Resource Paper

Resilience-Based Design and the NEHRP Provisions

developed by

National Institute of Building Sciences
Building Seismic Safety Council

for

the Federal Emergency Management Agency (FEMA)
2020 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

FEMA IDIQ Contract HSFE60-15-D-0022

February 2020

Summary

This paper addresses the potential relationship between future NEHRP *Provisions* and resilience-based earthquake design, especially in the context of definitions and priorities established in federal law by the 2018 NEHRP reauthorization. It extends concepts proposed in Resource Paper 1 in Part 3 of the 2015 *Provisions*. Federal policy now calls for increasing earthquake resilience at the community scale and identifies building codes and standards as tools for doing so. Resilience relies on the timely recovery of the built environment. Building codes and standards can therefore serve a resilience goal, at any scale, by providing design criteria based on functional recovery time. The current code-and-standard model is adaptable to resilience-based design, with the standard providing technical definitions and design criteria, and the code setting policy goals. The NEHRP *Provisions* can support resilience-based design by providing source material for a functional recovery standard. Specific design strategies and criteria would be required for different functional recovery times, much in the same way that the current *Provisions* set specific criteria for different seismic design categories. While many questions remain to be answered through research, the current *Provisions* suggest a set of requirements that might be used in the short term.

1. Background and current federal policy

1.1. FEDERAL POLICY NOW CALLS FOR INCREASING EARTHQUAKE RESILIENCE AT THE COMMUNITY SCALE AND IDENTIFIES BUILDING CODES AND STANDARDS AS TOOLS FOR DOING SO.

Resilience, especially at the community scale, is broad and complex. The NEHRP *Provisions*, historically, address the design of new buildings and building-like structures for earthquake loads. Because community resilience also involves existing buildings, infrastructure, and multiple hazards, as well as societal issues tangential to performance of the built environment, the *Provisions'* contribution to resilience will be limited. The purpose of this paper, given both the opportunities and the limits, is to consider what role the *Provisions* might play as stakeholders embrace concepts of community resilience.

Since the last edition of the NEHRP *Provisions*, the topic of earthquake resilience has emerged as newly compelling, if not entirely new. Since 2015, government agencies at all levels, non-governmental organizations, academia, and industry stakeholders have all published on the need for resilience, how to identify or measure it, and how it might be achieved. While there is no industry-wide consensus on the details, some basic concepts are now accepted widely enough to be referenced in federal policy (Public Law 115-307, 2018; Thune, 2018).

Of particular interest is *community resilience*, now defined in federal regulations by the 2018 NEHRP reauthorization as "the ability of a community to prepare and plan for, absorb, recover from, and more successfully adapt to adverse seismic events" (42 U.S.C. 7703). With the NEHRP reauthorization act, increasing community resilience is now a stated purpose of the program (42 U.S.C. 7702).

In addition, the act charges NIST to conduct research "to improve community resilience through building codes and standards" (42 U.S.C. 7704(b)(5)), linking the holistic concept of resilience with the specific subject of the NEHRP *Provisions*.

The link between community resilience and building codes and standards is not new. In 2016, a presidential Executive Order encouraged federal agencies to go "beyond [current] codes and standards," noting that "to achieve true resilience against earthquakes, … new and existing buildings may need to exceed [current] codes and standards to ensure … that the buildings can continue to perform their essential functions following future earthquakes" (Federal Register, 2016). The White House later extended the idea to privately owned and locally regulated buildings with a conference "to highlight the critical role of building codes in furthering community resilience and the importance of incorporating resilience … in the codes and standards development process" (The White House, 2016).

More recently, discussion of community resilience and earthquake design has begun to focus on the merits of codes and standards based on a building's *functional recovery*, as discussed in the next section.

1.2. KEY CONCEPTS

A functional recovery standard is necessary for resilience-based earthquake design. Resilience relies on the timely recovery of the built environment. Building codes and standards can therefore serve a resilience goal by providing design criteria based on functional recovery time. The current code-and-standard model is adaptable to resilience-based design, with the standard providing technical definitions and design criteria, and the code setting policy goals.

To understand the potential relationship between future NEHRP *Provisions* and resilience, it is useful to review key terms and concepts.

1.2.1. Resilience

Though now ubiquitous, the term *resilience* is still not consistently used or defined. The definition of *community resilience* given above is necessary, but it is not sufficient for purposes of building code or standard development, as it does not relate clearly to the tasks of seismic evaluation or design of buildings. That said, a review of proposed definitions of resilience from the last ten years (see the Appendix) reveals four common themes that should inform any efforts to develop a resilience-based code or standard:

- Resilience is an attribute of human organizations, not of physical buildings or structures. Earthquake resilience thus makes sense for any organization – a region, a neighborhood, a campus, a corporation, an industry, a business, or even a household – that comprises more than just its physical assets. As noted above, however, the organization of interest to NEHRP is the community, which is consistent with the role of a building code as public policy. This fundamental idea, that resilience is an attribute of organizations, conveys its holistic nature, but it also implies limits to what a building code or standard can achieve in resilience terms; this is further discussed below.

- Resilience is about the preservation and recovery of functionality, not just safety. In the context of building codes and standards, this means that resilience-based design criteria must consider not only structural and nonstructural components, but also certain building contents and even some externalities normally ignored by a code or standard, such as the functionality of infrastructure systems, the availability of repair contractors, or the performance of other facilities supporting related functions. Further, the focus on functionality suggests that resilience-based design criteria should vary with a facility's specific use and occupancy.

- Resilience incorporates an element of time. Unlike earthquake safety, which is gauged by the immediate and direct effects of structural response, and unlike design of emergency facilities already expected to be immediately functional, resilience-based design might contemplate the return of any lost functionality over hours, days, weeks, or even months. In resilience-based design, the emphasis is on the timely return to normal conditions, not just the performance during the emergency phase (which current codes already consider).

- Resilience implies an event from which the organization must recover. For earthquake resilience, the event is obvious. Outside the NEHRP context, the event might be another natural hazard, a natural event exacerbated by human activity (such as climate change), a socio-economic event related to natural causes (such as a power outage), or an entirely human-caused event (such as terrorism).

Given these four themes, *community resilience*, even as defined above, can be related to the timely post-earthquake recovery of certain community functions that rely on the built environment, such as housing, healthcare, commerce, culture, or government services. This understanding has been developed by NIST in its *Community Resilience Planning Guide for Buildings and Infrastructure Systems*, or CRPG (NIST, 2016).

As noted, however, the concept of resilience is applied to smaller organizations as well. The resilience of a business, for example, relies on the timely recovery of its essential parts, which might include a workforce, supply chain, customer base, facilities, and community services. To the extent that a business relies on its physical facilities, its resilience is linked to the functional recovery of buildings – even if only a single structure.

1.2.2. Functional Recovery

Though resilience is not an attribute of physical buildings, it is related to building performance as measured by the time it takes to recover basic functionality. This, too, is now reflected in the 2018 NEHRP reauthorization, which charges NIST and FEMA to convene a committee of experts to "assess and 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. 7705b). The charge is to be completed with a report to Congress by June 30, 2020.

Functional recovery is not yet formally defined, though the term has been used informally in the context of earthquake design (especially regarding infrastructure) since at least 1980. Unlike resilience, functional recovery is widely understood to refer to the performance and capacity of a distinct piece of the built environment, such as an individual building or infrastructure network.

Tentative definitions have been proposed to align with established concepts in earthquake engineering.[1] On its face, functional recovery is related to the third major category of potential earthquake losses – downtime – as used in FEMA P-58 and its source documents (ATC, 2018a, Section 1.5). Functional recovery is also related to the ASCE 41 performance levels Immediate Occupancy, which involves a structure safe enough to occupy with essentially no interruption, and Operational, which adds the uninterrupted performance of critical nonstructural systems (ASCE, 2017b). Functional recovery is similar to Operational performance, but as discussed below, with the allowance of a time delay and possibly with a relaxed set of necessary functions.

SEAONC BRC (2015) described functional recovery to mean "the owners' and tenants' ability to resume normal pre-earthquake operations, which can vary with occupancy," positioning it as the second of three post-earthquake milestones. Functional recovery comes after "reoccupancy, at which time the building may be safely occupied," if not usable, and before "full recovery, at which time even cosmetic damage is repaired and even non-essential functions are restored."

NIST (2018) also recognized multiple recovery milestones or functionality levels and, consistent with the CRPG, tied functional recovery to a desired or acceptable time: "[When] developing criteria ..., multiple functional levels that may differ in terms of the acceptable recovery time should be considered, depending on the building's role in the community, the services it provides, and the hazard level."

As for functional recovery itself, NIST (2018) describes it as the state in which "damage to the building's structural system is controlled, limited, and repairable while the building remains safe to occupy. The building's ability to function at full or minimally reduced capacity is also affected by the damage state of the non-structural systems of the building (e.g., building envelope, equipment, interior utilities), as well as the infrastructure that connects the building to its surrounding community."[2]

Perhaps the most formal definition has been provided by a bill introduced to the California Legislature. Anticipating the 2020 NIST-FEMA report, the bill defined 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

[1] Precedents outside of earthquake engineering also exist but are not as specific as those cited in the text. For example, NFPA (2018) includes a generic "Mission Continuity" objective involving "continued function" for "buildings that provide a public welfare role for the community," and ASCE (2019) contemplates an "Operational" performance level, paired with relatively frequent wind loads, for design of new buildings.

[2] NIST (2018) uses the term immediate occupancy, or IO, instead of functionality because of legislative language, explaining, "The term IO is used for general reference to a potential range of functional levels for consistency with the congressional language."

> acceptable time, where the maximum acceptable time may differ for various uses or occupancies (Assembly Bill 393, 2019).

The definition, while it describes a design standard as opposed to a building condition, covers all of the key ideas discussed above: consideration of structural and nonstructural performance, a focus on functionality, and acceptability measured by recovery time, allowing different times for different building uses. Importantly, designing for functional recovery does not imply that the building must recover immediately.

The AB 393 definition does two things. First, it describes a post-earthquake condition that might now be taken as the definition of functional recovery:

> Functional recovery is a post-earthquake state in which capacity is maintained or restored to support the basic intended functions of the pre-earthquake use.

For a building, "capacity" means that of the structural and nonstructural systems, as in the AB 393 definition. But, as NIST (2018) notes, it should also mean the capacity of contents, infrastructure, and even certain services external to the building, as needed "to support the basic intended functions."

Second, the AB 393 definition contemplates that "maximum acceptable" recovery times will be assigned to different buildings. With these two ideas, the AB 393 definition is combining the familiar roles of design standards (which establish objective technical criteria) and building codes (which set policy regarding minimum requirements).

1.2.3. The role of codes and standards

If resilience is an attribute of the whole community, and if community resilience is only partly a function of building design, how would the NEHRP *Provisions* contribute? After all, the *Provisions* are explicitly about the design of individual buildings.

Figure 1 describes the broad scope of the resilience movement and illustrates how apparently disparate ideas, documents, programs, etc. can all play a role. The "resilience field" is a two-dimensional space in which any resilience-related concept can be located in terms of whether it addresses more technical topics (like structural engineering) or more holistic ideas (like a company's mission statement or the well-being of a family) and in terms of whether it is meant to apply to an individual physical facility (like a typical architectural commission) or to the whole organization in question.

Consider the definition of community resilience from the 2018 NEHRP reauthorization: "the ability of a community to prepare and plan for, absorb, recover from, and more successfully adapt to adverse seismic events." The concept is explicitly about the whole organization – the community – and the broad tasks of planning, preparing, recovering, and adapting go well beyond the technical design of its physical assets. Thus the NEHRP concept of community resilience is located in the lower right quadrant of Figure 1.

By contrast, the *Provisions*, together with the codes and standards based on them, would be located in the upper left quadrant of Figure 1. They are technical, packed with specialized terminology about physical components, and they are written with the understanding that they will be applied one building, structure, or project at a time.

Though technical and applied to individual facilities, a building code can still be resilience-*based*, serving holistic, organization-wide resilience goals. Indeed, a functional recovery standard (using the AB 393 definition above) is necessary, if not sufficient, for resilience-based earthquake design.[3] The challenge is to conceive, write, and implement the code so that when it is applied by technical experts to individual facilities, it reflects the larger holistic goals of the community. Over time, as resilience-based codes and policies are applied to individual new and existing buildings, the aggregate effect should improve community resilience.

This idea, that technical provisions, narrowly applied, might improve an organization's earthquake resilience, is perhaps easier to grasp when applied to a smaller organization. It is not difficult to see, for example, how a corporation might serve its shareholders by applying a careful seismic due diligence policy to the office space it builds or leases. Similarly, by setting high design criteria, a campus can better protect its research funding and serve its educational mission (Comerio, 2000). Resilience-based codes and standards, written to address functional recovery time explicitly, will help such organizations.

(Figure 1 also shows how the NIST CRPG might provide a bridge between holistic thinking about community resilience and technical design of individual buildings to support resilience goals. The CRPG breaks the built environment into building "clusters" based on their use and occupancy, not their structural systems or materials, and it contemplates recovery goals for whole groups, not for individual facilities.)

[3] To be sure, a community could avoid the need for a separate functional recovery-based design standard by setting very lax recovery goals (which the current safety-based code would already satisfy), by stipulating that certain provisions of the current code are deemed to comply with various recovery goals (an approach that has been suggested as an interim strategy), or by taking an entirely different approach to resilience and recovery, for example through comprehensive insurance and planning schemes. The presumption of the NEHRP *Provisions*, however, is that earthquake *design* involves engineering with defined, repeatable procedures, and for that approach to work, a standard is needed.

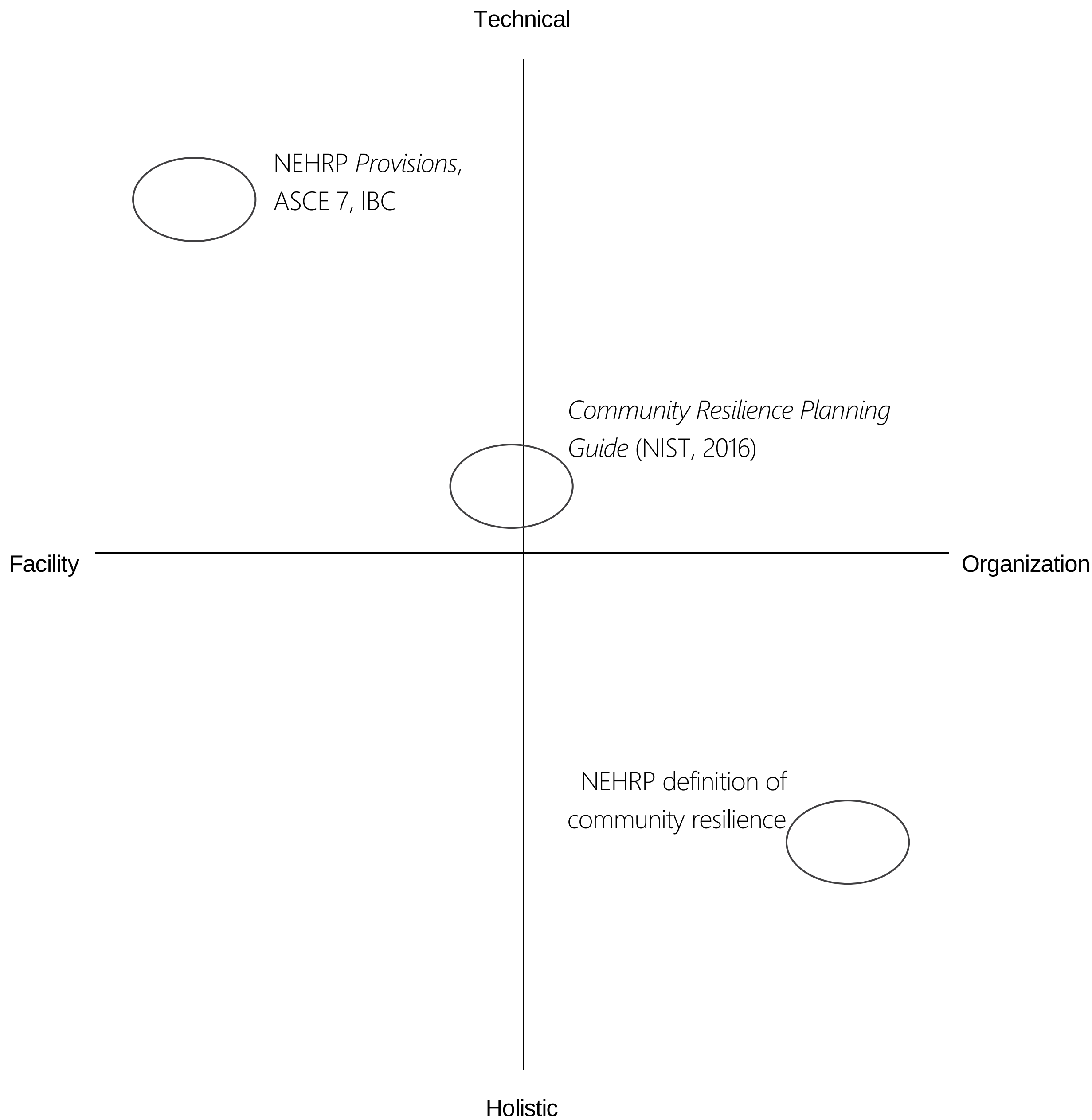

Figure 1. The Resilience Field (after Meister Consultants Group, 2017)

While a building code can be resilience-*based*, Figure 1 also confirms that there are important limits to what a code or standard can do to affect an organization's resilience. Because it is applied to individual buildings, a code has little impact on its neighborhood (or its city) or even on its own functional cohort (housing, schools, etc.) unless applied consistently over time. Even then, separate codes or mitigation programs are generally needed to address resilience risks posed by the vast existing building stock. Separate design standards and policies are also needed to address new and existing infrastructure, which the *Provisions* do not address. Most significantly, a building code cannot address most socio-economic externalities that affect community resilience.

Like the current building code, a functional recovery code would address the design of structural systems and bracing for nonstructural components. The scope would likely be expanded to consider contents bracing and adjacent buildings, two issues not far from the code's traditional scope. To begin to address socio-economic externalities, resilience-based codes and standards might be expanded further with provisions that think of the building in a more holistic way. For example, on-site backup utilities, reoccupancy plans, continuity of operations plans, retainers for repair contractors, and even insurance, while not traditional building code topics, are strategies related to building design that might be considered for a future resilience-based design standard, or at least for related building regulations (ATC, 2018d).

Ultimately, however, even if we rewrite our building codes as functional recovery standards, they would contribute to community resilience only in the way that the current safety-based codes and standards contribute to a holistic view of community safety and vitality. Our current codes limit collapse and fire – two sources of earthquake deaths and injuries – but a building code does not consider broader questions regarding the supply of clean water, food, sanitation, or medical services.

1.2.4. The code-and-standard model

To implement resilience-based earthquake design, we need a policy tool and a technical tool. The building code is the policy tool, setting performance objectives by assigning buildings to risk categories based on their use and the implications of damage. With a resilience-based code, each building would be assigned to a category representing a desired functional recovery time. As discussed above, the assignments would be made by considering the aggregate effect of applying the code over time.

Policy questions are normative; they consider desired outcomes, asking what the functional recovery time of a given building *should* be. In the long term, these preferences, together with benefit-cost analysis, should be informed by social science research linking objectively measurable recovery time to more holistic measures of organizational resilience. In the short term, absent the critical research, these policy decisions are likely to be influenced primarily by stakeholder estimates regarding perceived benefits and immediate costs (NIST, 2016). In either case, the policy questions, which include a jurisdiction's decision to adopt a recovery-based code as mandatory, voluntary, or applicable only in certain cases, are outside the scope of the *Provisions*.

The design standard (along with the *Provisions* as its resource document) is the technical tool. A functional recovery standard would provide the definitions and criteria estimated to achieve a given functional recovery time, independent of any policy about what time limit *should* be selected.

The code-and-standard model, familiar to users of the *International Building Code* and its adopted standard, ASCE 7, should be adaptable to resilience-based earthquake design. With reference to the NIST-FEMA committee charge, the code-and-standard model is one "option" for "improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake reoccupancy and functional recovery time."

2. A framework for NEHRP *Provisions* for resilience-based design

The NEHRP *Provisions* can support resilience-based design by providing source material for a functional recovery standard. Specific design strategies and criteria would be required for different functional recovery times, much in the same way that the current *Provisions* set specific criteria for different seismic design categories. While many questions remain to be answered through research, the current *Provisions* suggest a set of requirements that might be used in the short term.

Using a code-and-standard model, the NEHRP *Provisions* would be the basis for a functional recovery standard, which would then be cited by, or incorporated into, a resilience-based code. The code would assign desired or target recovery times. As discussed above, the scope of the *Provisions* would likely need to be expanded to cover topics like contents bracing and backup utilities.

The idea of adapting the *Provisions* to address functional recovery is not entirely new. In the 2015 *Provisions*, Resource Paper 1 built on work by NIST to propose assigning an explicit "function loss" performance objective to Risk Category IV (BSSC, 2015; NEHRP CJV, 2012). Design criteria for Risk Category IV had been assumed to deliver some measure of post-earthquake functionality, but the expectation was never quantified or clearly stated (ASCE, 2017a, Sec. C1.3.3). Using the Operational terminology of ASCE 41, the proposal would have aligned the criteria for Risk Category IV to provide a 10 percent probability of less-than-Operational performance in a Function-Level Earthquake, analogous to the 10 percent probability of collapse in a Maximum Considered Earthquake expected for buildings assigned to Risk Category II.

There are two main differences between that 2015 proposal and the concept of functional recovery presented here. With the 2015 proposal, functionality would only have been considered for buildings already assigned to Risk Category IV because of their "essential" nature, and meeting the objective would mean the building remains functional "immediately following" the earthquake shaking (ASCE, 2017a). That is, where functionality is considered important, immediate functionality (or Operational performance, in ASCE 41 terms) would be sought; otherwise, no attention would be paid to functionality. Here, every new building would be assigned a desired or target functional recovery time, and different building uses would have different assignments, from hours to days to weeks to months, consistent with concepts from the NIST CRPG.

The concept presented here would make functional recovery a supplemental (or perhaps primary) basis for earthquake design of all buildings, as opposed to a special objective only for "essential" facilities. This is not to say, however, that all buildings would need to be designed like hospitals and fire stations. On the contrary, by allowing functional recovery times as long as weeks or months, it is likely that many buildings would be designed and detailed just as they are now; the only difference would be that their estimated (or desired) recovery time would be explicitly stated, providing transparency to all stakeholders and facilitating resilience planning.

2.1. DEFINITIONS

As source material for a functional recovery standard, the *Provisions* would mostly address technical questions regarding demand, capacity, detailing, and acceptability criteria. Before that, however, they would also need to address questions inherent in the definition of functional recovery given above: What are a given building's "basic intended functions"?

The 2015 *Provisions* Resource Paper anticipated this question as well: "[A] framework is needed for determining what constitutes functionality following the earthquake. … Significant study and likely additional provisions development is required to quantitatively define these performance states. … [I]t is not known what various stakeholders will deem tolerable damage and still be 'functional' (sic)."

A plain reading of the definition suggests that functional recovery could be achieved with cosmetic damage still in place. Similarly, partial functional loss (for example, one restroom in a house with two), or the loss of one use in a mixed-use building (for example, the parking levels in an office building or the ground floor retail space in an apartment house) might be deemed acceptable. Beyond this, however, the possibilities quickly get into questions of habitability and even law. Are boarded windows acceptable? Or the loss of an accessible entry or an elevator in a low-rise building? Researchers have begun to study these questions (NIST, 2018; Center for Risk-Based Community Resilience Planning; Soga et al, 2019) but in the short term the gaps will surely need to be filled by consensus judgment, perhaps starting with the current building code's nonstructural bracing scope for Risk Category IV as a benchmark.

2.2. DEMAND

Among the issues that will need to be resolved in the course of developing a functional recovery standard is the selection of a design ground motion.

The 2015 *Provisions*, and NIST before it, defined a Function-Level Earthquake, FLE_R, analogous to the risk-targeted MCE_R (NEHRP CJV, 2012). These new spectral acceleration values would be set to ensure a uniform 10 percent probability of failing to achieve Operational performance. A similar approach could be taken for the functional recovery concept described here, but at least two new considerations would be needed. First, defining a risk-targeted ground motion this way presumes a known set of design criteria. But, as the 2015 *Provisions* noted, "current story drift limits of Table 12.12-1 of ASCE/SEI 7-10 do not provide adequate damage control to meet functional and/or economic loss objectives and would require substantial revision." Further, functional recovery is more closely tied to the performance of nonstructural components than safety is, but design criteria relating nonstructural performance to recovery time are far from robust. So if it is unclear what counts as functional (as discussed above), or what the acceptability criteria will be, then the FLE_R cannot yet be defined.

Second, the FLE_R corresponds to a performance level achieved immediately after the earthquake. If functional recovery is now going to be defined as a suite of target recovery times ranging from hours to months, a separate map of ground motions will be needed for each limit state, complicating the normal design procedures.

Adopting a risk-targeted demand for the functional recovery standard would help maintain at least philosophical consistency within the *Provisions*. That said, the non-uniform variation between expected FLE_R and MCE_R values is certain to cause some confusion. In the short term, and certainly until the definitional questions are addressed, it might be preferable to use the MCE_R or the Design Earthquake (or some specified fraction thereof) as the demand, if only to simplify the procedures. Though theoretically incorrect, this simplification would be entirely consistent with current practice, which uses the DE even for Risk Category IV facilities where functionality is expected to be preserved.

Complicating the issue further, if the functional recovery criteria are really meant to be linked to a community-wide resilience goal, then the use of site-specific ground motion data might itself be incorrect. For resilience planning, a scenario event is often more appropriate.

2.3. CAPACITY AND ACCEPTABILITY

In theory, the functional recovery design criteria would follow basic principles of performance-based engineering. For the current safety-based *Provisions*, the criteria for a new building assigned to Risk Category II should ensure that the probability of collapse is less than 10 percent, given the site-specific MCE_R ground motion: P(Collapse) < 10%, given MCE_R.

By analogy, it should be simple to state the functional recovery objective. The probability of *not* achieving functional recovery is small, say less than Y%, given the appropriate demand. With functional recovery defined in terms of a target time, T_{target}, this would be stated as:

$$P(T_{FR} > T_{target}) < Y\%, \text{ given } D_{FR}, \text{ where:}$$

- D_{FR} is the ground motion deemed appropriate for functional recovery, discussed above.
- Y is tentatively set at 10%, matching the Risk Category II safety criteria, consistent with the reasoning of the 2015 *Provisions* Resource Paper.
- T_{target} is the target recovery time for the building's use and occupancy, assigned as a policy matter by a resilience-based code.
- T_{FR} is the estimated functional recovery time, given the building's design and forthcoming consensus regarding requirements for functional recovery.

Each of those four values deserves its own research program. The first three, however, can be set by default or by consensus judgment. The last, T_{FR}, can be estimated with the FEMA P-58 methodology. FEMA P-58, however, predicts repair time, which is not the same as functional recovery time (ATC, 2018a, Section 3.9.2; ATC, 2018c, Section 3.2.2.3). The commentary to ASCE 7 acknowledges that "the fragilities of structural systems to ensure function are not well established" (ASCE, 2017, Section C1.3.3). Most important, the few studies that have been done show wide variation in repair or recovery times of code-designed buildings as functions of the lateral system, Site Class, and other factors (ATC, 2018b; ATC 2018d, Part 3; Haselton et al., 2018). So until a consensus standard is available, FEMA P-58 might be supplemented with user-defined inputs and appropriate adjustments of its repair time results.

Absent a consensus method of calculating T_{FR} for a specific new building design, another approach suitable to a first generation functional recovery standard might be to presume a value of T_{FR} by reference to a consensus checklist of design features or strategies associated with different recovery times. This appears feasible (and perhaps no less reliable at this stage than a calculation) because the range of estimated functional recovery times for a new code-designed building is already bounded in part by the nature of the current code. That is, the current building code (and the *Provisions* and ASCE 7) contains a set of design strategies and requirements already associated with different risk categories and seismic design categories. Criteria for a recovery-based design would likely use some or all of these available strategies, and in the worst case, a building with no special recovery goal would still be subject to the current safety-based code.

Regardless of how T_{FR} is determined, its value will certainly involve substantial uncertainty. Given our current state of knowledge, factors including variability in ground motion, quality of design, quality of construction, and post-construction use, alteration, and maintenance can be expected to add even more uncertainty regarding recovery time than they do regarding safety. In addition, actual recovery time will be influenced by the availability of skilled inspectors, repair contractors, and suppliers, regulatory decisions accounting for conditions outside the building itself, the decisions of affected stakeholders, and other externalities.

Figure 2 shows – in a hypothetical or conceptual way only – how current earthquake design requirements could be adapted into a functional recovery standard by assigning them to target functional recovery times. If one assumes that a building designed with the current code would reliably achieve functional recovery within a month (given the recovery-based demand, discussed above), then few additional requirements would be imposed for a building assigned a target functional recovery time of "1 Month" or longer. Where a shorter recovery time is desired or assigned, additional design strategies or tighter acceptability criteria would be "Required."

The list of potential requirements could come from the current *Provisions*, specifically from the set of design strategies and provisions already used for Risk Category IV. Supplemental requirements, shown in concept at the bottom of Figure 2, could introduce non-traditional strategies to address building contents, backup utilities, and even reoccupancy or recovery planning. Building contents would be expected to affect recovery of buildings or tenant spaces containing manufacturing, retail, broadcasting, out-patient medical services and other uses involving specialty equipment. Reoccupancy and recovery planning is expected to cut the functional recovery time significantly in large or complex buildings (ATC, 2018d, Part 3). However, as shown at the bottom of the figure, even these strategies might be ineffective, and therefore "Moot," where a very short target recovery time is assigned.

The designer would need to satisfy only the requirements indicated for the target functional recovery time set by the resilience-based code, T_{target}. Requirements would continue to vary by structural system and material if, for example, higher drifts are deemed repairable within a given time for some systems but not for others. All of the table entries would be subject to adjustment as new research and reconnaissance data becomes available, but the broad categories of target times – 1 Day v. 1 Week, as opposed to 24 hours v. 48 hours, for example – will help keep the provisions stable and are appropriate to our current level of knowledge.

Of course, the challenge lies in deriving consensus regarding the set of requirements to be associated with each value of T_{target}, without defaulting to the most conservative recommendations in every case.

Functional Recovery Design Requirement	Target Functional Recovery Time, T_{target}			
	1 Hour	1 Day	1 Week	1 Month
Structural				
Limits on lateral system selection	Required	Required	Required	–
Limits on drift	Required	Required	Required	–
Factor on required strength	Required	Required	–	–
etc.	…	…	…	…
Nonstructural				
Increased bracing scope	Required	Required	Required	–
Reliability factors on design strength	Required	Required	–	–
Ruggedness certification	Required	Required	–	–
etc.	…	…	…	…
Recovery-critical contents				
To be determined by user groups	Required	Required	…	…
etc.	…	…	…	…
Utility service				
Electricity backup	Required	Required	Required	–
Potable water backup	Required	Required	Required	Required
Wastewater alternative	Required	–	–	–
Telecommunications	Required	–	–	–
etc.	…	…	…	…
Reoccupancy and recovery planning				
Repair services on retainer	Moot	Required	Required	–
Pre-determined safety evaluation protocol	Moot	Required	–	–
Business continuity plan	Required	Required	–	–
Pre-defined permit application	Moot	Required	Required	–
etc.	…	…	…	…

Figure 2. Hypothetical prescriptive design requirements for a range of functional recovery times

3. References

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4. Appendix: Definitions of Resilience

There is no standard (i.e. formal, consensus) definition of resilience. Recent federal law charges FEMA with defining the term "resilient" by April 2020 for purposes of implementing disaster assistance programs (42 U.S.C. 5172(e)). Meanwhile, the following working definitions from other groups are useful because they have common themes, as shown by the underlining:

- UNISDR (2009): The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

- FEMA NDRF (2011): Ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies.

- NRC (2011): A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur.

- National Academies (2012): The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events.

- Presidential Policy Directive 21 (The White House, 2013; cited similarly in NIST, 2016, Section 1.3, and MitFLG, 2019, Appendix B): The ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

- US GAO (2014): The term resilience refers to the ability to prepare and plan for, absorb, recover from, and more successfully adapt to actual or potential adverse events.

- 100 Resilient Cities: Urban resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience.

- AIA NRI (2016): Resilience is achieved when systems remain adaptable and functioning when faced with major disruptions.

The new definition of *community resilience* provided in the 2018 NEHRP reauthorization is nearly identical to the National Academies and GAO definitions.

Comparing these definitions reveals four common themes:

- Resilience is an attribute of human organizations, not of physical buildings or structures. Key words from the foregoing definitions include *institutions*, *businesses*, *communities*, *city*, *nation*, *society*. One might add *household*, *campus*, *corporation*, etc. The organization of interest depends on one's perspective. For the practicing engineer, the organization of interest might be that of the client. From the perspective of the building code, which represents public policy, the key organization is probably the entire jurisdiction, perhaps even the region if the building code is linked to policy like a local hazard mitigation plan (LHMP).

- Resilience is primarily about recovery of functionality, not safety. Key words include *basic functions*, *important functions*, *institutions*, *businesses*, *systems*. From the terminology of our current codes and standards, one might add *use*, *occupancy*, *habitability*, *operational*, *essential facility*.

- With its emphasis on recovery, resilience incorporates an element of time. Key words include *timely and efficient*, *quickly*, *rapidly*. One might add *immediate*.

- Resilience implies an event from which the organization must recover. Key words include *hazard*, *emergency*, *disaster*, *adverse event*, *attacks*, *accidents*, *incidents*, *acute shocks*, *major disruptions*. One might add current code categories of design load such as *earthquake*, *wind*, *snow*, *rain*, *flood*. The focus is mostly, but not exclusively, on natural hazards characterized by discrete events. An earthquake is a perfect example. More generally, however, the broader precedents consider a wider range of shocks, and even what the 100 Resilient Cities program calls stressors. Shocks or events considered by some resilience initiatives have included:
    - Natural hazard events not considered in the building code: Wildfire, drought, heat, tsunami.
    - Natural hazard events exacerbated by humans: Climate change, species extinction, urban heat, wildland-urban interface fire, urban flooding.
    - Socio-economic events related to natural causes: Famine, power outage, dam failure, pandemic.
    - Human-made events: Terrorism, war.
    - Human-made stressors, as opposed to shocks: Poverty, sprawl, blight, economic depression.

The themes suggest some definitions that might be useful from the perspective of building codes and standards. Each definition proposed here is certain to require elaboration as needed to cover specific situations. Traditionally, that specificity is provided through a standards process.

- Resilience is the ability of an organization to recover its essential functionality in a timely fashion after a potentially damaging natural hazard event.

- A **resilience objective** is, for an organization, a combination of a desired or acceptable recovery time with a presumed hazard level.
    - The pairing of a resilience level with a hazard is borrowed from performance-based earthquake design.
- **Resilience-based design** is any design process or method intended to satisfy a specified resilience objective.
    - The emphasis is on having the elements of a defined objective, not on the methodology or even the discipline (architecture, engineering, financial planning, etc.).
    - Thus, a resilience-based code or standard is simply one that explicitly references the elements of a resilience objective. Consistent with the idea that resilience-based design is multi-disciplinary, a resilience-based design methodology can be one that deals with any aspect of the organization in question.
- **Resilience-based structural engineering** is the intersection of structural engineering with resilience-based design.
    - Similarly, resilience-based earthquake design is the intersection of earthquake design (or structural engineering considering earthquake loading) with resilience-based design.

With resilience and related terms defined, other concepts used in building evaluation, design, and regulation can be distinguished from resilience-related work. Importantly, not every good idea needs to be about resilience, and resilience need not encompass every good idea. In particular, the following practices and priorities are all valuable, though their relationship to resilience-based design is often at most tangential:

- Performance-based design, especially of individual projects or structures
- Building code adoption and enforcement
- Reduced property losses and repair costs (including “PML” analysis)
- Retrofit, especially safety-based retrofit
- Building rating
- New or advanced materials, systems, or analysis techniques
- Sustainability
- Economic recovery
- Baseline community functionality.