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# The ATC-58-2 Project
# Further Development of Next Generation Performance-based Design Criteria

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## *Abstract*

In 2012, the Applied Technology Council (ATC) completed the first phase of its ATC-58 Project with publication of the FEMA P-58 Next-Generation Seismic Performance Assessment Methodology. Shortly thereafter, ATC initiated work on a second Project phase intended to enable practical implementation of the methodology on seismic design and retrofitting projects. Major enhancements include improvement of the fragility library; calibration and benchmarking of results against actual building performance in earthquakes; development of simplified design aides to enable practical use in design; implementation of an environmental consequences module, cooperation with private software developers to allow enhancement of available applications software; and, outreach to stakeholders and decision makers to understand how the methodology can best be used to address their needs. Significant improvements to usability and usefulness have resulted.

*Keywords: performance assessment; design; loss assessment*

## 1. Introduction

Performance-based design is an approach by which design is conducted with the intent that a building will be able to provide specific desired performance in future earthquakes. It differs from traditional design approaches in which design is conducted to assure the structure conforms to prescriptive criteria that include minimum strength, stiffness and detailing practices. Although traditional design approaches are intended to provide a building with acceptable performance characteristics, these characteristics are rarely discussed with or known by the owner, and are not specifically evaluated by the engineer. In performance-based approaches, design initiates with the process of setting performance objectives, selected and agreed to by the owner. As design progresses, the engineer evaluates its ability to meet the selected objectives. When complete the design may or may not actually conform to the prescriptive criteria contained in the building code, but is expected to be capable of providing desired performance.

The first true performance-based seismic evaluation and design procedures were first developed more than 20 years ago under the Federal Emergency Management Agency's (FEMA) existing buildings program. FEMA's intent was to encourage reduction in society's earthquake risks by providing practical and effective tools that would enable building owners and their consultants to first identify then mitigate unacceptable risks in existing buildings. Initial efforts focused on unacceptable life safety risks. The Applied Technology Council (ATC), under contract with the National Science Foundation and FEMA, developed a series of documents including *ATC-14*[1], *ATC-22*[2], and *FEMA-178*[3] that focused on evaluation of life safety hazards in existing buildings by identifying the existence of critical vulnerabilities in common building types. FEMA then commissioned ATC, the American Society of Civil Engineers (ASCE), and Building Seismic Safety Council (BSSC) in a collaborative effort to develop rehabilitation design guidelines. As part of this effort the ATC-33 project developed the *FEMA-273/274 Guidelines and Commentary for Seismic Rehabilitation of Buildings*,[4] the first true performance-based seismic design procedure. Unlike the earlier seismic evaluation documents, the *FEMA 273/274 Guidelines and Commentary* defined a series of standard performance levels ranging from Immediate Occupancy, a state of minor damage in which building safety was not compromised; to Collapse Prevention, a state of incipient collapse. The guidelines permitted design to achieve any of these performance levels for any user-selected earthquake intensity.

The frequent earthquakes that occurred in California and elsewhere during the 1980s and 1990s created a demand for performance-based seismic engineering tools. Many building owners and tenants would ask engineers to evaluate their buildings, inform them of the probable performance. While life safety remained a concern of these stakeholders, often their interest included probable repair costs and business interruption time. Upon learning the magnitude of potential repair costs and business interruption time, owners would then request building upgrades intended to minimize these earthquake impacts. The *FEMA 273/274 Guidelines*, later updated and published by ASCE as the ASCE 31[6] and ASCE 41[7] standards, provided engineers the tools they needed to address these requests. So great was the need for these tools, many engineers began using early drafts of the new guidelines directly in their project work. By the time of the 1997 publication of *FEMA 273/274*, engineers and other earthquake professionals began asking for similar performance-based design procedures for new buildings. FEMA responded by first commissioning the Earthquake Engineering Research Center (EERC) at the University of California at Berkeley, and then the Earthquake Engineering Research Institute (EERI) to develop program plans for the development of next-generation performance-based seismic design criteria, applicable to the design of new buildings. The resulting FEMA 283[8] and FEMA 349[9] publications recommended broad research and development programs with projected budgets ranging from $23 to $32 million.

Following the 2001 terrorist attacks in New York and Washington D.C., national attention shifted away from natural disasters, and FEMA and other agencies found their available earthquake mitigation budgets greatly reduced. Still, FEMA sponsored the development of next-generation performance-based seismic design criteria, though not at the funding levels recommended by EERC and EERI. This effort was greatly facilitated by National Science Foundation (NSF) funding of three national earthquake engineering research centers that performed substantial studies in support of the development of performance-based seismic design criteria. NSF also supported many other researchers in performance of laboratory and analytical research in support of this goal. FEMA entered into a cooperative agreement with ATC to develop the new performance-based seismic design guidelines in two phases. The first phase, completed in 2012 with publication of the FEMA P-58[10] series of tools, provided a methodology and companion electronic calculation tool to enable evaluation of a building's probable earthquake performance in terms of potential earthquake-induced repair costs, repair times, probability of incurring unsafe placarding and casualties. The second phase of the project, initiated in 2013 is intended to provide design tools, incorporating and based on the FEMA P-58 methodology to enable design of new buildings and retrofit of existing buildings to meet seismic performance criteria including limiting repair cost, repair time, casualties and also metrics associated with environmental impact.

## 2. FEMA P-58 Methodology

The *FEMA P-58* methodology represents a major departure from earlier performance-based seismic evaluation and design procedures in several respects. Earlier methodologies characterized a building's performance by comparing analytically-predicted component force and deformation demands against acceptance criteria associated with three discrete performance levels – Immediate Occupancy, Life Safety, and Collapse Prevention. These earlier methodologies, embodied in *ASCE 41* are deterministic in nature. That is, a building is either found capable of meeting a given performance level for specified shaking intensity, or not. These performance levels are qualitatively tied to anticipated earthquake impacts including life safety and repair costs and times, but there is not direct linkage to these quantities that are of key interest to stakeholders. The FEMA P-58 methodology abandons the discrete performance levels, in favor of direct prediction of the metrics directly meaningful to these stakeholders, that is, the probable cost and duration of earthquake damage repair, as well as the number of casualties that may occur. Further, recognizing the many uncertainties inherent in ground motion estimation, earthquake response analysis, as well as damage and consequence prediction, the methodology adopts a probabilistic framework first developed by Cornell[11] and others at the Pacific Earthquake Engineering Research (PEER) Center to project the probability of exceedance of losses of different magnitudes. The methodology employs a Monte Carlo analysis approach to solution of the framework equation presented by Moehle and Deierlein[12] as:

$$v(DV) = \iiint G(DV|DM)dG\big((DM)\big|EDP\big)dG(EDP|IM)d\lambda(IM) \tag{1}$$

In the triple integral of Equation 1, *DV* is a decision variable such as the cost of repair; *DM* is a damage measure, such as amount of cracking in a wall; *EDP* is an engineering demand parameter, or more simply demand parameter, such as floor acceleration or story drift; and *IM* is a ground motion intensity measure, such as spectral acceleration. In the FEMA methodology, the term $G(DV|DM)$ is called a consequence function; $G(DM|EDP)$ a fragility function; $G(EDP|IM)$ a demand distribution and $\lambda(IM)$ the hazard function for the particular ground motion parameter used to characterized seismic hazards. The consequence functions, fragilities and demand distributions are all represented as lognormal functions with median values, $\theta$, and dispersion $\beta$.

The methodology permits three assessment types. Intensity-based assessment provides performance estimates conditioned on the occurrence of a particular earthquake intensity, wherein the hazard is defined by a user-specified response spectrum. Scenario-based assessment provides estimates of probable performance for a specified earthquake scenario, characterized by magnitude and distance from the site, and accounting for attenuation uncertainty. Time-based assessment provides estimates of probable performance considering all earthquakes that could occur, and the likelihood of each, accounting for hazard uncertainty.

When implementing the methodology, the engineer first builds a performance assessment model. The performance assessment model includes a description of the building's replacement cost and time, as well as a description of all of the building assets at risk of harm including vulnerable structural and nonstructural components and systems, contents, occupants and their distribution throughout the building. For each vulnerable component type, the engineer assigns a fragility function that specifies the possible damage states and the likelihood that each damage state will occur as a function of a predictive analytical response quantity such as floor acceleration, floor velocity or story drift. In addition, the user must identify a consequence function for each vulnerable component describing the repair costs, repair time and potential casualties that can occur if the component is damaged to a particular damage state. Components of similar type are identified as having correlated or uncorrelated damaged characteristics. Component damage should be considered correlated if failure of one component makes failure of other components of the same type more likely to occur.

The performance assessment model also includes an occupancy model, describing the number of persons likely to be present at different times of day and days of the week; a building collapse fragility and a residual drift vulnerability function. The collapse fragility function defines the possible collapse modes; and for each mode, the portion of the building that will experience collapse given that the mode occurs; the conditional probability that the mode will occur, given that there is collapse; and the median spectral acceleration and dispersion associated with collapse. The residual drift vulnerability function defines the probability that the building would be impractical to repair given a value of residual drift.

After assembling the building performance model, the engineer performs structural analysis to determine the probable values of predictive response quantities as a function of ground motion intensity. For regular structures with limited inelastic demand it is permissible to use a linear static analysis procedure, similar to that specified by ASCE 41, for this purpose. Regression expressions derived from nonlinear analyses of archetype structures allow the user to convert the demands predicted by the linear static analysis into median estimates of demand, considering probable nonlinear response. The methodology also provides recommended values of response dispersions. For irregular structures or structures anticipated to experience substantial nonlinear behavior, the engineer must perform nonlinear dynamic analysis using suites of ground motions scaled to each intensity level of interest in order to predict median values of the demand parameters and associated dispersions.

A Monte Carlo process is used to develop performance measure distributions. First the analytically-predicted demands are converted into demand distributions. If nonlinear analysis is performed, the median values of results from the analysis are assumed to be true medians and a dispersion is computed using the record to record variability from the analysis enriched to account for modeling and other uncertainties. If linear analysis is used the methodology assigns default dispersions. Then a mathematical procedure is used to generate a large number of simulated response states, termed realizations. Each realization represents one possible response state (peak floor acceleration, story drift, transient drift, etc.) given that the earthquake intensity of interest is experienced. When nonlinear analysis is used, correlation between the various demand parameters observed in the suite of analyses is retained. When linear analysis is used, all demands are assumed correlated with the same relations predicted by the analysis.

Once the demand realizations are formed, the performance computation procedure illustrated in Fig. 1 is followed. The figure schematically shows a pair of dice at each point in the procedure where a random outcome, consistent with the associated probability distributions is used to determine performance. The process starts with determining for the given realization, whether collapse has occurred, by querying the collapse fragility. If collapse is predicted, the building is considered a total loss, regardless of the collapse mode and repair cost and times are taken as the replacement cost and times. However, to compute casualties, a collapse mode is selected; then a determination is made as to the date and time of day of the earthquake, so as to compute the number of persons present in the collapsed area. Consequence functions are used to determine the probabilities of death and serious injury for persons in the collapse-affected area.

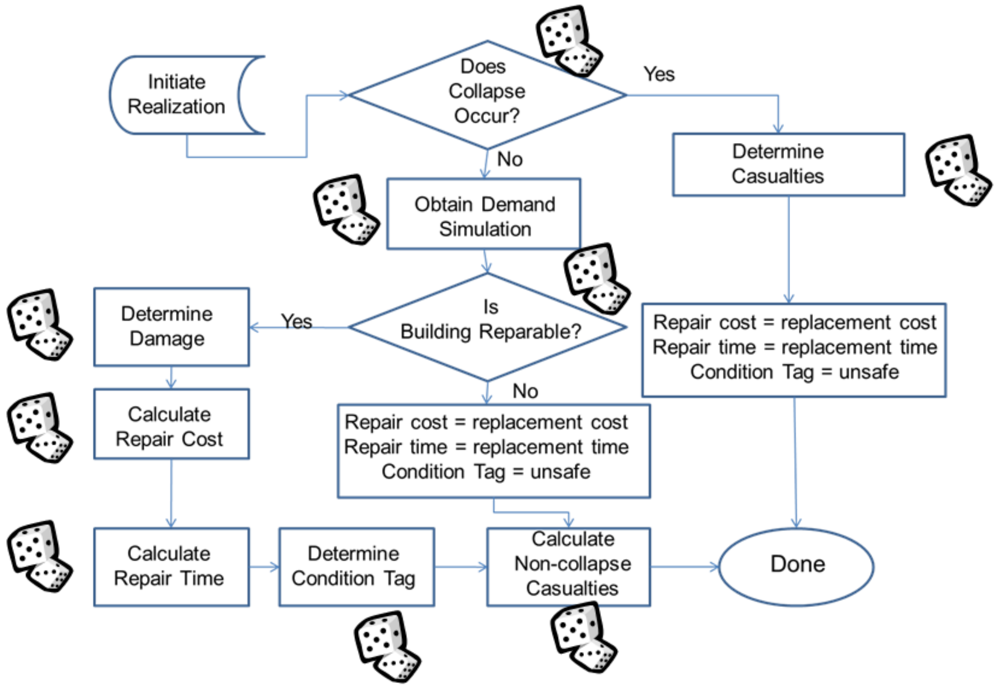


Fig. 1 – Performance Computation Process

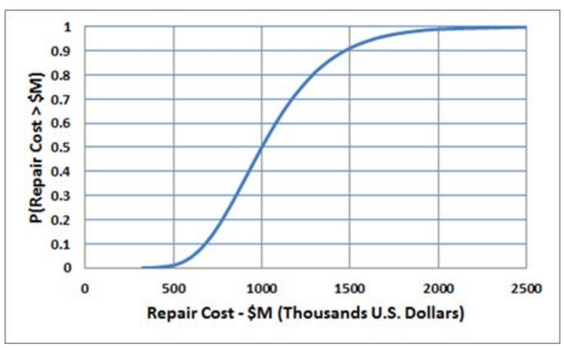


Fig. 2 - Representative Repair Cost Distribution from FEMA P-58 evaluation

If collapse is not predicted, the residual drift vulnerability function is queried to determine if the amount of residual drift is sufficiently large to preclude practical building repair. If so, the building is again considered a total loss. Regardless, a damage state is determined for each vulnerable component, using the realization demands and the individual component fragility functions. Once damage states are determined, the casualties associated with each damage state are determined. If the building is deemed repairable, the quantity of damaged components of each type in each damage state is determined, and the consequence functions for these components are used to determine an aggregate repair cost and repair time, taking into consideration the economies of scale that are achievable when a large number of repairs of a similar type are conducted. Finally, the computed consequences from the suite of realizations are assembled into an ordered array from the realization with the least consequence to those with the largest consequence, permitting the probability of incurring a consequence of a given magnitude to be determined. Performance is shown in the form of loss curves, such as that illustrated in Fig. 2, showing probability distributions for each loss.

The ATC-58 Phase 1 products include: a report (Volume 1) presenting discussion of the overall methodology; a free windows-based application called the Performance Assessment Calculation Tool (PACT) that provides a convenient way to assemble the building performance model and execute the Monte Carlo simulations; an implementation guide (Volume 2) that illustrates how to use the methodology to obtain performance assessments; an electronic data base of fragility and consequence functions for structural and nonstructural systems commonly found in buildings; a spreadsheet application that indicates the typical quantities of various components found in buildings of common occupancies; and a fourth volume (Volume 4) containing summary research reports that provide the basis for the methodology and its associated tools. These volumes and the associated calculation tool and spreadsheets can be downloaded free form the FEMA web site.

The *FEMA P-58* methodology can be used indirectly as a guide to building design or retrofitting, but does not include any direct design guidance or tools. To use the methodology for design one must first select performance objectives that are compatible with the metrics produced by the methodology; e.g. probability of incurring repair costs or repair times of varying amounts; perform a preliminary design; then use the evaluation methodology to determine if this design is capable of meeting desired performance objectives. If the design is unable to meet the objectives, the design must be revised and re-evaluated in an iterative manner until a successful outcome is achieved. This can be a time consuming process. Also, there are no present guidelines to indicate what performance, as measured using the FEMA P-58 metrics, should be expected of an existing building. This makes equivalence with prescriptive code performance expectations, a prerequisite to obtaining building permits in most cases, difficult. The Phase 2 project, initiated in 2013 is intended to address these limitations and facilitate application of the methodology to building design and upgrade.

## 3. ATC 58 Phase 2 Project

The primary purpose of the phase 2 project is to enable and encourage use of the *FEMA P-58* methodology in building design and upgrade. A first project task is to use (exercise) the methodology to quantify the likely performance of typical prescriptively-designed, code-conforming buildings. This will enable establishment of code-equivalent performance, and also recommended performance objectives for buildings of different occupancies and uses. Following this, the project will develop design aids to assist engineers to rapidly identify the performance characteristics of various structural systems, and the levels of strength and stiffness needed for each structural system in order to achieve specific performance objectives. Supplementary products will include specification guidance on installation of nonstructural components, to reduce their propensity for damage. Since use of the methodology as a design tool will depend in large part on the ability and desire of decision-makers, including building owners and tenants to specify buildings with specific performance capabilities, the project is also producing a series of educational aides targeted at these decision-makers. These tools will explain the performance-based design process, in terms the average decision-maker can understand and also assist the decision-maker to understand the potential benefits and costs associated with use of the *FEMA P-58* methodology in design and to select appropriate performance objectives for new and existing buildings. In addition, because concerns associated with climate change and conservation of our planetary resources are important to many decision-makers, the methodology is being expanded to characterize performance in additional metrics including, tons of greenhouse gases, energy usage and solid waste generation associated with earthquake performance. Finally, the project is updating the phase I products to improve and enhance the fragility and consequence functions, and calculation tool and is also cooperating with commercial structural applications software producers so that they can incorporate the methodology into their software packages.

## 4. Exercising the Methodology

The Phase 2 project team initiated work by using the FEMA P-58 methodology to evaluate the probable performance of a series of archetypical buildings including low and mid-rise structures incorporating light wood frame, concrete moment frame, concrete shear wall, and steel moment frame structural systems. In some of these evaluations, buildings of identical size, configuration, number of stories, structural system type and configuration were designed using similar occupancies, but different code-specified risk categories, so as to judge the effectiveness of present code requirements intended to affect building performance. For example, some buildings were designed both as medical office buildings, assigned to Risk Category II, while similar buildings were designed as hospitals assigned to Risk Category IV.

These initial studies produced surprising results. First, the probable losses for all buildings evaluated exceeded, significantly, the typical losses experienced by buildings in recent U.S. earthquakes. This led to a series of supplemental studies to evaluate why the methodology systematically predicted excessive losses. These studies revealed two primary sources for this over-prediction. The first of results the way damage states, damage state fragilities and associated consequence functions are determined. For a given component, an infinite range of damage states, ranging from no damage to complete damage are possible. However, for each component type, the methodology identifies a limited series of discrete damage states each consisting of a smaller range of damage having a set of similar consequences, i.e. repair methods and cost; unsafe placarding, etc. The fragility functions are constructed such that they predict the on-set of damage associated with a damage state while the consequence functions are targeted at the consequences associated with the mid-range of damage associated with the state. This introduces an inherent bias towards over-prediction of damage and consequences. Studies suggested that by using a greater number of damage states, each representing a smaller range of potential damage, this bias could be minimized. As a result, the project refined and improved many of the original fragility and consequence functions to include greater discretization and permit improved consequence prediction.

The second contributing factor in the excessive loss predictions is associated with inherent bias in typical structural analysis that results in under-prediction of building stiffness and computation of excessively large building response periods. To investigate this issue, the project conducted analyses of a series of real buildings of different types for which there were multiple in-structure response records, for earthquakes of different intensity. These studies demonstrate that typical analytical models substantially under estimate building stiffness, even for shaking approach design earthquake levels. The amount of bias in these analyses is dependent on building type, and also the analysts modeling technique and assumptions. The effect is most severe for inherently flexible structural systems such as steel and concrete moment frames, where it was found that analytical period predictions were 40% of values obtained from signal analysis of in-structure records. The effect of this on building performance estimates is significant. Building performance is a function of story drift, floor velocity and floor acceleration, with story drift being a dominant contributor for many buildings. If analytical prediction of building stiffness is low, then predictions of drift will be large.

There are many reasons that analytical models, even advanced models, under predict stiffness. Many structural models represent only the intended elements of the seismic force-resisting system, and only represent these in an approximate manner. For example, engineers often neglect the composite actions of floor slabs when modeling steel and concrete moment frames. Further, the stiffness of structural elements intended only for gravity load resistance are routinely neglected and the stiffening effects of nonstructural elements including stairways, parking ramps, exterior cladding and similar items are almost never included. Interestingly, these effects tend to be more prevalent in models used for nonlinear analysis, then linear analysis, because the added complexity associated with nonlinear modeling encourages engineers to simplify their models.

Initially the project team considered developing stiffness adjustment factors for buildings of different types, so that engineers could adjust their models to more accurately represent their dynamic response.

Ultimately the project rejected this approach because of the difficultly of developing such factors in other than an arbitrary and judgmental manner. Also, it was felt that it is important to encourage engineers to model their buildings more realistically, when engaged in performance-based design, then they would do when designing buildings prescriptively. However, for the purpose of benchmarking typical building performance the project team made allowances in archetype models for different structural systems to account for these stiffening effects.

Another interesting finding of these studies was that present prescriptive building code criteria, such as those embodied in ASCE 7-10[13], do not necessarily provide appreciably better performance in buildings designed to the requirements of higher risk categories, such as hospitals than do buildings designed for lower risk categories such as office buildings. ASCE 7-10 seeks to improve performance of higher risk category structures by requiring greater strength and stiffness. This does result in a reduction of structural vulnerability. However, it also increases building period, increasing acceleration demands and losses associated with damage to acceleration-sensitive components. Further, under ASCE 7-10, the design of nonstructural components such as stairs and cladding is keyed to the analytically predicted drift demand under design earthquake shaking. For higher risk category structures, where predicted design drifts are lower, the drift capacities of these drift-sensitive components is also lower, resulting in equal probability that these components will be damaged, given a particular intensity of motion. To obtain better performance, it is clear that it is necessary to balance structural strength, structural stiffness, and component fragilities. These are key design recommendations produced by the project.

## 5. Environmental Impacts

Under separate funding from FEMA, ATC, under its ATC-86 project, explored a preferred approach to incorporating environmental impact performance metrics in updates to the FEMA P-58 methodology. The project evaluated which environmental impacts would be of interest to FEMA P-58 users and also, the preferred way of computing these impacts. The results of this study were published as Volume 4 [14] of the FEMA P-58 series of reports. This report identified a series of eight separate impacts that could be evaluated and reported in the methodology including: green-house gas emissions; also termed climate change potential; primary energy usage; resource depletion; waste generation and disposal; photochemical smog potential; ozone depletion potential; eutrophication potential; acidification potential. Ultimately, the project elected to include only greenhouse gas emissions, primary energy and solid waste generation as metrics that would be reported, as these metrics seemed to have the most relevance to earthquake damage, and also to be of most interest to typical decision-makers.

The ATC-86 project also evaluated alternative approaches to computing the value of these metrics associated with earthquake damage. The two preferred approaches are the Economic Input-Output (EIO) approach and the Bill of Materials (BOM) approach. The EIO approach uses gross data on the relative impacts associated with broad sectors of the economy, that essentially relates economic activity, measured in a currency such as US$ to an environmental impact. Under such models, e.g., 1 million $US activity in construction can be related to Y tons of greenhouse gas generation, and other environmental impacts. Under the BOM approach, each damage repair activity is associated with a specific quantity of each environmental impact, in a very similar manner to the way in which construction cost estimators build up cost estimates. While the EIO approach, by nature, employs broad generalizations as to the impacts associated with particular damage; the BOM approach provides impacts that are specific to particular damage. While more complex to implement, the BOM approach is compatible with the way other impacts are estimated in the methodology. Unfortunately, however, industry consensus as to the impacts associated with many construction activities inherent in earthquake damage repair has not yet been developed. Also, the bill of materials generated within the existing consequence functions were developed to provide meaningful estimates of repair time and repair cost and in many cases are not directly useful to estimation of environmental impacts. Since the EIO approach would allow computation of environmental impacts directly form the repair cost estimates associated with each realization, the BOM approach would entail substantially more effort to implement. Therefore, although the BOM approach may eventually provide environmental impacts of enhanced quality relative to the EIO approach the project elected to implement the EIO approach.

In the updated methodology, performance measures continue to be evaluated as shown in Figure 1 above. After the cost impacts are computed for each realization, the EIO method is used to convert repair costs in dollars, to the three environmental impacts. Additional uncertainty is added to account for the broad generalizations inherent in the conversion process, and impact distributions, similar to those shown in Figure 2 are computed.

## 6. Design Aids

In order to develop design aids, the project evaluated the performance of thousands of archetype buildings for different levels of earthquake shaking ranging from 10% of $MCE_R$ shaking intensity to 100% of $MCE_R$ shaking intensity This exercise was performed for archetypes representing different structural systems, different occupancies and different Seismic Design Categories. These studies demonstrate that for modern, fixed-based, code-conforming buildings, with conventional structural systems; earthquake performance under moderate levels of shaking is dominated by damage of nonstructural systems and contents, rather than structural systems. Damage to these nonstructural systems is primarily dependent on story drift and floor acceleration. Moment-resisting frames of both steel and concrete and steel buckling-restrained braced frames, all of which have been considered to be high-performance structural systems tend to experience large story drifts, resulting in significant damage to partitions, cladding, stairways and similar drift-sensitive components. Shear wall buildings of masonry and concrete generally experience much lower drift, but tend to produce higher floor accelerations, resulting in higher damage to elevators, mechanical equipment, suspended ceilings, computer equipment and similar acceleration-sensitive components.

As shaking intensity approaches design levels, the influence of structural behavior on performance becomes more significant. Structural damage rather than non-structural damage is most likely to result in post-earthquake occupancy restrictions and long term loss of use. Structural collapse, at least for modern code-conforming systems is a relatively small contributor to economic losses as even at $MCE_R$ shaking levels, the building codes seek to provide a low probability of collapse. However, at design shaking and more severe intensities of motion, permanent residual drift becomes a significant contributor to losses. Studies conducted as part of the ATC 58 phase I project suggest that for conventional structural systems with ductile behaviors the expected value of permanent residual drift is approximately half the peak transient nonlinear drift. For typical structures a permanent residual drift of 1% of story height can represent an irreparable condition. Given that current U.S. building codes permit peak transient drifts of 2% of story height or more, at levels of shaking approaching and exceeding design levels, the probability of irreparable residual drift becomes significant. This problem is most significant for moment-resisting frames and buckling-restrained brace frames and is less of a problem for shear wall buildings.

To assist engineers in selecting structural systems that will meet desired performance objectives, the project is producing a series of structural system-specific performance curves that show median levels of performance metrics that can be anticipated at different levels of shaking, expressed as a fraction of $MCE_R$, and as a function of systems strength and stiffness. Figure 3 presents one such design aid, developed for steel special concentric braced frames. The figure presents median repair cost for steel concentric braced frame buildings in office occupancy for each of four combinations of strength and stiffness ranging from building code-permitted minimum strength and stiffness to practical upper bounds on both strength and stiffness for the particular system as well as combinations that include high strength and low stiffness and low strength and high stiffness. Since strength and stiffness of a system are typically related, the extent that the two can vary is limited by the selection of structural system. It is hoped that engineers will find figures of this type useful for guidance in selecting appropriate structural systems for particular projects as well as determining on a preliminary basis, the required stiffness and strength to achieve a particular performance capability.

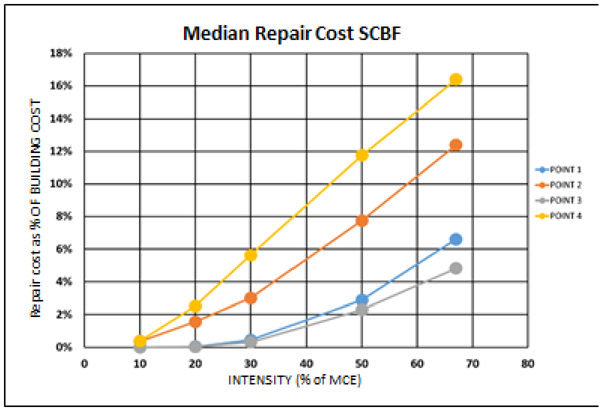


Figure 3 – Structural system-based performance diagram

Companion aides will provide guidance on the probable source of losses for buildings of given occupancy and structural system type at particular intensities of motion. Figure 4, for example presents the relative contribution to losses for a particular structural system at a given intensity of motion for the different combinations of structural strength and stiffness. Such tools would enable engineers and decision-makers the opportunity to understand what losses can be attributed to, and to seek design solutions that would minimize, or at least moderate such losses.

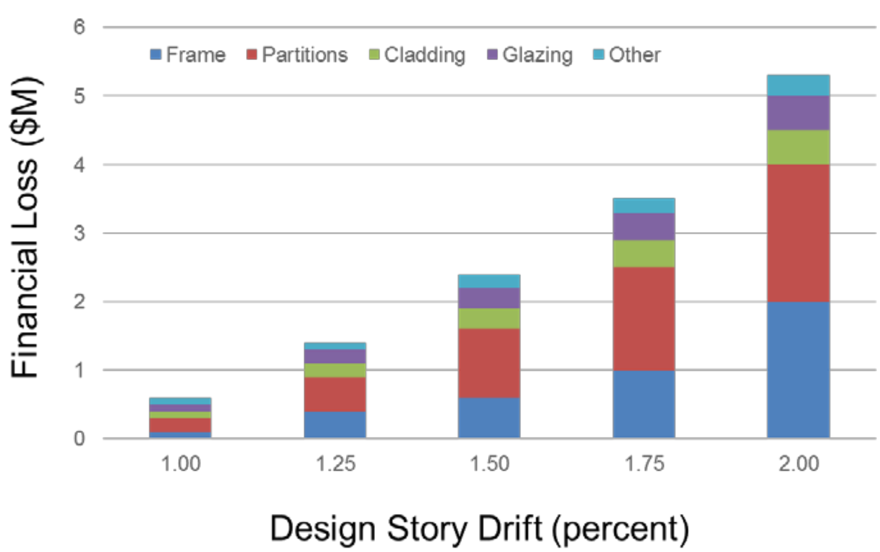


Figure 4 – Sources of repair cost loss for a particular structural system and intensity

## 7. Stakeholder Guidance

In addition to tools intended to facilitate design professional implementation of performance-based design, the project is developing a series of guides intended to assist decision-makers to take advantage of the benefits of performance-based design can offer. The first of these products, guides the decision-maker with a simple question and answer process to understand whether it makes sense for them to seek a performance-based design approach for their building projects. This tool, which can either be web- or paper- based, leads the decision-maker through basic understanding of when and why a performance-based approach, and the use of the FEMA P-58 methodology in particular, would be beneficial for a project. A second product guides the decision-maker through the process of implementing a performance-based design on their projects, focusing on ways that a project that employs the FEMA P-58 methodology might differ from a project that does not. This guidebook will address the different ways a performance-based approach can be used; project cost, schedule, and complexity implications; working with qualified design consultants; communicating results effectively; contractual documents; interactions with building officials; and other aspects of project implementation. A third product focuses on facilitating the discussion between a decision-maker and their structural engineer about performance goals that take advantage of the quantitative capabilities of the FEMA P-58 methodology. Together, these products aim to inform decision-makers about the new capabilities of the FEMA P-58 methodology and to help them use them successfully in appropriate projects

## 8. Summary

Since its publication in 2012, the FEMA P-58 methodology has seen increasing use in the structural engineering community, primarily as an evaluation, rather than design tool. The ATC 58 phase 2 project is expanding the methodology to include consideration of additional impacts of earthquake performance, to provide designers with tools to enable more rapid selection of appropriate structural systems to achieve desired performance, as well as the necessary strength and stiffness. The project is also providing a series of basic educational tools focused on decision-makers, to make selection of a performance-based design approach both more familiar and attractive to them, and to assist them in avoiding common pitfalls that can prevent effective implementation of performance-based design on projects.

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