and include ideas for buildings and infrastructure, both new and existing.

The following options are not necessarily a comprehensive view of all policy options, but instead serve as a diverse suite of possibilities that could advance implementation of design focused on realizing functional recovery for individual buildings and infrastructure systems, upon further development and consideration. Additional ideas or modifications to these ideas may emerge as discussions about functional recovery continue into the future.

Ideas for actions beyond the policy arena and for other stakeholders emerged during the development of this section, as did ideas for actions needed to address technical, definitional, and implementation questions, however these are not the focus of this document and need further exploration. EERI may consider expanding the scope of this document or adding additional types of ideas in its future work.

EERI has organized possible policy options into four categories:

1. Legislation and regulations that require designing and planning for functional recovery, in addition to safety.
2. Interim programs that encourage designing and planning for functional recovery.
3. The development of technical consensus, specifically in the form of standards that set objective design criteria and planning strategies for achieving specified functional recovery times.
4. The development of policy consensus, specifically in the form of building code provisions and infrastructure regulations that assign, with local customization, acceptable functional recovery times to buildings and lifeline infrastructure systems based on their role in supporting various community functions.

Policy options for legislation and regulations that require designing and planning for functional recovery, in addition to safety

Current codes and performance-based standards already offer tools that anticipate functional recovery provisions (NIST, 2017; Bonowitz, 2018; PUC, 2019). These existing tools should be adapted where needed and applied to bring attention to recovery issues, especially where a community's current assessments reveal urgency. Possible parallel strategies for buildings and lifeline infrastructure that could be applied by federal, state, and local government legislatures and executive branch agencies could include:

Buildings

- Require certain government-funded construction projects (at all levels) to use building code provisions for the highest risk category, Risk Category IV, even where the building use would not be considered "essential" by the current code. As an alternative to Risk Category IV criteria, allow the use of criteria developed by federal agencies for their own facilities (NIST, 2017) or tools like FEMA P-58 (ATC, 2012) or HAZUS to demonstrate an equivalent or acceptably short recovery time. Relevant buildings or projects would need to be determined by the government agency, state, or jurisdiction in the policy development process to meet their own recovery goals, timelines, or targets.
- Require certain private construction projects normally assigned to lower risk categories, Risk Category II or III, to use building code provisions for Risk Category IV. Allow FEMA P-58, HAZUS, or similar tools or criteria to demonstrate an equivalent or acceptably short recovery time. Relevant buildings or projects would need to be determined by a state or jurisdiction in the policy development process to meet their own recovery goals, timelines, or targets. Because this strategy addresses privately owned or financed projects, it will likely require a state or local amendment to the adopted model building code.
- For new buildings designed with Risk Category II provisions and significant retrofit/improvement projects for existing buildings designed with Risk Category II provisions, require the design team to state the expected functional recovery time as part of the building's design criteria and include it in the building's permanent public record on the approved building plans.

Lifeline Infrastructure

- Require lifeline infrastructure systems to classify their components based on criticality categories, examples of which are provided by Davis (2008), ALA (2005a), LADWP (2019),

Davis (2019a), and TIRAP (2017). Criticality categories relate each component within the infrastructure system to public health, safety, and community resilience. Similar requirements have been put in place in the past, notably, a California Public Utilities Commission policy that requested regulated utilities in the state to “develop and adopt a comprehensive policy on acceptable levels of earthquake risk with long term priorities and schedules for the reduction of unacceptable hazards” by 1995 and resulted in a new consensus-based policy for California utility providers (Inter-Utility Seismic Working Group, 1995).

- Require new lifeline infrastructure projects having the highest criticality categories be designed for expedited recovery beyond standard performance, where feasible, and identify dependencies to other systems or impediments that could limit recovery speed.
- For new lifeline infrastructure projects or significant retrofit/improvement projects for existing lifeline infrastructure, require the design team to state the expected functional recovery time as part of the design and response/adaptation criteria, identify the degree of network redundancy available in case of loss of function, and identify any potential impediments that could impact or delay achieving the criteria, thereby delaying system-level restoration of basic services and limiting jurisdictional or regional resilience goals.

Designing buildings for functional recovery makes sense if adjacent development and related infrastructure can support the desired recovery time (NIST, 2017; NIST, 2018). Buildings and infrastructure systems are funded, designed, and regulated by different organizations, and we acknowledge that each will make progress in its own way; in addition to being inevitable, independent actions by different communities might even be beneficial. Still, if a jurisdiction is going to require design for functional recovery, it has an obligation to provide or upgrade public infrastructure to match. Therefore, this category of policy options includes an additional necessary strategy:

- Plan and implement improvements to existing public and private infrastructure systems as needed to support mandated design of new buildings and lifeline infrastructure to achieve functional recovery.

The identification of acceptable recovery times is a policy decision that benefits from community participation and consideration of local factors. Thus, planning requirements may also be an additional strategy necessary to set the recovery goals:

- Federal or State agencies could require that jurisdictions identify locally-relevant recovery goals and targets for their buildings and infrastructure, and clearly state them in their local Hazard Mitigation Plans and/or Safety Elements of their General Plans. This could be a requirement to access government response or mitigation funding, or could be done by legislative action. The NIST Community Resilience Planning Guide (2016a) provides a sample framework for setting these recovery targets.

Policy options for interim programs that encourage designing and planning for functional recovery

Where a community’s assessment of current conditions finds less urgency, each of the strategies listed above can be applied on a more selective or voluntary basis. Government agencies can play an important role in this regard, using public projects or public funding to demonstrate and improve the feasibility of new ideas that appear costly in the short term but have higher benefit-cost ratios over the long term.

Some example programs include the “Seismic Action Plan for Facilities Replacement and Renewal” Program at the University of California, Berkeley (Comerio, 2006), and the University of California San Francisco “UCSF Seismic Safety Review” Program (UCSF, 2019) and its proactive Request for Proposals Process that sets high performance requirements.

As with mandatory programs, the improvement of lifeline infrastructure is important for achieving the benefits of recovery-based building design and should be based on a community wide assessment of where the lifeline infrastructure fails to support overall resilience goals. To help achieve this, State or regional governments should take steps to improve collaboration among lifeline infrastructure providers. A regional “lifelines council” with representatives of the relevant public agencies and private organizations can share information, improve understanding of system interdependencies, and establish coordination processes regarding mitigation, emergency planning, and system restoration. Recent work in San Francisco (2014) and New Zealand (NZLC, 2016; WeLG, 2019) provides examples to follow.

Policy options for development of technical consensus, specifically in the form of standards that set objective design criteria and planning strategies for achieving specified functional recovery times

The engineering community should begin working toward consensus on the definitional and technical questions described more fully in Part I of this white paper. The normal way to do this is through a conventional standards development process (as is currently being explored by the International Code Council (Dowty, 2019) in a road map for functional recovery of new buildings), but government agencies have roles to play as well. Possible strategies in this category for legislatures and executive branch agencies could include:

- The Interagency Committee on Seismic Safety in Construction (ICSSC) should extend its basic implementation guidance for “higher than building code” design objectives (NIST, 2017) by reviewing and comparing criteria developed by specific agencies.
- NEHRP agencies should support efforts by one or more standard development organizations to develop design provisions for functional recovery. NEHRP might use the White Paper currently in development by its Provisions Update Committee (2019) to define these efforts, and should build upon decades of existing research, practice, and standards development for seismic design.
- NEHRP agencies should develop funding requests to implement research recommendations in NIST Special Publication 1224 (NIST, 2018). These should include cost effective design solutions for achieving functional performance for a comprehensive suite of building elements and components.
- NEHRP agencies should support the development of improved post-earthquake reconnaissance strategies and data collection tools, deployed over time, in support of functional recovery. EERI has begun the exploration of this type of reconnaissance framework that could be used to inform these efforts (Tremayne et al, 2017).
- NEHRP agencies should develop funding requests to implement research recommendations in NIST publications GCR 14-917-33 and NIST GCR 16-917-39 (NIST, 2014; 2016b) in support of lifeline infrastructure resilience and recovery-based system design. These should include improved methods and tools for modeling, simulating, and monitoring lifeline systems to better understand network resilience and dependencies. These should include cost

effective design solutions for achieving functional performance for bridges and other types of lifeline infrastructure systems and components.

- NEHRP agencies should enhance social science research regarding the needs of infrastructure users and vulnerable populations, the abilities of users and vulnerable populations to utilize interim or back-up response strategies, and the societal implications of slow recovery. Findings will inform both the new technical standards and the necessary policy consensus.
- State and local government agencies should prepare to build on the NIST-FEMA report due by mid-2020, and identify specific agencies and departments to be tasked with considering and implementing design options for functional recovery.
- State and local code enforcement agencies should request the consensus input of local professional organizations (including EERI and the Structural Engineers Association of California) to develop sample criteria, code interpretations, and other guidance focused on design for functional recovery.
- Agencies should host exercises with many different stakeholders and utility providers, focused on identifying restoration times and impediments to recovery, while considering where design for functional recovery could limit impacts or speed recovery. It will be important in these cases to use a consistent hazard scenario and correlate losses and impacts across stakeholder groups to identify dependencies, collocation, collateral damage, and opportunities for repair cooperation. Similar approaches were used when developing and exercising results from the Northern California HayWired Scenario (USGS, 2018).
- Infrastructure regulators at state, district, and local levels should request the consensus input of local professional organizations (including EERI) to develop design guidance for functional recovery at the system level, accounting for interdependencies among systems, where possible.
- With appropriate government support, building designers, infrastructure providers and system designers should standardize and implement criteria to classify system components in terms of criticality and/or system wide functional recovery needs. In concept, each criticality category would have different minimum design criteria. Recent work by Davis (2008), ALA (2005), LADWP (2019), Davis (2019), and TIRAP (2017) provides examples to consider. Through this process, current practices should be evaluated for compatibility and consistency with new criticality categories. For example, current AASHTO Seismic Guide Specifications include seismic design criteria for bridges based on their seismic hazard that should be checked for consistency with other lifeline standards or guidelines.

Related to the basic technical questions outlined above are anticipated questions about the benefits and costs of designing for functional recovery as either a supplement or as an alternative to current practice. Merely designing intentionally for functional recovery, or stating the expected functional recovery time, does not necessarily impose any cost relative to current practice; cost increases would only be expected if the policy decision is made to require design for a shorter recovery time than current practices deliver.

- NEHRP agencies, together with federal executive branch agencies, should commission benefit-cost studies related to design for functional recovery. The studies should consider separately the benefits and costs to building developers, owners, and tenants related to

specific individual projects as well as the benefits and costs to state or local jurisdictions related to the adoption of functional recovery-based building codes and standards.

- Similarly, NEHRP agencies should commission benefit-cost studies related to design and retrofit options for infrastructure systems. The studies should consider separately the benefits and costs to lifelines developers, ratepayers, and taxpayers. For infrastructure systems, design and retrofit options include projects completed over different timeframes, from years to decades.
- Appropriate state and local agencies should commission similar studies accounting for local conditions.

Policy options for development of policy consensus, specifically in the form of building code provisions and infrastructure regulations that assign, with local customization, acceptable functional recovery times to buildings and lifeline infrastructure systems based on their role in supporting various community functions.

Independent of the definitional and technical questions, state and local legislatures and executive branch agencies should begin working toward consensus on the policy question outlined above. Often these issues are addressed by the agency that adopts and publishes the state or local building code. In recent years, however, many states have moved to amendment-free adoption policies, so the idea of incorporating functional recovery priorities (or even re-assigning Risk Categories) could require special efforts. Strategies for code adoption agencies and other policy-making bodies include:

- The ICSSC should extend its basic implementation guidance for “higher than building code” design objectives (NIST, 2017) by developing draft policy for acceptable functional recovery times for buildings and lifeline infrastructure systems serving various Federal functions.
- State and local code adoption agencies should prepare to build on the NIST-FEMA report due by mid-2020. For example, California should enact Assembly Bill 393 (2019) to take up related technical and policy topics.
- The decision to transition to a recovery-based building code is likely to be made at the state level. Because functional recovery is linked to community resilience, NIST (2016a) has recognized that recovery goals should often be linked to local conditions and preferences. Therefore, proactive jurisdictions should use the NIST *Community Resilience Planning Guide* and similar tools to develop recovery goals considering the capacity and fragility of their existing buildings and lifeline infrastructure. Selection of infrastructure recovery goals must consider the entire network of buildings and supporting lifeline systems and the recovery times defined by jurisdictions in support of their social and economic institutions.
- Jurisdictions should use their existing participatory community input process to identify locally-relevant recovery goals and targets for their buildings and infrastructure, and clearly state them in their local Hazard Mitigation Plans and/or Safety Elements of their General Plans. These community targets could be used to inform technical standard development or other legislative policies. States and Jurisdictions should apply for funding from new FEMA Disaster Recovery Reform Act (DRRA) sources, such as the pre-disaster grant program

called Building Resilient Infrastructure and Communities (BRIC), to support planning activities that apply functional recovery and seismic resilience concepts (FEMA, 2018; 2019).

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