Building the Performance You Need

A Guide to State-of-the-Art Tools for Seismic Design and Assessment

FEMA P-58-7 / December 2018

FEMA

nehrp

CONTENTS

Acknowledgements

This document was prepared by the Applied Technology Council (ATC) for the Federal Emergency Management Agency (FEMA) under the ATC-58 series of projects. It is one in a series of products representing the combined work of more than 200 consultants and individuals. ATC gratefully acknowledges the work of the ATC-58-2 Stakeholder Products Team, including Laura Samant (Team Leader), David Mar, Lori Peek, Maryann Phipps, Sharyl Rabinovici, and Tom Tobin for the conception and development of the information contained herein.

Notice

EXECUTIVE SUMMARY

After an earthquake, buildings designed to minimum building code criteria might be unusable and result in heavy financial losses. Is that acceptable for your building?

For some buildings, safety is the critical concern when it comes to large earthquakes. But for other buildings—such as those that house time-critical business activities, need to be reoccupied quickly, or represent a significant financial investment—building owners and occupants want more.

Building codes in the United States provide minimum standards to ensure that new buildings are very unlikely to have deadly collapses in large earthquakes. However, a new building constructed in accordance with the code could still experience heavy damage, be unusable for an extended period, and require demolition. Past earthquakes show that the costs associated with the loss of use of a building during repair can exceed the value of the building itself. Owners and tenants may face major disruption and loss of revenue, potentially including the need to abandon the building and find replacement space.

New performance-based seismic engineering tools empower you to make decisions about earthquake risk that are right for you and your building.

Performance-based design and assessment methods enable detailed analyses of the wide-ranging consequences of earthquakes for new and existing buildings. This information can be used to weigh trade-offs when designing a new building, renovating an existing building, purchasing or leasing space, or making decisions to manage the risk of currently owned buildings. Decision-makers can evaluate options and make personalized risk decisions that reflect their needs, values, budget, and timeline. In consultation with knowledgeable architects, engineers, and other design professionals, performance-based analyses can help reduce the chance of injuries, minimize uncertainty and downtime, and reduce future financial losses.

This Guide presents information project managers and decision-makers need to know to use a performance-based approach for seismic design and assessment.

A building project that uses performance-based seismic design and assessment methods is essentially the same as a typical project, but with a few key differences. This Guide provides an overview of decisions, steps, and implications associated with using a performance-based approach. It covers:

- When and why to use a performance-based approach
- How a performance-based approach varies from a conventional approach
- The types of projects a performance-based approach can be used for, and varying ways it can be used
- How to assemble a knowledgeable and effective team
- How to determine earthquake performance goals for a particular project
- Cost implications of using a performance-based approach

This Guide focuses solely on performance-based methods for managing the earthquake risk of buildings, but similar approaches can be used for other threats, such as severe storms, flooding, or fire.

1. BUILDING CODES MIGHT NOT GIVE YOU WHAT YOU NEED

Building codes mostly aim to protect lives, not your business or investments.

New buildings that meet all seismic requirements of the building code in the United States can experience widely different levels of earthquake damage when exposed to the same earthquake shaking. Some new buildings could have very light damage and be usable quickly. Others could be unusable for an extended time after a large but expected earthquake, and might even need to be demolished.

The International Building Code (IBC) for new construction, enforced in most parts of the United States, is a set of minimum rules for designing buildings. Procedures in the IBC are meant to: (1) protect lives in the largest earthquakes likely to affect a building, and (2) reduce property damage and economic loss in more frequent, moderate earthquakes.

Building codes are updated regularly, meaning that buildings constructed decades ago may be vulnerable in ways that more recent buildings are not. With limited exceptions, most cities do not require older buildings to be evaluated or retrofitted, even for building types known to be unsafe in earthquakes. Retrofitting can make damage less likely or less severe, but by how much depends on the design.

Building codes in New Zealand have similar aims as codes in the United States. When two major earthquakes hit Christchurch, New Zealand in 2011, buildings built to modern codes performed as expected—only two collapsed. However, 70% of buildings in the Christchurch downtown area were eventually demolished due to extensive damage. The Central Business District lay vacant for over two years. The economic and social consequences to building owners, occupants, and the community were massive.

> "After the 1994 Northridge earthquake, people were shocked at how long it took before buildings could be repaired and used again. More than one client said that while it was great that their building didn't fall down, the amount of downtime after the earthquake was an unexpected financial disaster. They assumed the code would produce better buildings."
>
> *Mason Walters*
> *Structural Engineer*
> *Forell/Elsesser Engineering*

Key Limitations of Building Codes

1. Even modern buildings designed to the current building code have some chance of collapse in earthquakes or might need to be demolished.
2. The building code does not address many aspects of a building that affect financial loss and whether a building is functional after an earthquake.
3. Code-compliant buildings are designed to resist forces from an earthquake of a particular intensity even though larger earthquakes are possible.
4. Most communities do not require older buildings to be evaluated or retrofitted, even for known earthquake vulnerabilities.

The building code does not cover everything that affects the downtime and financial losses of your building.

Earthquakes can damage all parts of a building, but the code's seismic standards do not cover all parts of a building.

The focus of the building code is preventing collapse of the overall **structural system** that supports a building's weight and withstands the forces of wind and earthquakes. There are no guarantees that elements connected to or inside the structure will be protected.

Everything else that is fixed in place and vital to a building's use are called **nonstructural** features or elements, and these building elements can be very vulnerable to damage, which can lead to costly and disruptive repairs. Some nonstructural elements are addressed by the code.

Nonstructural elements that can be damaged include:

- Outside façades, balconies, windows, doors, and awnings
- Electrical systems and lighting
- Mechanical systems such as elevators or heating and cooling (HVAC)
- Plumbing
- Communications infrastructure such as phone lines and internet cables
- Interior walls or partitions
- Ceiling panels
- Floor coverings (e.g., tiles)

Contents are movable and often valuable things inside a building, such as furniture, computer equipment, machinery, scientific apparatus, data and files, chemical and biological research samples, and product inventory. In many cases, bracing of contents is not required by the code.

These distinctions are important because earthquakes worldwide show that nonstructural and content damage are the most likely and often largest contributor to total losses. Businesses in the United States, New Zealand, Japan, Mexico, Italy, Chile, and elsewhere have lost valuable assets and experienced major delays in operations due to repairs of these elements that took months to years.

Interior damage in this Christchurch, New Zealand office building after the 2011 earthquake demonstrates the safety concerns and length of time it might take to restore nonstructural elements of a building to usable condition.

Photo credit: Russell Berkowitz, 2011.

2. INTRODUCTION TO PERFORMANCE-BASED METHODS

A performance-based approach enables you to consider a range of future earthquake consequences in decisions about new and existing buildings.

A performance-based approach to seismic design and assessment provides detailed information about what is likely to happen to a building in earthquakes and the resulting consequences. This information allows building owners and occupants to understand and proactively make decisions about how much damage is acceptable to them.

When designing a new building or retrofitting an existing building, a performance-based approach is both complementary to and fundamentally different from a code-based approach. A code-based approach entails following a series of rules that, based on decades of experience, are deemed by regulators to meet society's needs. A performance-based approach makes design decisions specifically to control a building's earthquake risk, reflecting the needs of the building owner or decision-maker. A building can both comply with code standards and be designed to meet performance needs defined by the owner.

As the table below shows, the code does not require engineers to consider many potentially important earthquake performance factors such as repair time or likelihood of receiving an unsafe placard. A performance-based approach enables consideration of these and other outcomes across a range of potential shaking levels that could affect the structure.

Performance-based approaches make sense for some but not all building projects.

A performance-based approach is most relevant in circumstances where it is important to have confidence in a building's expected earthquake performance. It can be appropriate for projects in which:

- The building represents a **significant financial investment**.
- The intent is to maintain an interest in the building for a **significant length of time**.
- It is important to be **able to reoccupy** the building quickly after an earthquake.
- The building has **high-value assets inside** that may be difficult or impossible to replace or move.
- The building is located in a location with particularly **high earthquake hazard**.
- The building has **symbolic, historic, cultural, or brand importance**.
- The building could command **higher resale or lease values** if it can be shown to be earthquake resilient.
- Demonstrating equivalence to code goals allows **flexibility in design** that could lower costs or enable architectural features not typically allowed by the code.
- The building owner or users want **more precise information about exposure and uncertainty**, for example to compare investment options or manage risk in a portfolio of properties.

The table on the next page shows four different contexts where performance-based approaches can benefit new and existing building projects.

Four Contexts for Performance-Based Projects

New Construction	Existing Buildings
1. DESIGNING FOR HIGH-PERFORMANCE A performance-based approach can be used to design a new building that will perform better in earthquakes than a basic code-conforming building. Owners work with their design team to define what levels of damage in earthquakes are acceptable to them and produce a design that meets their needs with a high level of certainty.	**3. RISK EVALUATION** A performance-based analysis can be used by owners, investors, buyers, and tenants that want to learn about an existing building's earthquake risk. Risk assessment can be conducted at various levels of detail and accuracy.
2. IMPROVED DESIGN FLEXIBILITY Performance-based methods can be used to show that a building that deviates from some code requirements or uses innovative systems or materials will perform equivalent to or better than what would be expected if the building was conventionally designed to meet the code. This use is subject to the discretion of local Building Officials. It can result in a building with better defined seismic resistance, lower up front construction cost, or approval for new techniques that might not otherwise be permitted.	**4. EFFECTIVE SEISMIC RETROFIT** During the seismic retrofit of an existing building, the design team and building owner make choices about how—and how much—to improve the building's seismic resistance. Performance-based methods can provide owners detailed information about the earthquake risk of various design options, which can be weighed with costs and other constraints.

The FEMA P-58 methodology is the state-of-the-art performance-based design and assessment method.

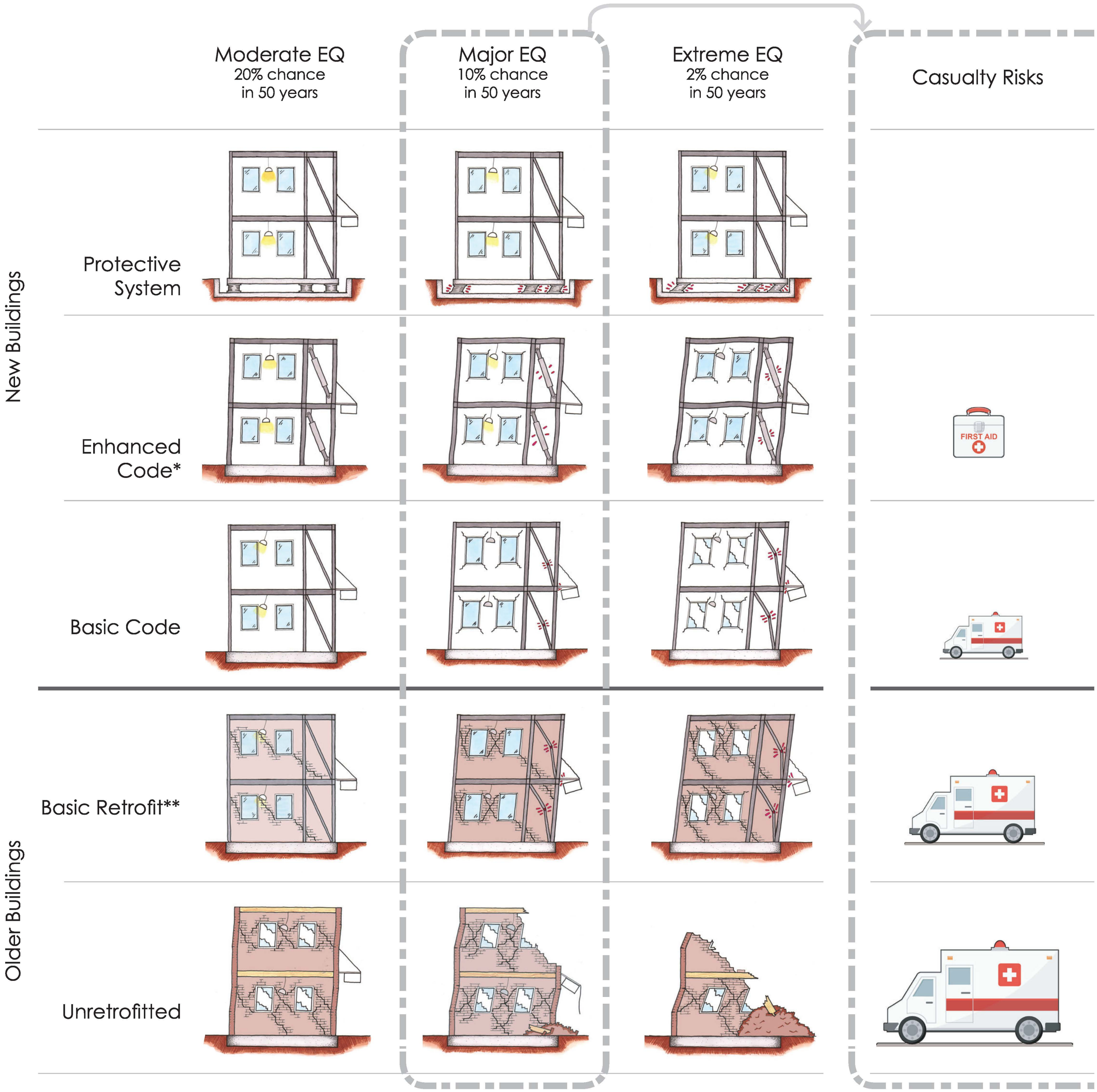
The FEMA P-58 methodology, prepared by the Applied Technology Council for the Federal Emergency Management Agency (FEMA), was originally released in 2012 after years of development, and can be used to calculate many aspects of earthquake performance more rigorously than previously possible. It allows decision-makers to compare options for their buildings based on feasibility and value by quantifying different types of outcomes in earthquakes.

A variety of modeling packages implement the FEMA P-58 methodology, including a downloadable program distributed free by FEMA and some commercial services (see the *Resources* section of this document).

The diagram on the next two pages illustrates the range of earthquake consequences that can be calculated by the FEMA P-58 methodology and how they might vary for different types of buildings.

OPTIONS FOR EARTHQUAKE RESISTANT DESIGN

Design Decisions Have Measurable Consequences

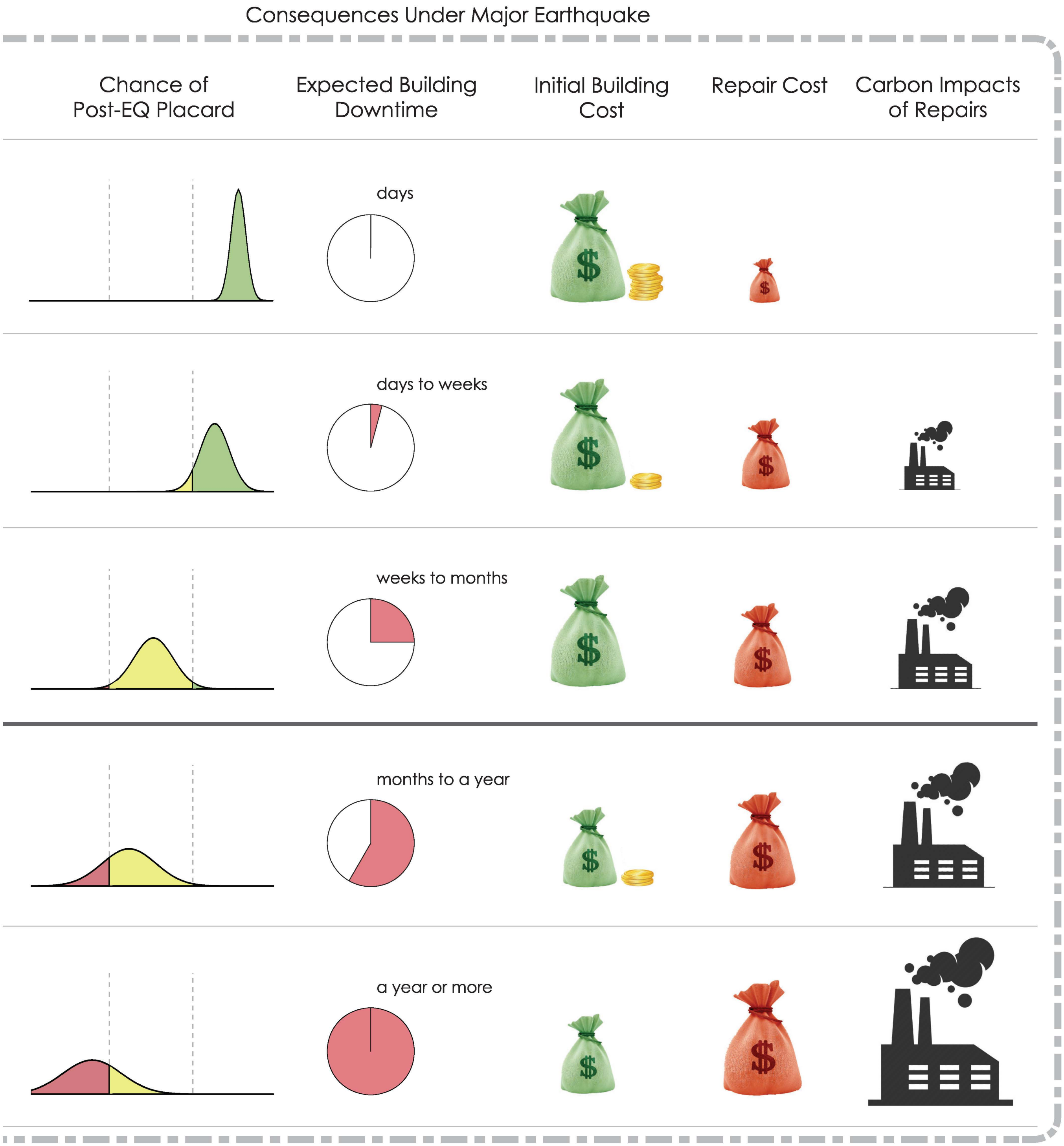


Earthquake damage varies depending on the level of shaking experienced and characteristics of the building's structure and other systems. Design choices affect the amount and types of likely damage.

* Includes Risk Category IV and other buildings with enhanced seismic resistance features.

** Some retrofitted buildings can experience much less damage.

New code-compliant buildings have very low risks of casualties in the US. Some older buildings have high safety risks.



Design choices affect the odds of a green tag (no restrictions), yellow tag (restricted entry), or red tag (unsafe, no entry).

Design choices affect the amount of time required before a building can be occupied after an earthquake.

More resilient buildings typically cost slightly more upfront, but result in lower post-earthquake repair costs and consequences.

Building materials require energy to produce. The amount and types of repairs required affect carbon releases and energy usage.

Comparison of Code-Based and Performance-Based Approaches

Type of Loss	Code-Based Approach	Performance-Based Approach*
Structural Damage	Damage at or below a level expected to keep occupants safe in large earthquakes.	Evaluates and controls the likely extent of damage to the building structure.
Nonstructural Damage	Some components are designed to remain in position. Other components and contents are not regulated.	Evaluates and controls the likely extent of damage to a building's nonstructural elements and some contents.
Casualties, including Deaths and Injuries	In newer buildings, occupants are expected to be safe. Retrofits of existing buildings are intended to improve but not guarantee safety.	Evaluates and controls the likelihood of deaths or injuries due to building damage.
Financial Losses from Structural and Nonstructural Damage	Not evaluated.	Evaluates controls the likely expected direct dollar losses from damage.
Likelihood of Unsafe Placard	Not evaluated.	Evaluates and controls the likelihood of receiving a post-earthquake unsafe placard (red tag) that restricts entry and use.
Repair Time	Not evaluated.	Evaluates and controls the likely duration of repairs, a key factor in how long a building will be unusable after an earthquake, and the chance a building will need to be demolished.
Environmental Impacts	Not evaluated.	Evaluates and controls the likely carbon and energy impacts due to building repairs or demolition.

* *Note:* Only the FEMA P-58 methodology can estimate all the listed aspects of earthquake performance.

3. OPTIONS FOR A PERFORMANCE-BASED PROJECT

You can use performance-based approaches in a variety of project stages with different degrees of effort and benefit.

A performance-based design or retrofit project is largely the same as a conventional project. The key difference is that the project team adds the step of explicitly deciding the earthquake consequences that are acceptable to them and takes actions to meet those goals.

A performance-based approach can be used in the early stages of a project to guide conceptual design decisions, or it can be used throughout a project to inform every aspect of the design and construction, including the selection and installation of finishes and equipment. The appropriate effort and degree of implementing a performance-based approach can be different for each project and decision-maker.

Flowchart of the Performance-Based Seismic Design Process

Step	Actions
Discuss Performance Goals Based on What is at Stake	• Consider risk to occupants, contents, activities, and investments • Assess realistic and worst case scenarios for shaking and damage • Determine recovery needs after an earthquake
Bring People on Board	• Assemble a qualified design team • Educate and involve key stakeholders in setting performance goals • Develop business case for the desired level of performance
Create Initial Design	• Use conceptual design tools like FEMA P-58 to make ballpark estimates about earthquake performance of design options • Comply with the legal requirements of the building code or demonstrate equivalent performance
Check Results and Adjust	• Refine project plans so expected damage and outcomes align with performance goals • If desired, use FEMA P-58 methodology to help identify which parts of a building are driving losses and fine tune the design
Finalize Details and Complete Work	• Ensure that finishes and nonstructural components of the building also meet performance goals • Monitor compliance with earthquake-related aspects of the design during construction

In the conceptual design stage, a performance-based approach helps you select the most suitable structural system.

Decisions made early in a building design process, during the conceptual design phase, can have a big impact on a building's earthquake performance. Important early decisions for new building designs include the shape of the building and the selection of its structural system. Simple analyses using performance-based methods can provide information to guide these choices.

Early in a project, a structural engineer can broadly explore earthquake performance implications of different structural systems and design options through the use of the publication *Guidelines for Performance-Based Seismic Design of Buildings (FEMA P-58-6)*, and companion computer tool (see the *Resources* section). With a few assumptions, an engineer can provide ballpark estimates about important aspects of earthquake performance and narrow in on the alternatives most likely to achieve the client's earthquake performance goals while meeting other practical constraints.

During detailed structural design, a performance-based approach provides information to help you understand trade-offs.

During the detailed structural design stage, an engineer can use performance-based methods to estimate project-specific dollar losses, required repair time, post-earthquake safety tagging, carbon emissions impacts, and potential casualties for earthquakes of various intensities. They can also identify which aspects of a building design is driving unacceptable losses, and adjust plans accordingly. This information can guide detailed decision-making and can be used to verify that the established performance goals are being met.

A performance-based analysis helps you select earthquake-resilient building components, anchoring systems, and equipment.

In the later stages of either new construction or a retrofit project, performance-based approaches can be used to drive decisions about earthquake-resilient components and finishes.

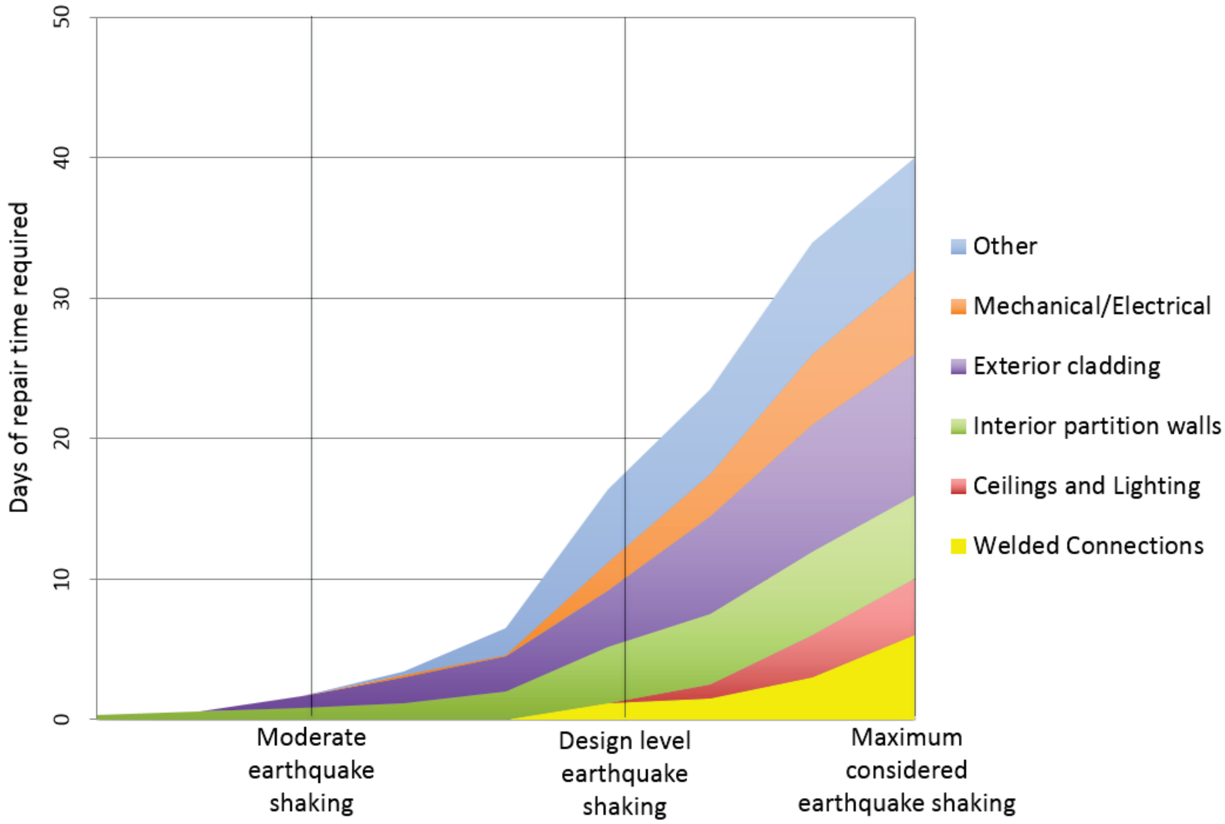
The FEMA P-58 methodology, for instance, provides breakdowns of the total loss by how much each building element contributes, as shown on the figures on the next page. Once the main drivers of unacceptable loss are identified, the design team can explicitly compare the performance of alternative design choices, finishes, anchoring systems, and materials to aid in selection and specification.

When you have a lot at stake, a performance-based assessment provides reliable estimates of risk for financial transactions.

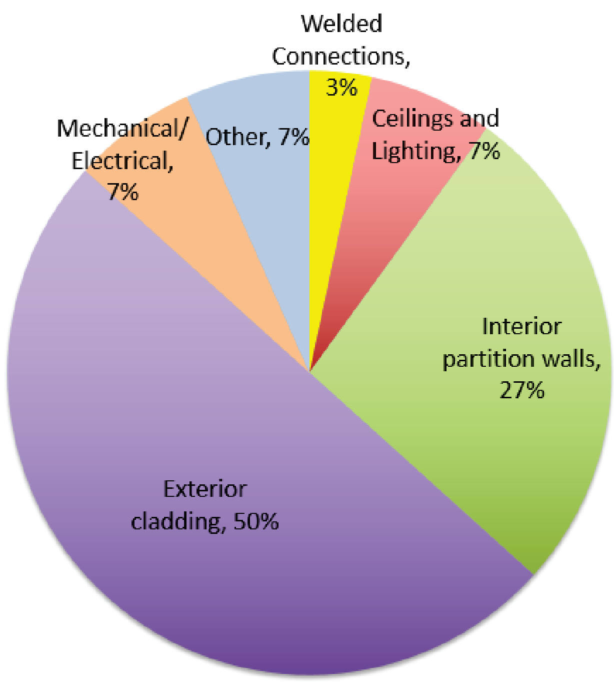
Commercial lenders and investors may be familiar with earthquake risk measures such as Scenario Expected Loss (SEL), Scenario Upper Loss (SUL), and Probable Maximum Loss (PML).

These traditional approaches provide information about the expected dollar losses of damage to a building in earthquakes. However, the accuracy and quality of these analyses can vary significantly. Performance-based analyses can be used to calculate reliable, high-quality SEL, SUL, and PML values for situations in which it is important to have an accurate understanding of risks and potential consequences.

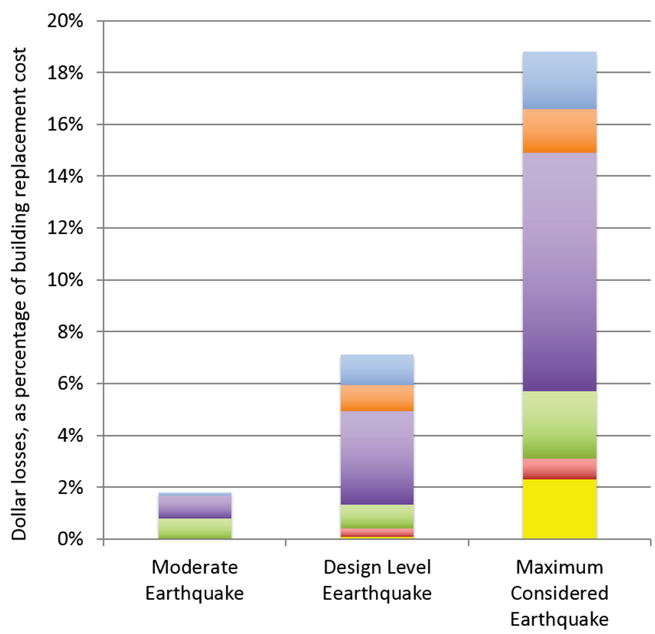
Three examples of ways to consider information about how building components contribute to earthquake performance for an example building.



Median days of repair time required for different levels of shaking, broken out by components responsible.



Percent of dollar losses due to various building components in a M6.5 scenario earthquake



Median expected dollar losses, broken out by responsible component

4. HOW TO DETERMINE YOUR EARTHQUAKE PERFORMANCE GOALS

Earthquake performance goals should reflect what really matters to you.

It is generally not practical to make a building "earthquake proof." The key task in performance-based design is to choose target levels of damage and loss that are acceptable when a building is exposed to different levels of shaking. The desired performance could be the same or better than would be achieved by following the rules of the code, depending on the goals and constraints for a particular ***project***.

It may seem awkward to think about any kind of risk as "acceptable," particularly when it comes to grave consequences such as building collapse. However, the code already reflects a level of acceptable risk—one that may or may not be right for a particular building. Without proactive analysis and discussion, choices that affect earthquake outcomes are made by default.

"We started taking the seismic performance of our buildings seriously when we realized that a large earthquake impacting one of our manufacturing facilities could cause us to miss a product cycle. That's unacceptable."

Jeffrey Soulages

Senior Structural Engineer
Intel, Portland, Oregon

Quick Guide to Determining Performance Goals

1. Identify important aspects of the building that could be affected by earthquakes.
2. Consider what is acceptable performance for the building in earthquakes of different sizes and likelihoods.
3. Work with your design team to translate performance goals into metrics that can be used for design and analysis, including the level of certainty with which goals need to be achieved.

Many factors play into setting performance goals, such as the importance of the activities that take place in the building, how quickly activities need to resume after an earthquake, and the costs of achieving the desired performance. The following questions can help guide performance goal-setting discussions:

1. ACTIVITIES IN THE BUILDING

- What is the building used for?
- Which activities are mission critical or affect relationships with competitors or partners, the organization's reputation, or the ability for important activities to take place elsewhere?
- How could the activities in the building be affected by loss of utility or lifelines systems, such as electricity, gas, water, or internet?
- How difficult or costly would it be to relocate the activities if the building is unusable for an extended period?

2. OCCUPANTS AND CONTENTS

- How many people use the building and how much time do they spend there?
- Are any users of the building particularly vulnerable, such as children, the elderly, or disabled?
- How challenging or time consuming would it be to replace or repair the contents of this building (for instance, machinery, inventory, information technology, or archives)?
- Are there contents in the building that are irreplaceable, such as research samples, precious artwork, or religious or historic artifacts?
- Does the building contain hazardous materials, or substances that could harm health or the environment if released?
- What are the consequences if employees cannot get into the building to get materials or accomplish tasks?

3. POST-EARTHQUAKE RECOVERY NEEDS

- What is at stake for the organization if this building is unusable for weeks to months or years during repair?
- Is this building required for emergency response or other activities immediately after an earthquake?
- Are there systems that are particularly critical to have functional after an earthquake, such as security or refrigeration?
- Will people need to shelter at the site if they cannot safely travel home?

4. FINANCIAL INVESTMENT

- How severe are the financial consequences if the activities in the building are disrupted after an earthquake?
- How severe are the financial consequences if the building is so damaged it needs to be demolished?
- After an earthquake, will there be sufficient liquidity to pay for repairs as quickly as they are needed?
- Could reputation, public relations, or brand be affected by what happens to the building?

Performance goals should consider issues that could threaten assets, damage inventory, or interrupt mission-critical processes.

Your performance goals should be different for earthquakes of different sizes and frequency.

In general, smaller earthquakes occur more frequently than larger and more damaging earthquakes. After a major earthquake, it is typically reasonable to accept some building damage, financial loss, and building closure. However, after an earthquake of a more moderate size and higher likelihood of occurrence, decision-makers might desire the same building to be functional shortly after the event. Acceptable earthquake performance goals for a building will vary for earthquake shaking of different strengths and likelihoods.

With the help of qualified design professionals, careful review of project circumstances should lead to a clearer picture of the most important building performance issues. A performance goal-setting worksheet, as shown below, can be set up to track discussions. It is not necessary to write something in every box. Rather, the purpose of the worksheet is to think and communicate about how acceptable performance changes with the likelihood and size of an event. This process will also help uncover whether a code-level design provides the desired performance with adequate assurance. If not, an iterative design process can then help explore options and whether their costs are worth the expected outcomes.

Performance Goal-Setting Worksheet

Performance Category	After a Moderate, More Likely Earthquake	After a Large, Rare Earthquake	After a Major, Very Rare Earthquake
Level of safety	(e.g., no injuries)	(e.g., <1% chance of injuries)	
Maximum acceptable building repair time	(e.g., one day)	(e.g., one month)	
Maximum acceptable cost for structural and non-structural repairs	(e.g., 1% of building replacement cost)		(e.g., 20% of building replacement cost)
Level of protection for contents		(e.g., 90% chance of industrial machinery intact)	(e.g., 50% chance of industrial machinery intact)
Acceptable chances of collapse	(e.g., <1%)	(e.g., <5%)	
Acceptable chances of red tag/unsafe placard		(e.g., <10%)	(e.g., <25%)

5. SELECTING AND WORKING WITH A QUALIFIED DESIGN TEAM

Assembling a skilled and efficient team is key to project success.

Everyone involved in a performance-based project, from project leaders to architects, engineers, other design professionals, vendors, and contractors and subcontractors, needs to understand earthquake performance goals and be able to work together to achieve them. Investing in the services of professionals well-versed in or open to performance-based approaches at the outset of a project can save money in the long-term.

Frequently but not always, use of performance-based seismic engineering requires structural engineer team members with in-depth knowledge of ground shaking hazards, structural materials behavior, and in-depth structural analysis. The *Resources* section at the end of this Guide is a good starting point for team members who want to learn more about the technical aspects of performance-based methods for design and assessment.

Questions for Prospective Team Members

Ask potential design team members the following questions to launch a discussion about earthquake performance:

- What is your experience with performance-based seismic design and analysis?
- Does a performance-based approach make sense for conceptual or detailed structural design phases of this project?
- What earthquake performance objectives seem right for this project?
- What do you think are the most seismically vulnerable nonstructural components in our building and what can be done to protect them?

Encourage regular communication and collaboration of all team members to help achieve your project goals.

Successful design teams generally communicate early and often during the design process amongst each other and with representatives of the building owner or decision-maker. Frequent communication allows design team members to understand each other's constraints and the earthquake risk implication of various design choices.

All design team members make decisions that contribute to earthquake performance, not just structural engineers. Even seasoned design professionals may not be aware of all the ways other peoples' work can affect what happens to a building in an earthquake. For example:

- **Architects** plan the building configuration (footprint, shape, number of stories), select materials such as exterior cladding, ceilings, interior walls, escape routes, and other architectural features. Each of these decisions can affect the seismic performance of the building. Architects also play a critical role in coordinating interaction among other design consultants.

- **Mechanical engineers** help plan and oversee proper installation of equipment, piping, and essential systems such as ventilation, heating and air conditioning (HVAC). These systems can be very vulnerable to earthquake shaking, depending on design.

- **Plumbing specialists** design a building's water systems. Design and installation decisions impact leaks or breaks in earthquakes that can lead to flooding and loss of use of the entire building after an earthquake.

- **Electrical specialists** plan and implement power supply to mission-critical IT infrastructure, security, HVAC, and lighting systems as well as back-up power and fire alarms.

- **Fire protection engineers** design sprinkler systems that might be needed to fight post-earthquake fires and could flood the building if damaged by the shaking.

- **Interior architects or interior designers** often select elements like suspended ceilings, decorative wall hangings, and large furniture, which can be hazardous if not properly anchored.

- **Structural engineers** select and design the structural system, critical both to minimizing structural damage and also building movement that can damage architectural, mechanical, and electrical components. Structural engineers typically lead the performance-based seismic design process.

> "Our entire design team meets together, beginning in the conceptual design phase. All of our subcontractors discuss the performance needs of the aspects of the project they work on—not just seismic performance, but every aspect of performance. We need our structures and systems to work under a wide range of scenarios. This allows us to identify issues and solve them before they become problems."
>
> *Geoff Neumayr*
> *Chief Development Officer*
> *San Francisco International Airport*

San Francisco Airport recently underwent millions of dollars in upgrades, including new buildings that took advantage of performance-based seismic design.

Photo credit: John Swain Photography

6. COST CONSIDERATIONS

A performance-based project is not necessarily more expensive than a conventional project, but can be more complex.

Every building project is unique, and it is not possible to make a generic statement comparing the costs of a performance-based project with a project that does not employ performance-based methods. In some cases, early investments in seismic performance-based engineering lead to cost savings in the construction phase. In other cases, decisions to invest in greater seismic resilience result in a more expensive building project.

"Our client needed their new Public Safety Building to be operational after the maximum credible earthquake. Using performance-based methods, our design team found that strategically positioning sensitive equipment within the building in areas that are expected to shake less in earthquakes allowed us to meet the client's goals without adding significant costs to the project."

Kevin Miller, AIA
GSBS Architects, Salt Lake City, Utah

Salt Lake City used a cost-effective performance-based approach to enable its Public Safety Building to operate after a disaster.

Following are some important cost and logistical considerations:

- **Time for Setting Goals.** All design team members will need to put thought and time into determining, analyzing, and meeting desired building performance goals, ideally in a collaborative fashion. This can require more time for consultants than projects that do not include these tasks.
- **Analysis Time.** More time and input information may be required to conduct performance-based assessments than required for prescriptive code-based approaches.
- **Structural Elements.** If higher earthquake performance than provided by minimum code standards is desired, the structural system itself may cost more than a minimally code-compliant structure. However, this is not always the case. Sometimes, extra time spent on design can result in a better performing structure that does not require larger or more expensive structural elements.
- **Better Components.** For nonstructural elements and contents with better than minimum code performance, such as finishes, utilities, and fire protection systems, ensuring that each of these systems meets articulated performance goals can require analysis and iteration by design team members. Possibly, the team would need to include additional consultants to conduct this analysis. This can also result in the selection of higher cost components than might otherwise have been used.
- **Interior Arrangement.** In order to achiever superior performance, it may be necessary to locate some critical business or building functions in lower levels, so as to minimize earthquake effects on these functions. This can result in less than optimal arrangement for other perspectives, or require other accommodation in building layout.
- **Permitting.** If performance procedures are used to avoid one or more code requirements, the building authority may take additional time to review the project and issue building permits. The building official may also require independent reviews by other design professionals.

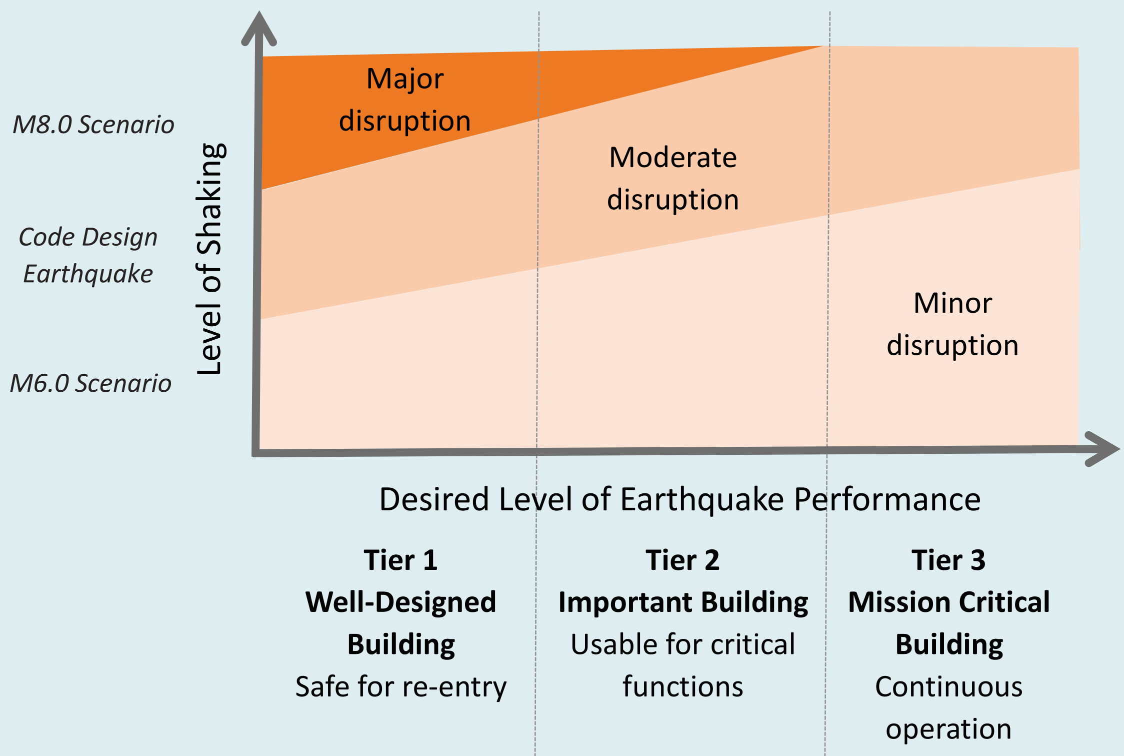
7. EXAMPLE USES

Earthquake Performance Planning at the Campus Scale

The University of California San Francisco (UCSF) operates a world-class hospital, research institution, and medical school. As part of its billion-dollar facility expansion and improvement program, institutional leaders put significant thought into how much earthquake damage it can tolerate in its buildings.

UCSF created three tiers of seismic performance and requires integrated design-build teams to present options for each of these tiers so that they can be compared in terms of costs and benefits. Each tier addresses objectives for structural and nonstructural systems, including explicit limits on downtime and damage that could affect UCSF's core mission, people, and assets.

UCSF's desired performance for each tier varies based on the size of the earthquake as shown in the diagram below. Detailed policies define what "minor," "moderate," or "major" disruption mean in terms that are meaningful to UCSF, such as destruction of laboratory samples, loss of student housing, or hazardous chemical releases.



UCSF's Mission Bay campus features mixed uses including administrative offices, patient care, research facilities, housing, public transit, and parking. Buildings have been categorized into tiers based on UCSF's performance policy.

Roseville City Hall Annex: A Five Star Building

In 2016, the City of Roseville, California completed construction of its new City Hall Annex building. The building was designed to meet code standards, without using a performance-based approach. However, due to the critical operations and services that would take place in the building, the design team incorporated a number of features to increase the building's earthquake performance.

The design team and the City believed the building would have significantly better performance than an average building complying with minimum code requirements. To confirm this was true and to communicate the findings clearly, the City sought an earthquake performance rating of the building. Their design team conducted a performance-based assessment that enabled the City to obtain the highest possible ratings by the U.S. Resiliency Council: five stars for safety, repair cost, and recovery time.

The non-profit U.S. Resiliency Council (USRC) was founded in 2011 to implement an earthquake performance rating system. The USRC certifies qualifying engineers to issue ratings (from 1 to 5 stars) for three important considerations of building earthquake risk: (1) safety; (2) repair cost; and (3) time to regain function. Under the USRC system, a 5-star rating means the chance of fatalities is next to zero, damage will be under five percent of replacement cost, and the building will be re-occupiable within days of a major seismic event. This is well beyond what could be expected by a typical building designed according to minimum code requirements.

Performance-based analyses were used to earn the Roseville, California City Hall Annex a five star seismic resilience rating for safety, repair cost, and recovery time.
Photo credit: John Swain

8. CONCLUSION

Detailed earthquake performance information empowers informed decisions about your buildings.

Performance-based seismic design and assessments enable developers, owners, tenants, and investors to clarify exactly what levels of earthquake damage and loss are acceptable, feasible, and affordable to them.

Armed with the information that performance-based methods provide, stakeholders can:

- **Achieve a more resilient building** that has less damage and improved functionality after an earthquake, as well as reduced environmental impacts.
- **Better understand and control their risk exposure** and reduce uncertainty.
- **Increase the value of a property** at time of sale.
- **Differentiate rental properties** from competing properties, because tenants are in a more resilient building and will be able to resume operations more quickly after an event.
- **Thoroughly evaluate choices** when considering purchase or renovation alternatives.
- **Enhance recruitment, retention, reputation, and public relations** by going beyond minimum requirements to better protect the public as well as employees and their livelihoods.
- **Make a contribution to community resiliency** and getting the local and regional economy back on track after an earthquake.
- **Gain greater confidence and peace of mind** from having clearly defined seismic performance goals and a plan for achieving them.

> "Seismic performance-based methods are the future. New structural engineers are learning how to use these methods to better understand the difference between a structure that is safe and one that is both safe and can be quickly reoccupied following a major earthquake."
>
> *Stephen Mahin, Ph.D.*
> *Nishkian Distinguished Professor of Structural Engineering*
> *University of California, Berkeley, California*

Performance-based seismic design and analysis is the future. Newly available technical analysis tools, such as the FEMA P-58 methodology, can more quickly and reliably than ever before calculate how much damage and loss is expected, how long post-earthquake repairs will take, and how many environmental impacts will result. This empowers better decisions about how much and what types of investment in seismic resilience makes sense for each building project.

RESOURCES

The FEMA P-58 Methodology

- FEMA P-58-1, *Seismic Performance Assessment of Buildings, Volume 1 – Methodology*, Second Edition, 2018: This document provides a detailed, technical overview of the FEMA P-58 methodology.
- FEMA P-58-2, *Seismic Performance Assessment of Buildings, Volume 2 – Implementation Guide*, Second Edition, 2018: This document provides guidance on implementing a seismic performance assessment using the FEMA P-58 methodology.
- FEMA P-58-5, *Seismic Performance Assessment of Buildings, Volume 5 – Expected Seismic Performance of Code-Conforming Buildings*, 2018: This document summarizes the assessed performance of code-conforming buildings using FEMA P-58 performance metrics.
- FEMA P-58-6, *Guidelines for Performance-Based Seismic Design of Buildings*, 2018: This document provides guidance to engineers for using insights from the FEMA P-58 methodology to select building characteristics necessary to achieve the desired performance.
- Online Quiz: *Could Your Project Benefit from New Earthquake Risk Analysis Techniques?*: A brief online interactive tool that provides insight on whether a building-related project is likely to benefit from the use of performance-based methods, http://femap58.atcouncil.org/.
- FEMA website for Seismic Performance of Buildings: This site includes downloads of all the major FEMA P-58 reports and computer tools, https://www.fema.gov/media-library/assets/documents/90380.
- Applied Technology Council website for FEMA P-58: This site includes downloads of all major FEMA P-58 reports and computer tools, as well as background research reports used to develop the methodology, http://femap58.atcouncil.org/.

Other Performance-Based Engineering Methods

- ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings,* 2013, American Society of Civil Engineers (ASCE), Structural Engineering Institute: This standard presents procedures that use performance-based principles to evaluate and retrofit existing buildings.
- *Guidelines for Performance-Based Seismic Design of Tall Buildings*, 2017, Pacific Earthquake Engineering Research Center (PEER): This guideline presents recommended procedures using a performance-based approach for seismic design and review of tall buildings, http://peer.berkeley.edu/.
- *An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in The Los Angeles Region - A Consensus Document* (2014 Edition with 2015 Supplements), Los Angeles Tall Buildings Structural Design Council: This document provides a performance-based approach for seismic design and analysis of tall buildings, http://www.tallbuildings.org/.

Other

- U.S. Resiliency Council (USRC) Earthquake Rating System, http://usrc.org/.
- REDi Rating System, ARUP, https://www.arup.com/publications/research/section/redi-rating-system.
- SP3, Seismic Performance Prediction Program, based on FEMA P-58 methodology, https://www.hbrisk.com/.

DEFINITIONS AND ACRONYMS

Code	This refers to the International Building Code (IBC) for new buildings, which is the model building code adopted by most U.S. states. The IBC presents standards for the design of new buildings, including the design of seismic force resisting systems. Note: many states and localities make modifications to the IBC when they adopt it, creating variations in code requirements among communities.
Conceptual structural design	Early structural design steps for a building, such as selecting the structural system that will be used and determining general layout.
Contents	The movable but often valuable things inside a building, including furniture, computer equipment, machinery, scientific apparatus, data and files, chemical and biological research samples, and product inventory.
Design team	A team of professionals involved in designing a building, typically including an architect, structural engineer, and others such as mechanical engineers, plumbing specialists, electrical specialists, and fire protection engineers.
Earthquake performance	Refers to the amount and types of damage and consequences that a building experiences during earthquake shaking.
Existing building	A building constructed sometime in the past, possibly prior some to Building Code improvements that address seismic risk issues.
FEMA P-58	A state-of-the-art performance-based seismic engineering methodology that enables users to estimate the amount of expected dollar losses, repair time, casualties, chance of receiving an unsafe placard, and carbon emissions for a building exposed to earthquake shaking.
Finishes	Refers to non-structural elements of a building that have a decorative function, including, for example, the exterior cladding of a building, interior floor surfaces, and paneling on interior walls.
Intensity	A measure of the strength of shaking produced by an earthquake at different locations, expressed in terms of the effects of the shaking on people, the built environment, and nature.
Maximum Considered Earthquake (MCE) shaking	The maximum intensity of earthquake shaking considered by the Building Code for a specific site. This is intended to represent the most severe shaking a building is ever likely to experience. However, with very low probability, a building could experience more severe shaking.
Nonstructural damage	Earthquake damage to nonstructural elements of a building, which are the parts of a building that are fixed in place but are not part of the structural system. Nonstructural elements can include façades, balconies, utility systems, partition walls, and ceiling panels.

Partitions	Refers to interior walls or other room dividers that are not structural elements.
Performance-based seismic engineering (PBSE)	Engineering techniques to determine the amount of damage a building may experience in response to earthquake shaking, and the consequences of that damage, so that information can be considered for design and analysis.
Performance-based approach	A process to design or analyze a building that uses or considers the amount of damage a building may experience in response to earthquake shaking, and the consequences of that damage.
Performance-based design	A formal process for design of new buildings, or seismic upgrade of existing buildings, which includes a specific intent to achieve defined performance objectives in future earthquakes.
Performance goals / performance objectives	A defined set of expectations regarding the amount of damage a building may experience in response to earthquake shaking, and the consequences of that damage.
Probable Maximum Loss (PML)	A term used to express the amount of financial loss expected to a building when it is exposed to earthquake shaking. Scenario Expected Loss (SEL) and Scenario Upper Loss (SUL) are more specific forms of probable maximum loss that are sometimes used in financial transactions associated with buildings.
Resilience	The ability of a community, system, or organization to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events, such as earthquakes.
Replacement cost	The cost to reconstruct a building today in essentially the same way it exists now.
Scenario Expected Loss (SEL)	A calculation of the mean expected repair costs for a building that experiences earthquake shaking with a specified return period (often 475 years), expressed as a percentage of the replacement cost of the building. This calculation is sometimes used for financial transactions associated with buildings.
Scenario Upper Loss (SUL)	A calculation of the expected repair costs that have a 90% chance of not being exceeded for a building that experiences earthquake shaking with a specified return period (often 475 years), expressed as a percentage of the replacement cost of the building. This value is sometimes used for financial transactions associated with buildings.
Seismic retrofit	Upgrades to an existing structure to reduce the amount of damage that will occur due to earthquake shaking.
Structural system	The load resisting system of a building, such as columns, beams, joints, and walls that are designed to support a building under normal gravity loads and when it is exposed to earthquake shaking and strong winds.

FEMA

FEMA P-58-7
Catalog No. 1894-10