# Design Tools for Resilient-Based Design

## By the SEAOC Resilience Committee

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This is the third of a series of monthly articles prepared to help structural engineers to become leaders in community resilience. In the previous articles (click here) we noted that engineers can make a direct and immediate contribution toward improving community resilience by designing buildings with post-earthquake recovery time in mind, determined by the building's function, client desires, and expected hazards.

This article discusses the tools that are currently available to quantify the seismic performance of buildings in terms that are valuable to the building owner and the public – safety, repair costs, recovery time, and environmental impact. The ability to design and retrofit buildings to recover functions in a reasonable time period is critical to achieving community resilience. While these concepts are applicable for all hazards and for both buildings and infrastructure, this article series addresses only the seismic performance of buildings.

## The FEMA P-58 Methodology

The Federal Emergency Management Agency (FEMA) acknowledges that performance-based design is key to mitigating losses caused by natural disasters and specifically earthquakes (FEMA, 2018). FEMA contracted with the Applied Technology Council (ATC) in 2001 to develop Next-Generation Performance-Based Seismic Design Guidelines for New and Existing buildings. The first phase of this work was completed in 2012 in the form of three documents which outlined a probabilistic methodology to assess specific building performance in terms of repair cost, time, and safety. The second phase of the effort was completed in 2018 and provided updates to the documents presented in phase one. Phase two also provided additional guidance to engineers and building stake holders. The series of documents and tools produced in this project are collectively referred to as FEMA P-58. Most recently, in 2020-2021, work is underway to develop an official FEMA P-58 approved method of estimating building repair time for functional recovery. This functional recovery method will include assessing the functionality of sub-systems within the building, will include construction repair scheduling for repairing damage to systems which prevents function, and will incorporate updated impeding time treatment (time to prepare to make repairs, e.g. design repairs) that are compatible with an updated FEMA P-58 red-tagging prediction method.

The FEMA P-58 Methodology provides a framework to assess the probabilistic performance of new or existing buildings in terms of repair cost, repair time, safety (casualties and injuries), red tagging, and environmental impact. This performance-based method is unique because it provides engineers the ability to design new buildings or retrofit existing buildings to achieve specific levels of performance based on owner decision variables. The result metrics (repair cost, repair time, and safety) can then be used by the building professionals and building stake holders when selecting the level of seismic performance that fits the unique needs of their buildings.

The FEMA P-58 Method framework is based upon the Pacific Earthquake Engineering Research Center (PEER) framework for performance-based earthquake engineering (Moehle and Deierlein, 2004). The PEER framework uses a multi-level integral to determine probabilistic building performance, the FEMA P-58 Method applies this concept using Monte Carlo Simulation (see outline, Figure 1). The factors effecting seismic performance which are considered are as follows (FEMA, 2018):

- Ground shaking intensity
- Building responses (e.g. peak interstory drift, peak floor accelerations, residual interstory drift)
- Susceptibility of structural and non-structural components to damage
- Population of people and components within the building

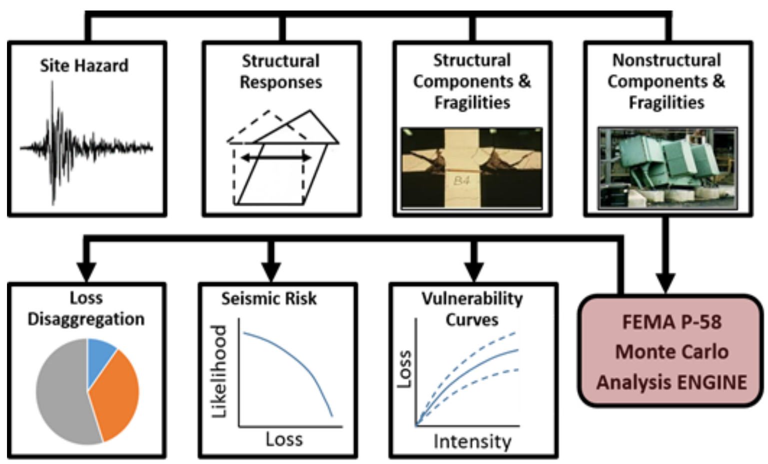



Figure 1. Outline of the FEMA P-58 seismic risk assessment methodology (Wade et al., 2018).

The performance metrics which result from the FEMA P-58 Method allow building professionals and stake holders to examine performance metrics at various intensities. For example, the mean repair costs (arithmetic average repair cost normalized by building replacement cost) associated with a 475-year and 2475-year event are presented for an 8-story steel moment frame designed to code and located in 12 different cities across California (Figure 2).

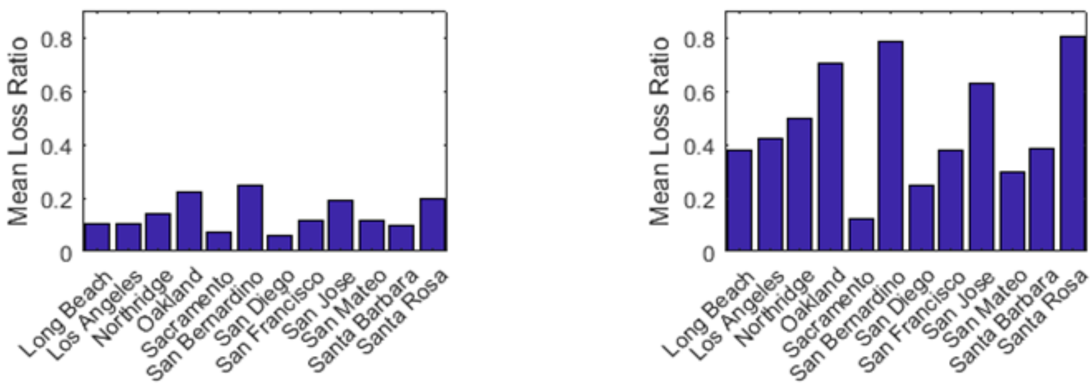



Figure 2. Expected repair cost normalized by building replacement cost for an 8-story steel moment frame building (a) 475-year event, (b) 2475-year event (results from a study conducted using SP3).

## Arup Downtime Assessment Methodology (DAM)

Arup's DAM builds on the FEMA P-58 work (Almufti et. al, 2013). The DAM categorized component damage states into bins based on its impact to the building recovery. While FEMA P-58 estimates the quantity of damaged components, it does not identify how that particular damage state impacts building recovery. The DAM identifies which damage components need to be repaired for re-occupancy (repair class 3), functional recovery (repair class 2), and full recovery (repair class 1). This allows the engineer to understand which repairs are needed for each recovery state of the building.

The DAM provides guidance for estimating *recovery* time. FEMA P-58 estimates the time it takes to complete the repairs. There are other factors that will influence how long it will take a building to recover its functions. Impeding factors include all the activities for repairs such as engineering design, financing, permitting, and contractor mobilization. Utility disruption and other externalities can also delay a building's recovery. The DAM provides guidance on these topics and how to include them in the FEMA P-58 analysis.

## Applications and Software

### PACT/PET

It is valuable for engineers to be aware of the applications available to perform this kind of analysis. FEMA P-58 developed two tools to assist engineers using the methodology. The Performance Assessment Calculation Tool (PACT) is a free tool that performs the probabilistic calculations and accumulation of losses described in the methodology. The Performance Estimation Tool (PET) is an interactive spreadsheet developed based on the application of FEMA P-58 to 1,755 archetypical buildings. It can be used as a design aid to quickly determine the level of strength and stiffness to achieve specific performance objectives for the systems and occupancies represented within the database (ATC, 2018). PACT and PET do not include concepts from Arup's Downtime Assessment Methodology.

## Seismic Performance Prediction Program (SP3)

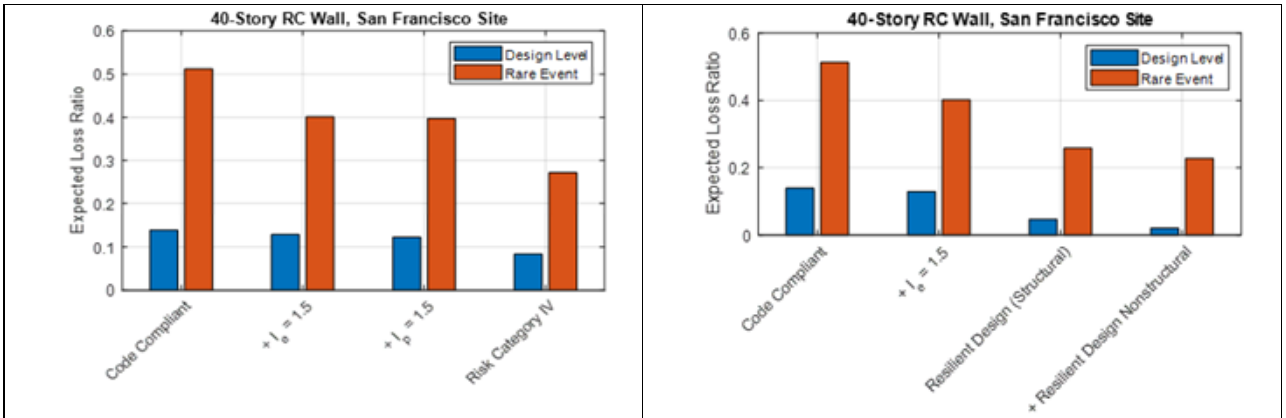
SP3 was first introduced in 2014 and was created to streamline the rigorous FEMA P-58 Method to make it more accessible to practicing engineers. Unlike PACT, which implements only the P-58 Method and requires lengthy user input, SP3:

- Automates inputs including USGS hazard data, building component inventory, and more using extensive databases and engines
- Supports functional recovery time assessment for resilient design (currently including REDi, but will soon include the FEMA P-58 Functional Recovery Method once it is released by ATC)
- Supports USRC and REDi Ratings
- Supplies an expanded component database (allows assessment of proprietary resilient structural systems, tilt-up buildings, etc.)

SP3 is currently used for design of new construction, evaluation and retrofit of existing buildings, mortgage risk assessment, portfolio assessment, and in insurance applications. The software is flexible and can be used for a number of applications:

- Resilient Design – A P-58 analysis where the user provides structural analysis results and identifies all of the building components. This is done to check if the design is meeting the project performance objectives.
- Building Specific Risk Assessment – Detailed building specific risk assessments are used for high-level mortgage risk assessments and to inform insurance decisions.
- Level 0 Analysis – A P-58 analysis can be completed with a minimum of five pieces of information (location, structural system, number of stories, occupancy, and year of construction). SP3 will utilize internal databases and engines to provide a building- and site-specific analysis. While the limited inputs results in a greater uncertainty, this analysis may be used early in a design to help ensure the project is on a path to meet the project's performance goals or for a low-level mortgage risk assessment.
- Portfolio/Inventory Assessment – SP3 may be used to analyze inventories of buildings rapidly (from tens to millions). It is tailored for owners analyzing risk to portfolio of properties, agencies performing regional disaster response planning, and insurers assessing portfolio losses.

An example of an SP3 analysis with successively increasing detail is presented from Haselton et al., 2019. A code conforming 40-story reinforced concrete shear wall building is initially analyzed using minimal SP3 inputs resulting in repair costs of approximately 12 and 50% of the building replacement cost for a design and rare event respectively. Prescriptive adjustments to the design were incorporated adjusting building strength, stiffness, and finally risk category IV and performance tracked with each adjustment to the design. The reduction in repair cost is shown in Figure 3A. The building design was then adjusted for enhanced performance by increasing design strength, optimizing for structural performance and finally optimizing for non-structural performance (Figure 3B). See Haselton et al. 2019 for examination of different structural systems, optimizing strategies, and result metrics including recovery time.




3A. Enhanced Prescriptive Requirements

3B. Enhanced Design for Functional Recovery

Figure 3. Expected performance for a 40-story reinforced concrete shear wall building with enhanced design requirements (Haselton et al., 2019)

SEAOC does not endorse specific products, but it is important to illustrate the latest technology available to the profession. SP3 is chosen because it is widely used in industry and the academic community.

## Conclusion

Resilience is an attribute of organizations and is primarily measured by restoring functionality after a disruptive event like an earthquake. To achieve resilience it is critical for buildings to be designed to meet the expectations of the community. FEMA P-58 and its implementation tools give engineers the ability to design buildings and assess their performance based on safety, repair cost, downtime, and environmental impact. This technology is already being used in the industry. SP3 is used by 80% of the large west coast structural engineering firms. In order to become leaders in community resilience, structural engineers need to familiarize themselves with FEMA P-58 and make sure that the building design meets their client's expectations.

**If you are interested in joining the SEAOC Resilience Committee, please email Jonathan Buckalew (jbuckalew@nyase.com) and Anna Lang Ofstad (anna@zylient.com).**

*Conflict of interest disclosure: Katie Wade is employed by Haselton Baker Risk Group who created and maintains the Seismic Performance Prediction Program (SP3)*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