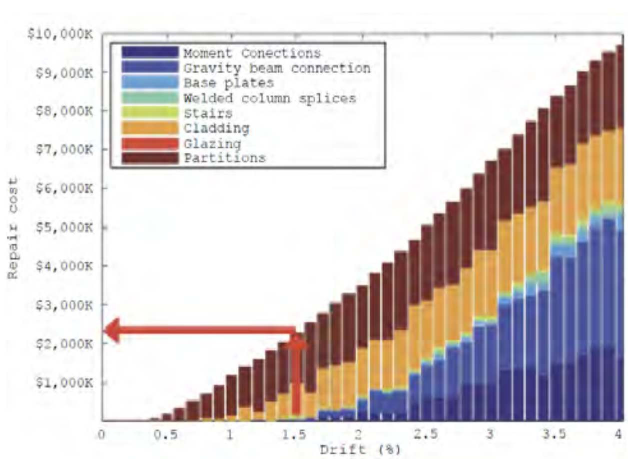
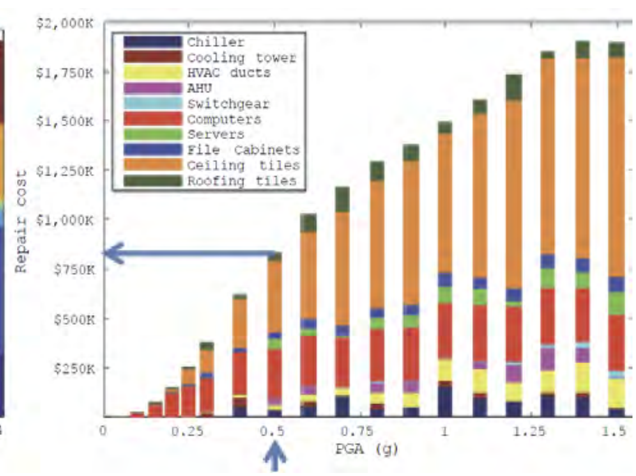
ATC **58-5**

Proceedings of

FEMA-sponsored workshop on design guidelines and tools to implement next-generation performance-based seismic design





ATC Applied Technology Council

Funded by
Federal Emergency Management Agency

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Cover illustration: Variation in repair cost (percentage of replacement cost) as a function of shaking intensity.

ATC-58-5

Proceedings of FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design

August 14, 2014
San Francisco, California

by

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Funded by

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Preface

In 2012, the Applied Technology Council (ATC) completed a 10-year program under contract with the Federal Emergency Management Agency (FEMA) to develop a next-generation methodology for seismic performance assessment of buildings. This program was conducted under a series of projects known as the ATC-58/ATC-58-1 Projects. The resulting products, collectively referred to as FEMA P-58, *Seismic Performance Assessment of Buildings, Methodology and Implementation*, describe a general methodology and recommended procedures to assess the probable seismic performance of individual buildings based on their unique site, structural, nonstructural, and occupancy characteristics. In the FEMA P-58 methodology, seismic performance is characterized on a probabilistic basis in terms of the potential for incurring damage or losses in the form of repair costs, repair time, casualties, unsafe placarding, and environmental impacts.

In 2012, FEMA funded a subsequent 5-year program (identified as Phase 2) to utilize the performance assessment methodology in benchmarking the performance of U.S. model codes and seismic design standards and in developing performance-based seismic design criteria. Designated the ATC-58-2 Project, the purpose of this next phase of work is to: (1) develop products that assist stakeholders in selecting appropriate performance objectives for buildings of different occupancies; and (2) assist design professionals in efficiently developing building designs that meet these objectives.

This *FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design* is one of the first major efforts conducted under the Phase 2 program. The purpose of this workshop was gather input from practicing structural engineers on key issues associated with implementation of performance-based seismic design using the FEMA P-58 methodology, including: (1) communicating performance objectives and performance expectations to owners; (2) preferences on performance-based design tools and guidance; and (3) insight on the typical characteristics associated with code-compliant seismic-force resisting systems.

ATC is indebted to the members of the ATC-58-2 Project Team who planned and organized the workshop, including Ron Hamburger (Project Technical Director), members of the Project Management Committee including John Gillengerten, Bill Holmes, John Hooper, and Laura Samant, and members of the Performance Products Team including David Bonneville and Vesna Terzic.

ATC gratefully acknowledges the group of invited workshop participants for their contributions to the discussions. The names and affiliations of all who attended the workshop are provided in Appendix A.

ATC also gratefully acknowledges funding provided by the Federal Emergency Management Agency, guidance and support in the conduct of this work provided by Michael Mahoney (FEMA Project Officer) and Robert Hanson (FEMA Technical Monitor), workshop logistical support provided by Bernadette Hadnagy, and report production services provided by Carrie Perna.

Jon A. Heintz	Christopher Rojahn
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Chapter 1

Introduction

Most new buildings today are designed to conform to the minimum criteria set forth in the applicable building code, typically either the *International Building Code* (ICC) or the *International Residential Code* (IRC). The ICC references ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*, for structural design criteria for buildings, including consideration of seismic resistance. The IRC utilizes a simplified prescriptive approach to structural and seismic-resistant design. Structural engineers, owners, and other stakeholders, such as developers, have differing expectations and understanding as how a building is likely to perform in an earthquake. Most structural engineers understand that the criteria contained in the ICC and IRC presume that it is acceptable for buildings to sustain substantial damage in earthquakes, while owners and other stakeholders believe that the building code requirements are intended to provide protection against damage. Often, these expectations are not discussed during the course of building design as owners and other stakeholders commonly assume that the protection afforded by the building code is sufficient for their needs, and structural engineers often assume owners and other stakeholders are unlikely to want to invest in obtaining better performance. This difficulty in understanding and communicating seismic performance expectations and objectives is an impediment to wider use and acceptance of implementation of performance-based seismic design concepts.

Performance-based seismic design is an alternative procedure for design that requires direct communication among the owner/developer, structural engineer and other stakeholders, as to what building performance is desirable and how much this performance is worth. Use of this approach, first developed in the 1990s for application to seismic upgrade of existing buildings, can produce buildings that perform better in earthquakes than buildings designed for code conformance. Performance-based seismic design can also result in design and construction of buildings that can perform similar to code-conforming designs, but can be constructed at lower cost or having other attributes not permitted by code conformance.

In 2012, the Applied Technology Council (ATC) completed a 10-year program under contract with the Federal Emergency Management Agency (FEMA) to develop next-generation concepts for seismic performance assessment of buildings. This program (Phase 1) was conducted under a series of projects known as the ATC-58 and ATC-58-1 Projects. The resulting products, collectively referred to as FEMA P-58, *Seismic Performance Assessment of Buildings, Methodology and Implementation*, (FEMA, 2012a; 2012b; and 2012c), describe a general methodology, recommended procedures, and new metrics for assessing and communicating the probable seismic performance of individual buildings based on their unique site, structural, nonstructural, and occupancy characteristics.

FEMA has since funded a subsequent phase of work (Phase 2), designated the ATC-58-2 Project. The purpose of this work is to utilize the recently completed methodology in developing performance-based seismic design guidance for engineers and stakeholders. This report is a summary of a *FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design* held in San Francisco, California on August 14, 2014 that gathered input from practicing structural engineers on key issues associated with implementation of performance-based seismic design using the FEMA P-58 methodology.

1.1 The FEMA P-58 Methodology

In present-generation procedures, such as ASCE/SEI 41-13, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2013), performance is expressed in terms of a series of discrete performance levels (e.g., Operational, Immediate Occupancy, Life Safety, and Collapse Prevention), coupled with earthquake ground motion intensities for which such performance is to be obtained. Although the standard performance levels establish a vocabulary and provide a means by which engineers can communicate seismic performance to clients and other stakeholders, limitations in present-generation procedures include: (1) questions regarding the accuracy and reliability of available techniques for predicting performance; (2) questions regarding the level of conservatism underlying the acceptance criteria; (3) an inability to reliably and economically apply performance-based procedures to the design of new buildings; and (4) the need for alternative ways of communicating performance to stakeholders that is more meaningful and useful for decision-making purposes. These limitations prompted the development of next-generation performance-based procedures.

In the FEMA P-58 methodology, seismic performance is characterized on a probabilistic basis in terms of the potential for incurring damage and resulting losses in the form of repair costs, repair time, casualties, unsafe placarding, and environmental impacts. The general methodology and recommended procedures can be applied to seismic performance assessments of new or existing buildings of any type, regardless of age, construction, or occupancy.

Implementation of the methodology requires basic data on the vulnerability of structural and nonstructural components to damage (fragility), and information on the impacts resulting from that damage (consequence), which can be used to: (1) assess the probable performance of a building; (2) design new buildings to be capable of providing desired performance; or (3) design seismic upgrades for existing buildings to improve their performance.

1.2 Phase 2 Purpose and Objectives

In 2012, FEMA funded work under Phase 2 to utilize the FEMA P-58 series of products and supporting materials (developed under Phase 1) to develop performance-based seismic design guidance including assistance in selection of appropriate performance objectives, systems, configurations, and structural characteristics to meeting these objectives in regions of varying seismicity. Phase 2 also includes work with stakeholders to determine effective methods of communicating seismic performance. This information will be used to shape the development of a series of products that:

- Assist decision-makers in selecting appropriate performance objectives for buildings of different occupancies;
- Assist design professionals in identifying appropriate strategies for structural design of buildings to achieve specified performance objectives;
- Assist design professionals in developing efficient preliminary designs that will achieve specified performance objectives and require relatively little iteration during the design process;
- Quantify the performance capability of typical buildings designed to current prescriptive building codes to assist in development of code-equivalent performance objectives, identify inconsistencies in current prescriptive codes, illustrate the inherent limitations of prescriptive codes, and demonstrate the advantages of performance-based design; and
- Provide guidance on simplified design of buildings to achieve different performance objectives.

As part of this work, Phase 2 is also planned to: (1) exercise the FEMA P-58 methodology and identify needed improvements, if any; (2) enhance the methodology to estimate environmental impacts and potential loss of function associated with earthquake damage; (3) benchmark the performance of typical code-confirming buildings utilizing next-generation performance matrix; (4) interact with stakeholders to tailor design guidance to better suit current decision-making needs; and (5) develop training materials to assist in implementation.

1.3 Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design

This *FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design* is the second in a series of planned Phase 2 interactions with stakeholders. The first workshop, held early in the Phase 2 developmental process (2013), was attended by building owners and developers of various types, as well as corporate and institutional building managers, architects, building, officials, insurers and lenders, and was used to establish a framework and vocabulary for interaction between decision-makers and design professionals to facilitate seismic risk communication and provide insight into building performance expectations. Findings from the 2013 workshop are presented in ATC-58-4, *Proceedings of FEMA-Sponsored Workshop on Communicating Seismic Performance Metrics in Design Decision-Making* (ATC, 2014).

The purpose of this second workshop was to gather input from practicing structural engineers on key issues associated with implementation of performance-based seismic design using the FEMA P-58 methodology, including: (1) communicating performance objectives and performance expectations to owners; (2) preferences on performance-based design tools and guidance; and (3) insight on the typical characteristics associated with code-compliant seismic-force resisting systems.

Workshop findings will be used to guide the development of the methodology for the studies and the Phase 2 engineering guidance products.

Chapter 2

Workshop Program

A one-day *FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design* was held in San Francisco, California on August 14, 2014. This chapter summarizes the workshop program and describes the structure of the workshop sessions.

2.1 Workshop Overview and Agenda

The workshop was broadly organized into three parts, as shown in Figure 2-1: (1) discussion of communicating seismic performance objectives and expectations to building owners; (2) presentation and discussion of design tools and guidelines; and (3) presentation and discussion of bounding the design space. The workshop concluded with a summary of the discussions and final advice to the project team.

To allow participants time to consider the key issues to be covered in the workshop, materials distributed before the workshop included discussion topics in the form of questions for each of the key issues. Due to time constraints, not all of the discussion topics could be covered in-depth at the workshop.

Workshop discussions were structured to:

- Develop an understanding of how structural engineers determine an owner's performance expectations and objectives;
- Gain new insights into how structural engineers relate the probable performance of buildings to the owner;
- Understand how structural engineers deal with uncertainty when discussing performance with a building owner;
- Collect information on performance metrics that are meaningful to a building owner;
- Identify the types of design aids that would assist structural engineers in communicating performance-based design concepts to architects and owners;
- Develop ideas for aids structural engineers desire to facilitate implementation of FEMA P-58 in design;

ATC-58-2 Project

Invited Workshop on
Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design

August 14, 2014
9:00 am – 4:00 pm

Simpson Gumpertz & Heger, Inc.
100 Pine Street, 17th Floor
San Francisco, CA

Objectives: This workshop will be used to gather input from practicing structural engineers on key issues associated with implementation of performance-based seismic design using the FEMA P-58 methodology, including: (1) communicating performance objectives and performance expectations to owners; (2) preferences on design tools and guidance for use in performance-based design; and (3) insight on bounding the range of strength and stiffness characteristics associated with code-compliant seismic-force resisting systems.

Time	*Subject*	*Leader*
9:00 am	Introductory remarks and self-introductions	Jon Heintz, All
9:15 am	An Overview of the FEMA P58 Methodology	Ron Hamburger
10:00 am	Goals of the ATC-58-2 Project	Ron Hamburger
10:15 am	*Discussion* – Communicating performance objectives and performance expectations to owners • How do you determine an owner's performance expectations and objectives? • What types of projects and clients are concerned with seismic performance? • When in the design does this discussion occur? • How do you relate the probable performance of the building to the owner? • Who participates in these discussions? • How do you deal with uncertainty when discussing performance with an owner? • What performance metrics are meaningful to an owner?	John Gillengerten
10:45 am	Design Tools and Guidelines	Vesna Terzic
11:15 am	*Discussion* – Design Tools and Guidelines • Would design aides make implementing performance-based design easier? • Would you use design aides? • What type of design aides would be most helpful?	John Gillengerten/ Vesna Terzic

Figure 2-1 Agenda of FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design.

	• What types of buildings (occupancy, risk category) would design aides be used for? • Would you prefer an integrated approach to design aides that: (1) guides selection of design criteria for systems and components; or (2) provides information on the performance of systems and components, given a drift or PGA? • Would design aides for nonstructural performance help improve implementation of nonstructural bracing and anchorage by individuals responsible for specifying/designing such items? • What type of information can be shared with non-engineers? • If an owner/client is not interested in seismic performance, would you still use performance-based design aides to guide decisions?	
Noon	Lunch (provided)	
1:00 pm	Bounding the ASCE /SEI 7-10 Design Space	David Bonneville
2:00 pm	*Discussion* – Bounding the ASCE /SEI 7-10 Design Space • How much influence do you have on: selection of the lateral system; number and spacing of lateral system elements; presence of irregularities; drift targets and design base shear? • What controls the design of the lateral system? • Where there are choices in ASCE 7 design procedures, which are chosen and why? • ASCE 7 provides minimum requirements for strength and stiffness. What are realistic upper bound configurations for different systems (e.g., moment frames; braced frames; shear walls; light frame structures)? • In light frame structures, is the whole building sheathed, or just the designated shear walls? • Which systems should be investigated with bounding studies? • Is SSI used to reduce base shear? • What are typical assumptions for: redundancy (rho); panel zone stiffness; cracked section properties; foundation fixity; effective spans of beams; effective lengths of braces?	John Gillengerten/ David Bonneville
3:45 pm	Summary/Wrap up	Ron Hamburger
4:00 pm	Adjourn	

Figure 2-1(cont.) Agenda of FEMA-Sponsored Workshop on Design Guidelines and Tools to Implement Next-Generation Performance-Based Seismic Design.

- Identify realistic upper bounds for strength and stiffness for typical buildings designed to the requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010); and
- Develop an improved understanding of the influence structural engineers have on the selection of building attributes that impact seismic performance such as selection of the lateral force-resisting system and the presence of structural irregularities.

In addition to 14 project team members, 13 invited participants attended the workshop representing 13 different structural engineering firms. Invited participants are all practicing structural engineers. Most are at the project manager level, and routinely deal with architects and owners in the design process and are familiar with both the details of structural design as well as the bigger picture conceptual concerns of the project team. Appendix A provides a list of participants and their affiliations.

2.2 Morning Session and Discussions

At the outset of the morning session, project team members set the context for the workshop and provided an overview of the FEMA P-58 methodology and the goals of the ATC-58-2 project. Appendix B presents visual aids used in the overview presentation.

Following the introductory presentations, all workshop participants were asked to respond to a series of questions on how they communicate seismic performance objectives and expectations to building owners. These discussions are summarized in Section 3.1.

The next session introduced alternative design aid and guideline concepts. When fully developed, these tools could be used to help the design teams and owners set performance objectives, select from different lateral force-resisting systems that would deliver the desired performance, and guide selection of design criteria for nonstructural systems and components to limit losses (e.g., repair cost, downtime, and unsafe placard). Team members showed participants conceptual graphical presentations of different types of design aids that could be used to assess seismic performance as a function of building drift and ground shaking intensity. Figures 2-2 and 2-3 show sample design aids presented. Appendix B provides visual aids used in this presentation. Following the presentation, workshop participants discussed questions posed by the project team. These discussions are summarized in Section 3.2.

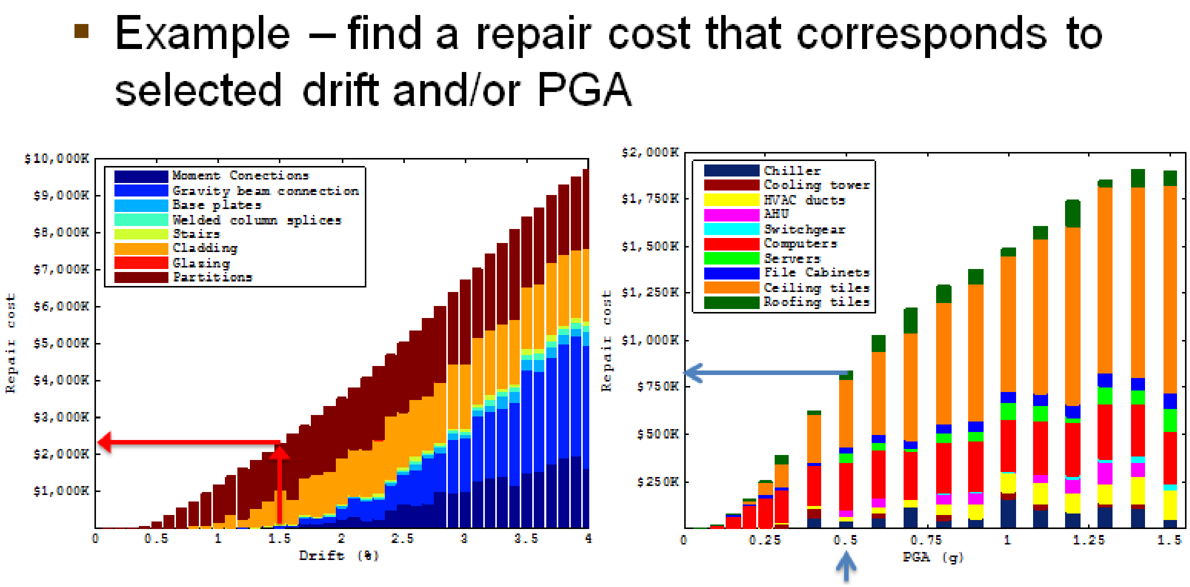

Figure 2-2 Sample design aid relating expected repair cost to drift and ground motion intensity.

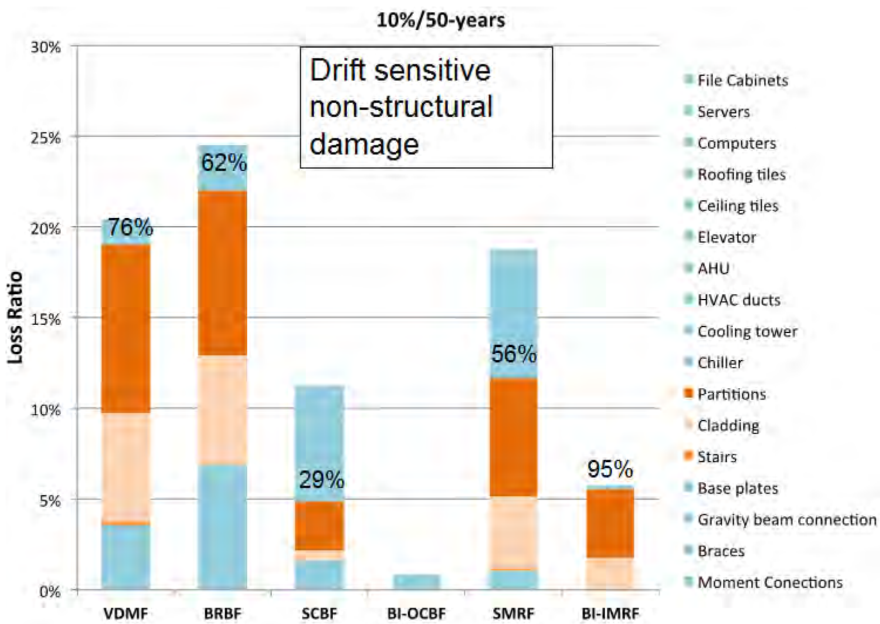

Figure 2-3 Sample design aid showing damage to drift sensitive components for different lateral force-resisting systems for a particular site subject to an earthquake with a 10% probability of exceedance in 50 years.

2.3 Afternoon Session and Discussions

In the afternoon session, project team members presented an overview of the concept of a design space for seismic design of code-compliant buildings. The design space for a particular seismic force-resisting system encompasses the likely range of lateral strength and stiffness combinations that code-compliant designs may have. Figure 2-4 shows a graphical depiction of a possible design space for low-rise steel special moment-resisting frame structures. In the figure, lateral yield strength (% g) is presented on the vertical axis and design story drift (%) on the horizontal axis. Each point represents a study model, designed to comply with current code. Different points were obtained by varying design parameters, such as bay spacing, number of bays of moment frame, and estimated period. The shaded portion shows one possible design space for this lateral force-resisting system.

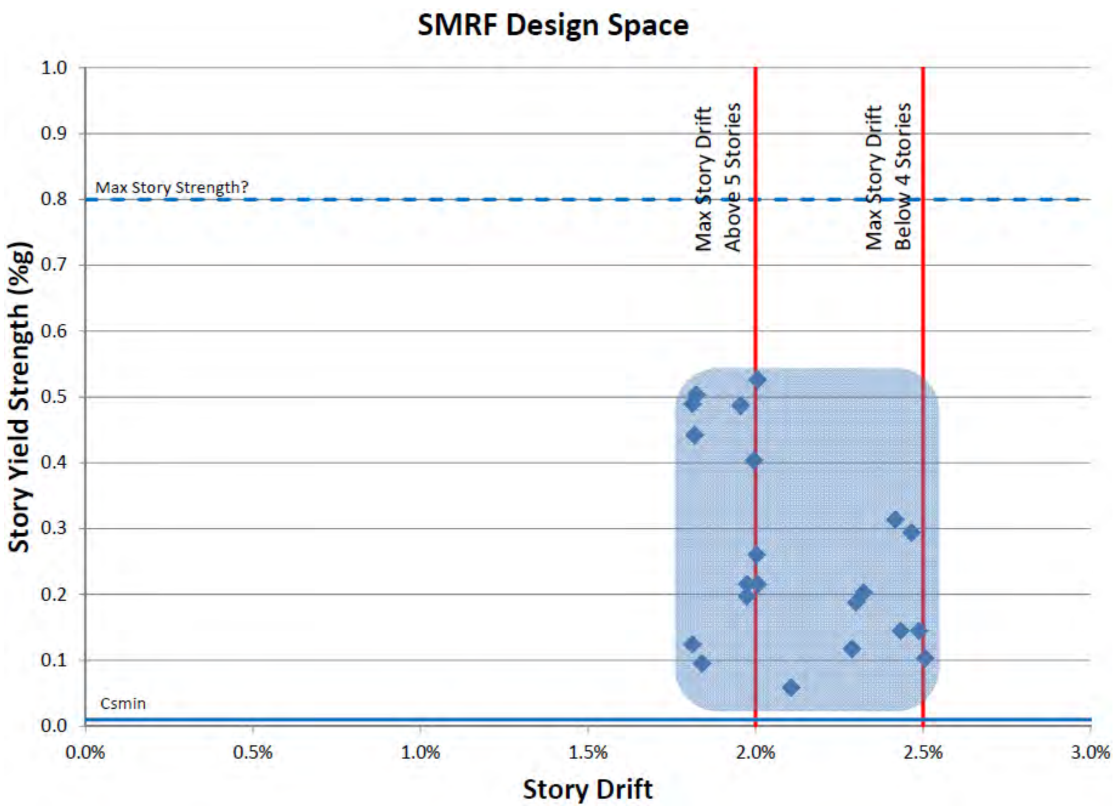

Figure 2-4 Possible seismic design space for steel special moment-resisting frames.

Appendix B provides visual aids used in this presentation. Following the presentation, workshop participants discussed questions posed by the project team. These discussions are summarized in Section 3.3.

In addition, at the close of the workshop each participant was asked to provide one piece of advice to the project team. The responses are summarized in Section 3.4.

Chapter 3

Workshop Findings and Conclusions

This chapter summarizes key points raised in each session of the workshop, followed by a summary of overarching findings and conclusions drawn from the discussions.

3.1 Communicating Seismic Performance Objectives and Expectations to Building Owners

During this session, workshop participants discussed the challenges associated with communicating seismic performance concerns to building owners.

3.1.1 What Types of Projects and Clients Are Concerned with Seismic Performance?

- Institutional clients and those that hold buildings for longer periods of time tend to be more interested in seismic performance. Speculative developers and those who tend to hold their buildings for a short time are generally not interested in seismic performance. Their focus is more toward meeting a minimum standard of care or practice, or the legally defined performance standard (i.e., the building code). Although there are developers who care about tenants, there are others who only care if they believe they might be held liable for poor seismic performance.
- The performance metrics that resonate with clients depends on the stakeholder. For educational facilities, the concern is for the safety of the students. For example, a university in the San Francisco Bay Area has retrofitted their student dormitories to protect their students. Although developer concerns are generally driven by cost, they may be interested in enhanced seismic performance if it can be marketed to potential tenants. Data centers and high-tech manufacturing firms are interested in minimizing the potential for business interruption. One client base isolated items critical to their operations to reduce the chance of business interruption.
- Even clients with a high interest in seismic performance are driven by the “value proposition,” which is based on the cost of performance enhancements versus the perceived benefits obtained.

3.1.2 How Do You Determine Owner Performance Expectations and Objectives?

- Engineers often rely on their personal relationships with the owner or architects to frame their understanding of the clients' performance expectations. They know what the client is interested in, and may not discuss seismic performance if they believe the client is uninterested.
- Some workshop participants use words and images of buildings in different damage states (e.g., collapse prevention) along with potential methods to reduce losses to describe performance options to clients.
- Most owners assume they are safe if their buildings comply with current codes and standards. For special or unusual projects, there may be additional discussion with the client about seismic performance.

3.1.3 When in the Design Does the Performance Discussion Occur?

- Many in the group indicated that if a discussion occurs, it is early in the design process (at Schematic Design level).
- Some participants indicated that they enter the discussion about performance during value engineering, which often occurs at about 50% Design Development. The firm may include performance-based design services in their proposal, either as value engineering or as an enhanced performance alternative.
- Another opportunity may arise during the due diligence phase, where the benefits of exploring performance-based design options can be considered.
- Many participants stated that it is important to raise seismic performance issues early in the design process. A discussion ensued as to whether "early" is the ideal case, or if it really even happens that way since participants in a stakeholder workshop held earlier in the project stated that the structural engineer is not even involved in the design process early on. It was noted that at one educational facility, seismic program decisions about performance goals are made for all buildings prior to design work on any of them.
- A straw poll was conducted regarding the percentage of design projects performed by the participants where the engineer is selected by the developer/owner (and not the architect). Figure 3-1 presents the results of this informal survey. The poll indicates that approximately half of the time, engineers are engaged in projects by the owner/developer.

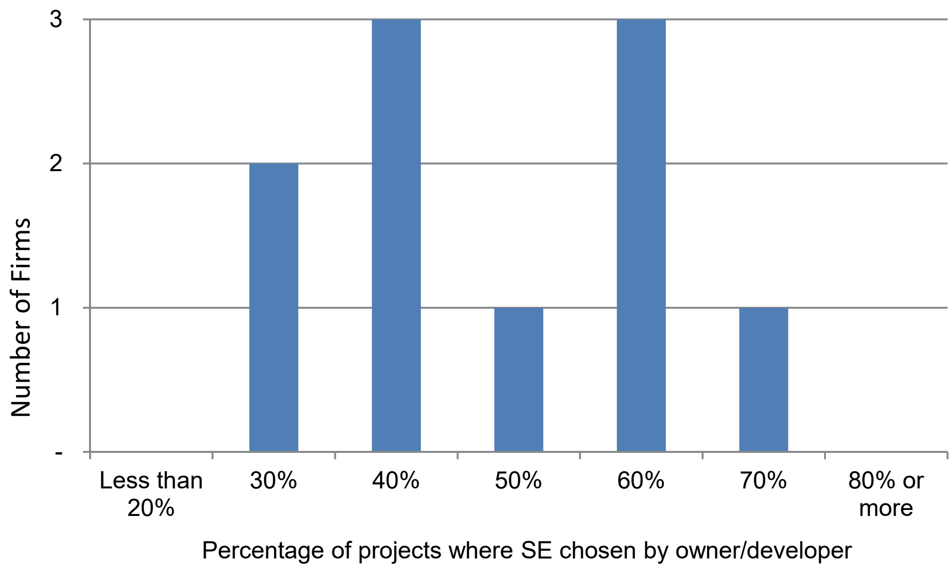

Figure 3-1 Percentage of projects where the structural engineer is selected by the owner/developer.

3.1.4 How Do You Relate Probable Seismic Performance of the Building to the Owner?

- One participant gave an example of working for a developer through an architect and giving estimates of downtime and some cost estimates. The feedback was positive, and the developer was very interested in high-performance buildings.
- Several participants noted that they utilize the vocabulary set forth in ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014), to describe performance because it is widely used and is incorporated in a standard. This is despite the observation of the participants that owners do not understand the descriptions of performance targets in ASCE/SEI 41; however, the terms used provide an opportunity to further explain the concepts. Several participants noted that they express uncertainty in some way when communicating with owners.
- The participants noted that calculation of losses is rarely expected and is only done by a few engineers. Almost all of the participants expressed that they "hedge their bets" with language that implies a range of possible performance outcomes.

3.1.5 Who Participates in These Discussions?

- The responses indicated a range: the number of individuals can vary greatly, from a whole room of 20-25 people to a single person. The process often starts with everyone and then ultimately reduces to a manager or decision-maker. As the process drills down into greater detail, the discussions include fewer people. It is most critical that the decision-maker is there. For larger projects, it is important that the peer reviewer and building department are also included.

- One participant recalled a meeting held after the decision was made to pursue enhanced performance objectives. In this case, the group included almost the entire design team: the owner, architect, structural engineer, mechanical electrical plumbing (MEP) consultant, and contractor. In recent follow-up meetings the owner also included the insurer to see if insurance costs could be reduced.

3.1.6 How Do You Deal with Uncertainty When Discussing Performance with an Owner?

- The majority of the participants (70%) express performance uncertainty to their clients in some way. Some of the participants use terms such as "likely" and "unlikely" when discussing performance with clients, and feel that their clients understand that estimating seismic performance is not an exact science. One participant who does not discuss uncertainty with his clients protects himself legally by designing to a standard of care.

- Some participants express performance in terms of chance of meeting or missing a performance objective.

3.1.7 What Performance Metrics Are Meaningful to an Owner?

- The participants expressed that performance metrics should relate to safety (dictated by the building code) and costs (losses) associated with the earthquake damage. Owners care about downtime more than losses; while insurers and lenders are more concerned about financial loss aspects. The performance metric of interest depends on the occupancy.

- Seismic performance is currently dominated by the "value proposition." Performance enhancements are judged on the perceived value that is obtained, in reduced downtime or lower repair costs. The "opinions of experts" do not carry much weight; and the cost-effectiveness of enhanced performance measures must be established by more actuarial-type information to be believable.

3.1.8 What Types of Earthquake Losses Are of Most Interest?

This question was posed in reference to scenario-based losses (e.g., 1906 San Francisco earthquake), intensity-based losses (e.g., 50% probability of exceedance in 50 years), or annualized losses (i.e., average annual repair cost over a specified period).

- The participants expressed that scenario-based losses are often better for communicating performance to clients. Some clients find probabilistic estimates difficult to understand and find scenario-based assessments (e.g., a repeat of the Loma Prieta Earthquake) easier to relate to. Intensity-based assessments are also important because they can be related to building code requirements. It was noted that seismic demands used in assessment are different for new and existing buildings.
- Scenario-based assessments are useful for areas where a single-earthquake scenario is appropriate (e.g., the San Francisco Bay Area). For areas such as Los Angeles that have several faults capable of generating large earthquakes, intensity-based assessments and annualized losses may be more suitable.
- In general, the participants expressed that there may be a difference between how a risk analysis is done and how the results are communicated to the stakeholder. Many participants agreed that intensity-based assessments are needed for design but scenario-based assessments are useful for communication of the results.
- The participants discussed the usefulness of scenarios using lower than the Design Basis Earthquake (DBE). For some types of structures serviceability is an important criterion. For example, high-rise condominiums are often checked for serviceability using an earthquake with a 43-year return period. Some participants expressed that the decision depends on whether they are studying a new or an existing building. For new buildings, they might just look at the DBE; while for existing buildings, they might include other shaking intensities as well.
- The participants were asked if they have encountered insurers who say they care about the loss values for a single building. It appears to depend on the insurer. Some participants stated that the insurer might be interested in loss studies for high-value buildings, such as major structures in San Francisco that could have a significant loss impact. In general, though, the insurers just absorb potential losses for these buildings into a large portfolio. It was also noted that insurers probably do not trust engineering predictions.

3.2 Design Tools and Guidelines

In this session, the workshop participants reviewed sample design aids. The samples are shown within the presentation in Appendix B. These aids have a number of potential uses, including communicating expected seismic performance expectations to owners and clients, aids for selecting lateral force-resisting systems and nonstructural components based on desired seismic performance objectives, and the relative contribution of different building components to seismic performance. The workshop participants discussed the types of informational aids that would be most useful for communicating performance-based design concepts.

3.2.1 Is There a Need for Design Aids to Implement Performance-Based Design, and How Would They Affect How You Do Your Work?

- The participants expressed that design aids are needed. Several participants are already using design aids that they have developed in-house. They would like the design aids to be consensus based. Young engineers with a good understanding of probability and statistics can help with early adoption of the design aids and the FEMA P-58 methodology in general.

- Several participants stated that eventually performance-based design (PBD) aids will need to be developed into a standard of care and legal standard. A discussion about early adopters of the methodology followed: Would people use the PBD design aids before it becomes the standard of care? Some of the participants have developed similar in-house tools for preliminary design, where they are particularly useful for system selection. Other participants would have an issue with making the FEMA P-58 methodology the standard of care until it is better vetted. Overall, the design aids were seen as valuable tools for improved seismic design.

- The participants felt that it was most important to focus on the 99.9% of buildings that are designed by code (and not by PBD). They expressed a need for some conservatism embedded in the design aids, so when PACT assessment is conducted at 50% Design Development level, the losses are not higher than the initial estimate made using the design aids. To aid in assessing the expected accuracy of the method, it would be good to report the dispersion of losses along with median estimates.

- Some participants said they would likely run PACT before giving the owner any numbers related to performance. Early adopters of the FEMA P-58 methodology are running PACT already.

- Design aids that give information about the big-picture initial decisions regarding structural system selection and nonstructural component performance are considered useful. Design aids can drive the development of the structural design in positive ways, even if the exact level of improvement caused by a change in the design cannot be quantitatively described.

- Tools for early adopters that help explain why PBD is important would help make a case for performing the studies.

3.2.2 Which Design Aids Make Implementing Performance-Based Design Easier?

- The participants stated that all of the design aids presented would be useful and would serve as a great introduction to the FEMA P-58 methodology for the industry.
- When asked if they would prefer a collection of different plots and charts or an electronic tool ("mini-PACT"), the participants agreed that mini-PACT would be useful to help with making decisions early in the design process, e.g., help with selection of lateral force-resisting system. Mini-PACT could use standard occupancy models, provide a tool that allows input of basic structural system data and occupancy, and report median results. Charts would also be useful for such information. Tools that help make a case for which lateral force-resisting system to use would be useful.
- The level of detail ("resolution") in the design aids was discussed. An overall concern was expressed that having too much information, at too high of a resolution, may present a barrier to it being useful. Instead, tools that expose stark differences in performance are needed. These can allow the engineer to provide information to support decision-making and then let a user zoom in, if necessary. Simplicity of the inputs and outputs are most important; simplicity of the algorithms is less important, because it is not visible.
- Downtime is often more important than losses. If an owner asks for a specific level of downtime (e.g., one week), what is an acceptable range, is one month acceptable? Some participants noted that they had entered into design contracts to provide this kind of a performance target. In some cases, the absolute numbers matter (e.g., probable maximum loss (PML) and insurance) and in other cases absolute numbers are not important, and relative comparisons suffice.
- The types of information that should be included in the design aids were discussed. Graphically rich presentations with photographs that include cost comparisons for different lateral systems were preferred. These would be effective for sharing PBD concepts with architects and owners. The cost comparisons should be in relative terms, rather than absolute

numbers, and can be done graphically. The design aids should be clearly benchmarked to the performance provided by code-compliant structures. When simplifying the FEMA P-58 methodology either for design aids or "mini-PACT," it should not add conservatism to the answer (i.e., the median reported results should be the same one would get from PACT). The higher variability in the output results due to the lack of details should be reported and lack of uncertainty should be documented.

3.2.3 How Large a Range of Performance Measures (10th to 90th Percentile) Are We Willing to Accept?

- Many participants expressed that the range of predicted performance measures (uncertainty) depends on how the results are used and presented. A poll on the desired range of uncertainty was conducted. The participants were asked if they would use the FEMA P-58 methodology if the range of the 10^{th}-to-90^{th} percentile results varied by ±30%, ±50%, ±100%, and ±200% from the median. The example assumed a median downtime of 100 days. The participant responses presented in Figure 3-2 show that most of participants were willing to report FEMA P-58 downtime predictions if the variation from the median downtime was ±50%, but only few would report it if the variation from the median downtime was ±100%. A typical response to the question of accuracy in predicting the losses was that they would never report an answer without a caveat that the result is based on FEMA P-58. The ability to report the uncertainties (rather than just reporting a median value) was judged to be very important.

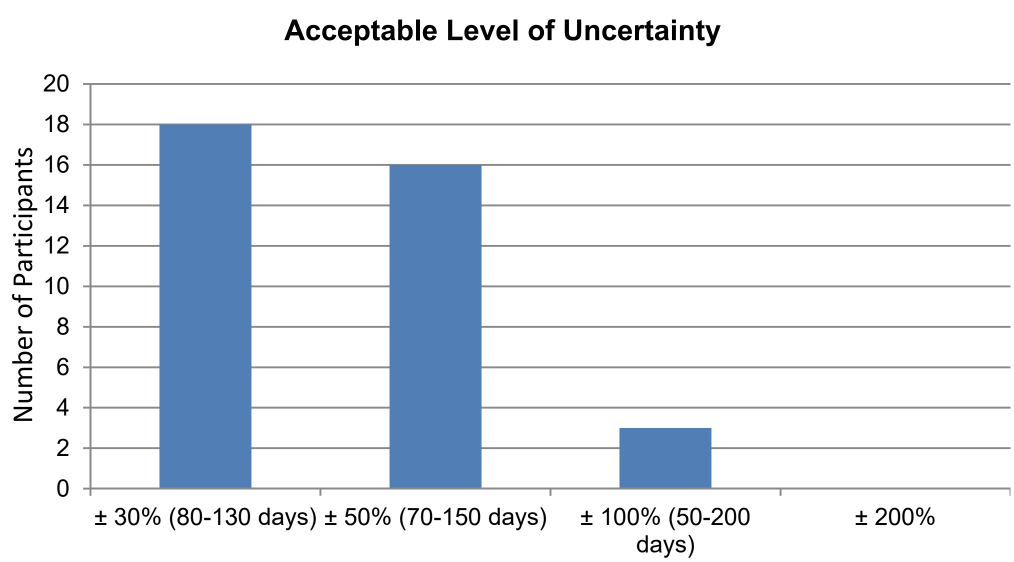

Figure 3-2 Number of participants who would use the FEMA P-58 tool, given different ranges of downtime (10^{th}-to-90^{th} percentile results) predictions.

3.2.4 Would Design Aids for Nonstructural Performance Help Improve Implementation of Nonstructural Bracing and Anchorage by Individuals Responsible for Specifying or Designing Such Items?

- Seismic design of nonstructural components is often outside the structural engineers' scope of work. As an example, a participant noted that they select the structural system, calculated seismic demands for the curtain walls, and then tell the component designer or subcontractor to accommodate the demands.

- It was noted that there are few ways for the structural engineer to affect seismic design of nonstructural components. It often comes down to the structural engineer trying to influence the architect to specify higher performing nonstructural components. The structural engineer can include the nonstructural bracing requirements in their specifications to ensure that installation of the components is done correctly. It was suggested that model specifications for seismic design of nonstructural components for different performance objectives can be created as design aids. It is important to include information on the cost differentials associated with specifying different performance levels. Another approach would be to provide design aids for use by the individuals in charge of the seismic design of the components.

3.2.5 Would You Prefer an Integrated Approach to the Design Aids that Guides You through a Process of Selecting the Structural System and Nonstructural Criteria, or Aids that Provide Information on Component Performance, Given a Drift or Peak Ground Acceleration?

- The general consensus of the group was that both approaches would be useful. The integrated approach to design aids would guide selection of design criteria for systems and components (i.e., how to design if a specific performance objective is given). The component performance approach provides information on the performance of systems and components given a drift or peak ground acceleration, and could be used to guide component selection if the structural design is already set. When asked which approach would be preferred if only one is available, the integrated approach was thought to be most important, but "…we still want it all."

3.2.6 If an Owner or Client Is Not Interested in Seismic Performance, Would You Still Use Performance-Based Design Aids to Guide Decisions?

- A number of participants said they would use the design aids, especially for special projects.

- Some participants noted that the information in the design aids could be used to shift paradigms, e.g., to illustrate whether a ductile structure is better than stiffer one.

3.3 Bounding the Design Space

In this session, workshop participants discussed bounding of the design space that will be used to benchmark the performance of buildings in compliance with ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), using the FEMA P-58 methodology. The types of lateral force-resisting systems to be studied were identified, and the design decisions that influence the seismic behavior of different types of structures were discussed. The presentation slides related to this discussion are provided in Appendix B.

The design space is illustrated in Figure 3-3.

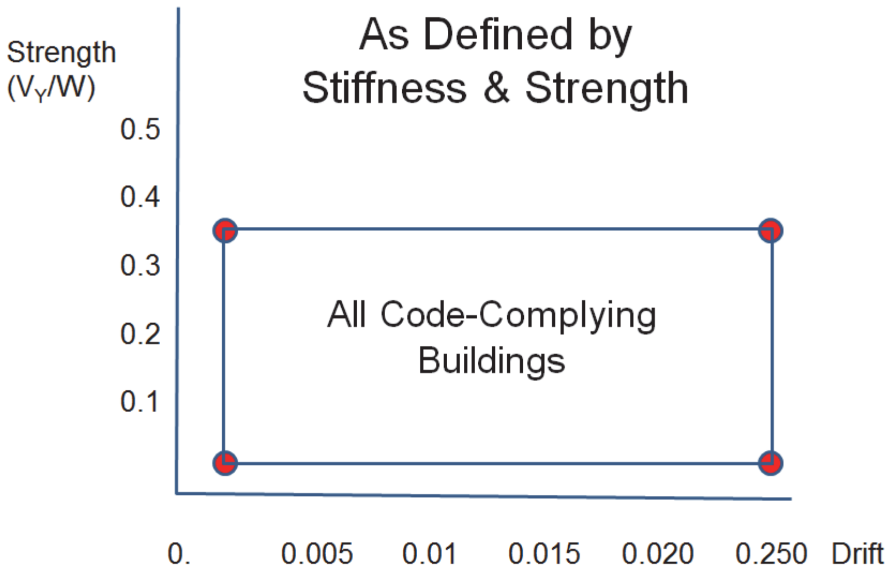

Figure 3-3 Illustration of design space and illustrative boundaries.

3.3.1 *Which Lateral Force-Resisting Systems Should Be Investigated in The Bounding Study?*

- Buckling-restrained braced frames (BRBF) should be included. These steel structures are designed closer to the drift limit compared with conventional braced frame systems such as special concentric braced frames, because the designer has the ability to precisely size the brace capacity.
- Eccentric braced frames (EBF) should not be included. Although this system is still used occasionally, it has been largely supplanted by the BRBF. It is still sometimes used for shorter buildings or in cases where

diagonal or chevron braces would interfere with openings. It was noted that the response of an EBF structure might be very similar to that of a BRBF structure.

- Steel and concrete moment-resisting frames should be included. On the west coast, steel moment-resisting frame structures are much more common than concrete moment-resisting frame structures. Only special moment-resisting frames (SMRF) should be considered. These structures are designed for a broad range of story drifts, from 1% to 2.5%. Drift targets are set by Seismic Risk Category, but in some cases buildings are designed for story drifts as low as 1% to protect curtain walls.
- Concentric braced frames should be included. Ordinary concentric braced frames (OCBF) systems are sometimes used for low-rise steel structures. Special concentric braced frames (SCBF) are more common.
- Light frame construction should be included. It was noted that most residential construction may be governed by the *International Residential Code* rather than ASCE/SEI 7-10.
- Special reinforced concrete shear walls (SRCSW) should be included. The participants suggested that squat and tall shear wall structures, frame and bearing wall structures, and coupled and uncoupled shear walls should be investigated. Tilt-up structures should also be considered.
- Special masonry shear walls (SMSW) should be included. This system is commonly used for low-rise retail-type structures and mid-rise hotels. It was noted that there will be many similarities between SMSW and SRCSW structures.
- Base-isolated structures should be included. The participants noted that this is a preferred approach for structures that must remain operational following an earthquake.
- Damped systems should be included. Adding damping devices to a structure can be a simple method of improving the design.
- Dual systems should not be included. Dual systems are generally not used for buildings less than 12 stories tall.
- It was suggested that it may be possible to group similarly behaving systems into categories and streamline the benchmarking process.
- It was also noted that the benchmarking effort is constrained by the limitations of the FEMA-P-58 analysis method. For example, the

distinctions between rigid and flexible diaphragm structures are not captured.

- The participants recommended that if foundation flexibility (piles versus rocking) and soil-structure interaction are considered, they should be evaluated separately.

- A question was raised whether the performance evaluations will be based on building drifts calculated using C_d (linear elastic analysis per ASCE/SEI 7-10), or based on the "real" drift. It was noted that although the code design is based on C_d, the FEMA P-58 assessment is based on the actual expected drift (simplified analysis procedure of the FEMA P-58).

3.3.2 What Controls the Design of the Lateral Force-Resisting Systems for Code-Designed Buildings Less Than 12-stories Tall?

- Steel SMRF: The participants indicated that steel SMRF structures are always drift controlled. Several of the firms represented use design drifts lower than those permitted by code to improve performance. The configuration of the frames is sometimes constrained by limits on beam depth-to-span ratios.

- Concrete SMRF: These structures are less likely designed right up to the code drift limits. Strong column/weak beam requirements and moment frame joint shear limits heavily influence the proportions of the system. The axial load ratio in columns also influences the proportions of the structure. Some firms use an axial load ratio of $0.4A_gf'_c$, but this is office-dependent; some participants felt that a ratio of 0.4 is too high.

- Braced frames: The participants generally use the minimum number of braced bays, which foundation design issues including uplift may govern. The diaphragm design also influences the number of braced bays. These buildings are typically designed using a fixed foundation assumption.

- Shear wall buildings: Depending on the building configuration, shear wall buildings often have more wall length than needed to meet the seismic design requirements. Shear wall building design can be controlled by shear strength or flexural strength, depending on how the engineer approaches the design. An important design consideration is selection of the cracked section properties for analysis. Some of the ratios of the cracked versus gross stiffness EI_{eff}/EI_g used for analysis are: 0.8 for a serviceability check for shear walls subject to an earthquake with a 43-year return period, 0.5 to 0.8 for code wall design (some firms go as low as 0.35), and 0.15-0.20 for design of coupling beams.

- Most of the structural systems are designed using the modal response spectrum analysis method. Light frame and small (low-rise) buildings may be designed using the equivalent lateral force procedure. Nonlinear response history procedures are used for BRBF structures, and may be used for concentric braced frames to control the size of columns.
- With regard to foundation design, soil-structure interaction is not usually considered for new code-designed buildings, although some participants routinely consider it in their designs. An exception is steel braced frame structures and shear wall structures, where the lateral system may be allowed to rock. Some firms design strong foundations, while others utilize ductile elements such as grade beams.
- There was a general sentiment that when the building period exceeds about 1.5 seconds in areas of high seismic risk, site-specific hazard analysis should be required. Mapped hazard values are otherwise used for design. Site-specific hazard analysis is not used except for large, important projects like university buildings, critical corporate office buildings (even if they are low-rise), and buildings taller than around 240 feet.
- Building period calculations for lateral analyses are based on a computer model for all but light frame or very simple structures, and subject to the upper limits on period in ASCE/SEI 7-10. The alternative period formulas for moment-resisting frame and shear wall structures are generally ignored. The simplified period formulas are used for light frame design, since these buildings rarely modeled on the computer.
- The participants were asked if they consider the floor and roof slab systems in the modeling and design of the structure. None of the participants consider it. It was noted that by not considering such items, losses are overpredicted.
- For buildings with a rigid podium structure and a flexible upper portion, the two-stage analysis permitted in ASCE/SEI 7-10 is used. It was noted the FEMA P-58 simplified method cannot be applied to these types of structures.
- Different aspects of building configuration were discussed. The participants try to avoid building configurations that trigger the need to apply a redundancy factor. The types of buildings that trigger the redundancy factor include buildings with torsional irregularities, core-only braced frames, and long rectangular buildings. The bay sizes for the

lateral system are usually set by the architectural design and for special moment frames by beam depth and strong column/weak beam requirements. The participants stated that in general, the shorter bay length, the better. For high-rise structures, the bay spacing is typically limited to about 20 feet.

- The participants discussed the influence of architectural layout on the seismic design. In shear wall structures, sometimes the architectural layout provides more walls than is needed. For example, big box buildings tend to have added strength. When the architectural design results in structural irregularities, the building tends to have extra strength. However, the participants felt that the influence of architectural layout was not worth investigating in this project.

3.3.3 How Much Influence Do You Have on Important Attributes of the Seismic Design, such as Selection and Configuration of the Lateral Force-Resisting System, Structural Irregularities, and Level of Conservatism?

- Participants expressed that structural engineers have a great deal of influence in the selection of lateral force-resisting system, although certain types of construction tend to result in certain choices. It was also noted that developers have a keen sense of the “proper” steel and concrete weights for the structural system, and that engineers must keep their designs in an acceptable range.
- Engineers will apprise the owner of the added costs of building features that result in structural irregularities, and let them decide if it is worth it. In the case of significant vertical irregularities, such as discontinuities and transfer girders, the engineer may be more forceful in arguing against them with a value judgment. It was noted that some types of irregularities are often unavoidable, such as having a tall first story.
- With regard to conservatism in design, each office represented has specific practices and standard details. Significant conservatism can occur as a result of the architectural design. Although this may potentially have an impact on design, the participants recommended that design conservatism not be considered specifically, since it is covered in the upper and lower bounds of strength and stiffness in the design space.
- In general, participants do not include the gravity system in the analytical model of the building. However, it was noted that neglecting the influence of the gravity system might be one of the reasons for overpredicting losses in smaller earthquakes. The gravity system may be included in the model in essential buildings such as hospitals.

3.3.4 What Are Realistic Upper Bound Combinations of Lateral Strength and Stiffness for Different Systems?

- ASCE/SEI 7-10 provides minimum requirements for lateral strength and stiffness. With regard to lateral strength, the simplified method in FEMA P-58 bounds the yield strength of the building as a function of the design base shear. The lower bound yield strength is taken as 1.5 times the design base shear and the upper bound is taken as Ω_0 times the design base shear. The participants expressed that the absolute minimum lateral yield strength of a structure would be the expected material strength divided by the capacity reduction factor, φ. This is approximately 1.5.
- The upper bound lateral strength could be 5 to 10 times of the minimum base shear strength for some structures (e.g., tilt-ups). The normal upper bound ratio for most cases is approximately 3.0.
- For drift-controlled moment frames, the yield strength will be related to Seismic Risk Category. Moment frames subject to lower allowable drifts will have significantly higher yield strengths.
- The upper-bound lateral yield strength of SCBF structures is often governed by the brace slenderness requirements that may result in a brace section with significant overstrength in tension. Also, since brace sections are rarely built-up, a larger size than needed for optimum design strength may have to be selected. Lateral yield strengths for SCBF structures were thought to be at least 2.5 times the design base shear. The participants stated that the design drift of typical SCBF structures rarely exceeds 1.25%.
- The participants stated that BRBF structures would be designed close to the limits for drift. The lateral yield strength is much closer to the code base shear than for other lateral force-resisting systems. Considering strain hardening, the lateral yield strengths for BRBF structures were thought to be 1.5 times the design base shear.
- For concrete shear wall structures, drift ratios rarely exceed 1.5%. The ratio of yield strength to design base shear was thought to be between 1.5 and 3.0. However, the yield strength could potentially be much higher if the concrete walls are used as the part of the building envelope.
- Light frame structures are designed using the equivalent lateral force method, considering only those wall elements that are designated as part of the lateral force-resisting system. The actual strength of these structures may be much higher if the rest of the walls (e.g., partitions) are considered. Most participants rarely check story drift when designing

light frame structures, and those participants that do, struggle to meet the drift limits.

3.4 Advice for the Project Team

At the close of the workshop, each of the participants was asked to provide one piece advice to the ATC-58-2 project team.

- The participants want to promote PBD and reduce barriers for using the procedures. Accordingly, the design aids and tools must be simple and user-friendly to be widely accepted. However, oversimplification can cause misuse.
- The design aids should be useful for communicating PBD concepts to those who may not have used it before. The challenge is to determine how best to communicate PBD concepts to the owner, helping them understand advanced design versus code design. Design aids and tools that allow the engineer to have a draft performance evaluation ready to show the owner "in a week" as a first cut are needed. The performance metrics produced by the design aids must be understandable to owners.
- The design aids need to be clear about what assumptions and uncertainties are embedded in their development. The possible conservatisms in the simplified methods must be quantified.
- Architects are a key player in promoting PBD, because they control the design of components, such as cladding and glazing that greatly influence seismic performance, and they interact directly with the owners. Workshops specifically targeted at architects can inform them of the important influence they have on seismic design, and equip them to market PBD to owners. Standardized architectural specifications covering enhanced design options for seismic bracing and anchorage for nonstructural components and systems would be useful.
- Benchmarking the design aids and tools to common practice is a key task, the results obtained from the procedures need to be consistent and repeatable between designers. Benchmarking the methodology to industry-standard PML procedures is also needed. Validating the procedures using actuarial-type data will help engage the insurance and financial industries.
- Being able to identify biggest loss drivers (e.g., partitions) would make a big impact. If optimization or sensitivity analysis can be built into the software, it can help identify what is important to performance.

- Guidance on the how to approach items that require judgment in PACT-type analysis is needed. If a design tool based on PACT is developed, it must be much simpler to use than PACT, and should allow the user to opt for a more complete analysis, at the price of higher complexity.

3.5 Overarching Findings and Conclusions

Key themes expressed throughout the day included the following:

- Decisions of clients on seismic performance are driven by the value proposition. Accordingly, a key to the acceptance of PBD is the ability to demonstrate that an investment in improved performance makes financial sense.
- Performance metrics need to be established by actuarial-type of information. Main performance metrics should relate to safety (dictated by the building code) and losses associated with the earthquake damage. The performance metric of interest depends on the occupancy. Losses related to downtime are of greater interest to building occupants and owners, and losses related to repair of the building are of greater interest to insurers and renters.
- It is important to express performance uncertainty to the clients so that they understand that estimating seismic performance is not an exact science.
- Seismic performance issues are best raised early in the design process.
- There is a need for the consensus-based design aids that need to be developed into a standard of care and legal standard.
- Design aids with simple inputs and outputs to expose stark differences in performance would provide useful information that support decision-making.
- Design aids should have optimization and sensitivity capabilities to identify the biggest drivers of losses and recommend possible design options that would minimize these losses.
- Design aids would benefit from graphically rich reports (outputs) that include charts and also photographs of the possible damage states. These results can be used to effectively communicate PBD concepts to architects and owners. It is necessary that the dispersion (or range of possible outcomes) is reported in addition to the median estimates of the losses.

- Workshops and products specifically targeted at architects are needed to inform them of the important influence they have on seismic design, and equip them to market PBD to owners.

3.6 Recommendations for Use of Workshop Findings and Conclusions

Recommendations for use of workshop findings and conclusions during Phase 2 project activities include the following:

- Design aids should be developed to provide loss estimates of the buildings designed to code-requirements and to provide guidance for the big picture initial decisions regarding structural system selection and nonstructural component performance to drive the development of the structural design in positive ways.
- Benchmarking the seismic performance of code-compliant buildings provides a baseline against which the benefits of PBD can be measured. Validating these benchmarks and benefits of PBD with actuarial-type data will improve the credibility of the methodology with owners and architects.
- The lateral force-resisting systems to be investigated should include: BRBF, SMRF, CMRF, OSBF, SCBF, light frame construction, SRCSW, tilt-up structures, SMSW, base-isolated structures, and viscously damped moment frames. Similarly behaving systems can be grouped into categories to streamline the benchmarking process to the extent possible.
- The benchmarking effort may be constrained by the limitations of the FEMA-P-58 simplified analysis method. The possible conservatism of the simplified method of FEMA P-58 used within the benchmarking study must be quantified.

Appendix A
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Appendix B

Plenary Presentations

B.1 Morning Session Presentations

B.2 Afternoon Session Presentations

ATC-58-2 Project

Design Guidelines and Tools Next-Generation Performance-Based Seismic Design

Invitational Workshop

San Francisco – August 14, 2014

FEMA P58 Overview & Workshop Goals

ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

History & Context

- ATC-58 was triggered by the profession's enthusiastic response to ATC-40 & FEMA 273/274
  - Application to New Buildings
  - Greater capability
  - Defined reliability

ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

Government Response

- FEMA-283/FEMA-349 Action Plans
- $30 Million program
  - Basic research
    - Analytical
    - Laboratory
    - Social Science
  - Guidelines Development
    - Engineering Procedures
    - Stakeholder's Guides

ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

ATC-58 Program

- Two-phased program
1. Development of Framework and Basic Performance-Assessment Engine
   – Completed in 2012
2. Development of Design Criteria and Stakeholders Guides
   – Presently underway

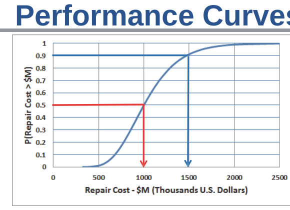
ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

FEMA P-58

- Probabilistic expression of performance:
  - Casualties
  - Repair Costs
  - Repair Times
  - Environmental Impacts
- Conditioned on:
  - Earthquake intensity
  - Earthquake scenario
  - All possible earthquakes

ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

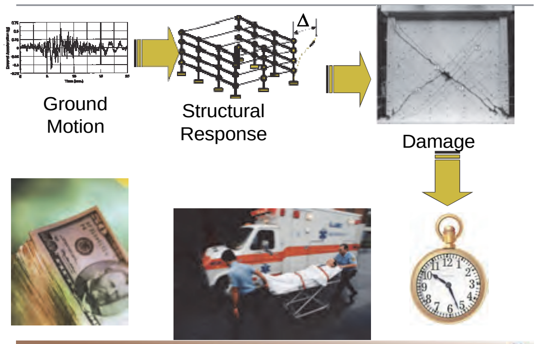
Performance Curves



- 50% probability that repair cost will not exceed $1M
- 90% probability repair costs will not exceed $1.5M
- Expected repair cost is $1.1M

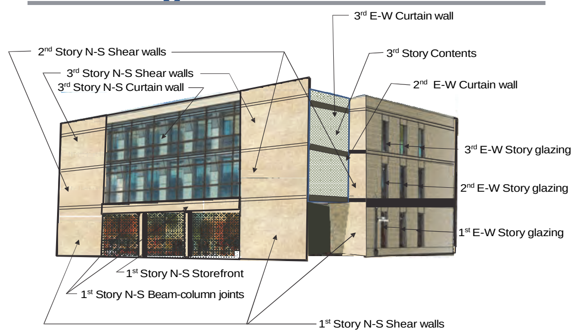
ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

Performance-prediction Process



ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

Building Performance Model



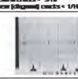
ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

Building Performance Model

- General Data
  - # stories, replacement cost, replacement time, cost indicies
- Fragility Groups
- Performance Groups
- Population Model
- Collapse Fragility

ATC Workshop on Design Tools and Guides for Next-Generation Performance-Based Design

Fragility Specifications

B1044.000 Reinforced Concrete Shearwalls			
[illegible]	Reinforced concrete and finishes both sides		
[illegible]	Square feet of wall area		
DAMAGE STATES, FRAGILITIES, AND CONSEQUENCE FUNCTIONS			
[illegible]	DS1 Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16"	DS2 Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8"	DS3 Max. crack widths > 3/8" Significant spalling/loose cover
[illegible]			
[illegible]	1.5%	3.0%	5.0%
[illegible]	0.2	0.3	0.4
[illegible]	70%		
[illegible]	Patch cracks each side with caulk; Paint each side	Remove loose concrete; Patch spalls with NS grout; Patch cracks each side with caulk; Paint each side	Shore; Demo existing wall; Replace; Patch and paint
[illegible]	[illegible] per sq ft up to [illegible] sq ft; [illegible] per sq ft over [illegible] sq ft; 0.2	[illegible] per sq ft up to [illegible] sq ft; [illegible] per sq ft over [illegible] sq ft; 0.3	[illegible] per sq ft up to [illegible] sq ft; [illegible] per sq ft over [illegible] sq ft; 0.3
[illegible]	days	weeks	months

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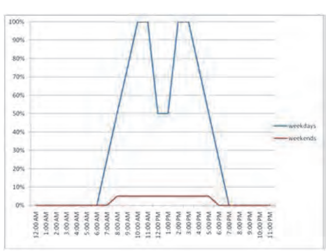
Population Models

- Common Occupancies
  - Office
  - K-12 Education
  - Healthcare
  - Residential
  - Retail
  - Laboratory
  - Warehouse
  - Hospitality



Peak occupancy =
1 person per X00 square feet

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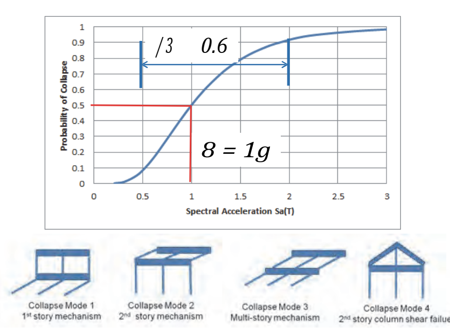
Collapse Fragility



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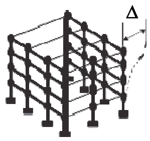
Analyze Building Response

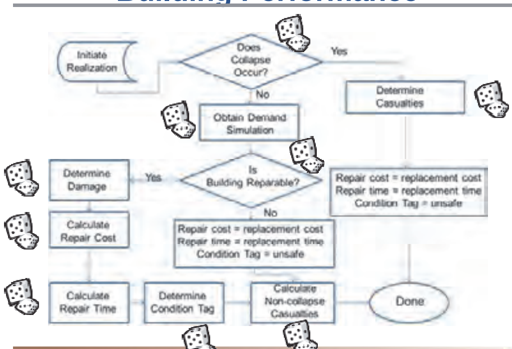


- Model structure
- Analyze
  - Nonlinear Response History Analysis
  - Simplified Linear Analysis (similar to ASCE-41 LSP)
- Predict median:
  - Story drifts
  - Floor accelerations
  - Floor velocities
  - Residual drifts
- Dispersions

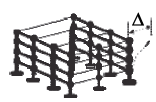
Calculate Performance

- Monte Carlo Process
- Hundreds to thousands of "spins"
- For each "spin" termed a "realization"
- Unique
  - Demands
  - Damage
  - Consequences

For Each Realization We Compute Building Performance

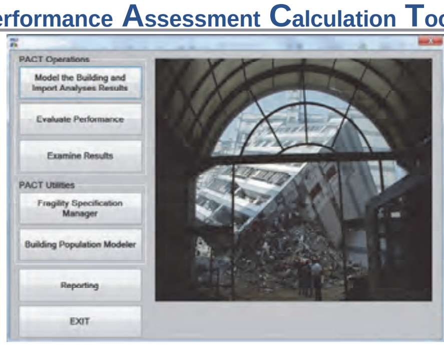


For Each Realization We Compute Building Performance

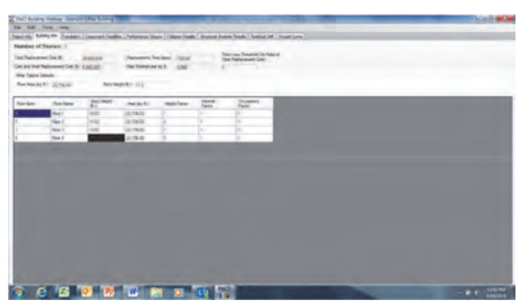


- If collapse occurs
  - Loss = complete
  - Compute casualties
- If collapse does not occur,
  - Determine residual drifts
  - Determine damage to each performance group
  - Determine casualties
  - Determine if building is "red-tagged"
- Result is an itemization of area of collapse, or required repair actions
- Assemble realizations from least to most severe consequence

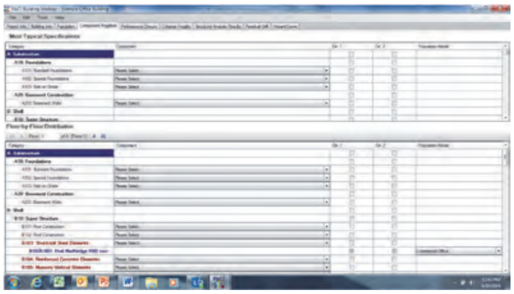
Performance Assessment Calculation Tool



General Data



Fragility Groups



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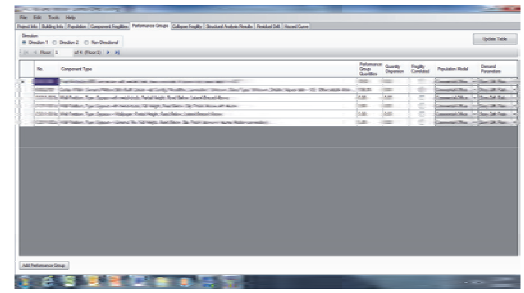
Performance Groups



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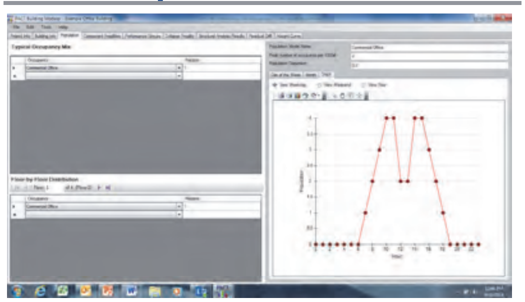
Population Model



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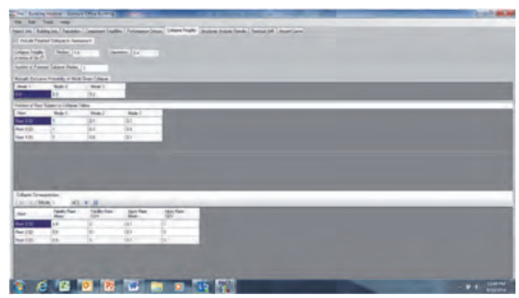
Collapse Fragility



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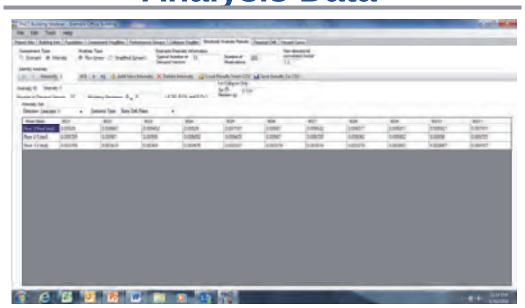
Analysis Data



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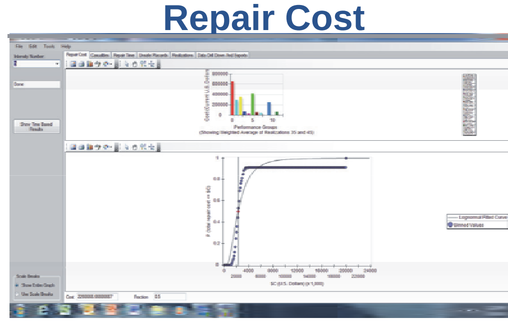
Repair Cost



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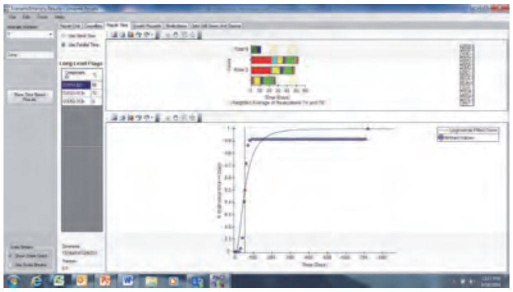
Repair Time



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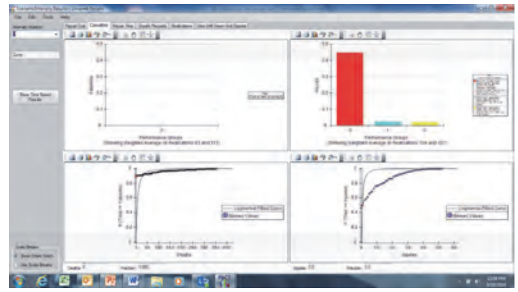
Casualties



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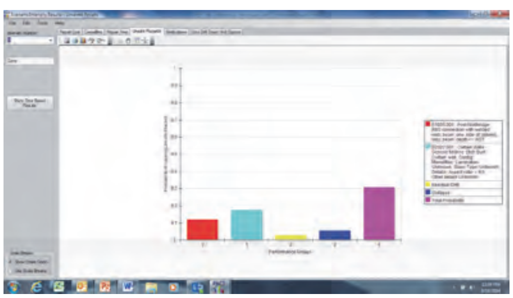
Red Tags



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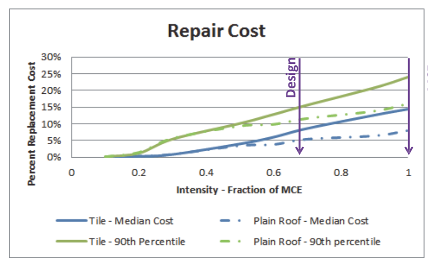
Single Family Dwelling



Characterizing the Seismic Performance of Code Conforming Buildings

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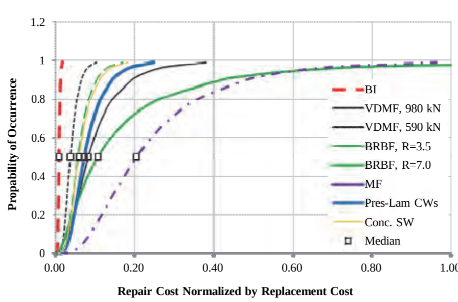
Office Building Repair Cost - DE



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Where we are today

- FEMA P58 is a fully functioning
- It is not being used much

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This is not a surprise

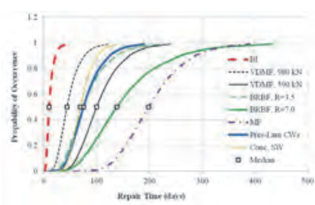
- There are no code-equivalent performance objectives in the FEMA P58 framework
- The methodology is cumbersome to use

Phase II Project

- Provide practical design tools that will compliment and facilitate the use of the P-58 methodology
- Provide educational materials that will facilitate client demand for the products of P-58

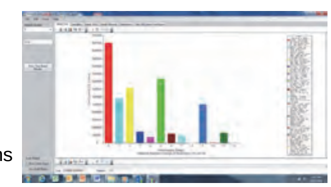
Goals of Phase II Project

- Define expected performance of code-designed buildings
  - Enable establishment of code-equivalence
  - Formation of design performance objectives



Goals of Phase II Project

- Define principal contributors to performance
  - Enable formulation of design strategies and recommendations for different performance objectives



Potential Products

- Recommended:
  - Appropriate performance objectives for buildings of different uses
  - Optimal framing systems for different performance objectives
  - Nonstructural strategies for different performance objectives
  - Minimum strength and stiffness for different performance objectives
- Enable design (or at least preliminary design) without PACT

Your Help is Needed

- How can we best express performance in the P-58 paradigm?
- What structural systems should we worry about?
- How much control can we really have on nonstructural vulnerability?
- What is the realistic range of designs (in terms of strength and stiffness) for code-conforming buildings?
- What types of design tools will be most helpful for you?

ATC-58-2 Project

Design Guidelines and Tools Next-Generation Performance-Based Seismic Design

Invitational Workshop

San Francisco – August 14, 2014

Design Tools and Guidelines

Vesna Terzic

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FEMA P-58 in the design?

Goal:

Understand engineer's needs and find ways to meet them!

Disclaimer: The presented graphs are for demonstration purposes only! They do not reflect the reality.

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Performance-based seismic design

- Set performance objectives
- Select several structural systems to be considered
- Use design aids:
  - a. To guide selection of design criteria for systems and components to limit the losses (e.g., repair cost, downtime, safety placard); or
  - b. To provide information on the performance of systems and components, given a drift or PGA
- Compare the systems
- Select the system

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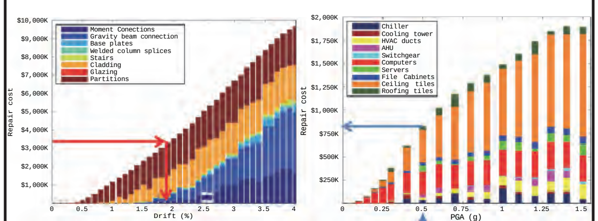
"Pushover" graphs

- Example – find drift limit given the hazard and the repair cost limit (e.g., RC=4,000K, DR=1.8%)



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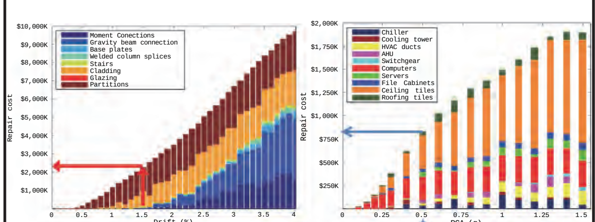
"Pushover" graphs

- Example – find a repair cost that corresponds to selected drift and/or PGA



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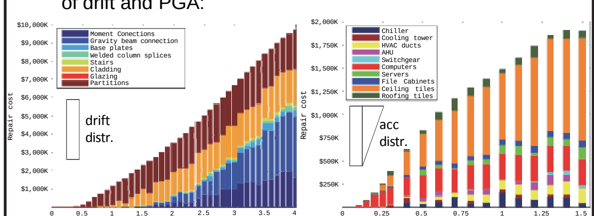
"Pushover" graphs

- Example – "pushover" graphs for repair cost as a function of drift and PGA:



This graphs are function of the drift and acceleration distribution along the building height

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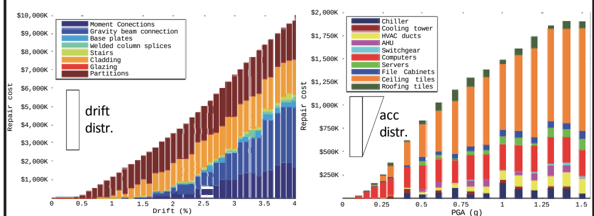
“Pushover” graphs

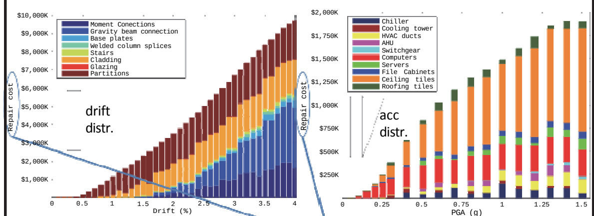
- Example – “pushover” graphs for repair cost as a function of drift and PGA:



Each graph is building specific (e.g., occupancy, # of stories, footage, floor mass) and lateral-resisting system specific

“Pushover” graphs

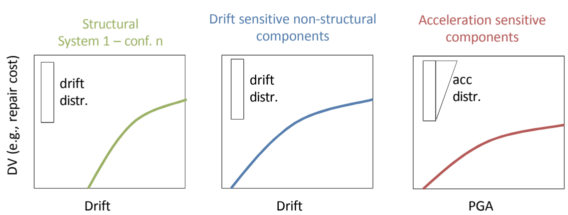
- Example – “pushover” graphs for repair cost as a function of drift and PGA:



Similar graphs can be developed for the downtime, probability of an unsafe placard,…

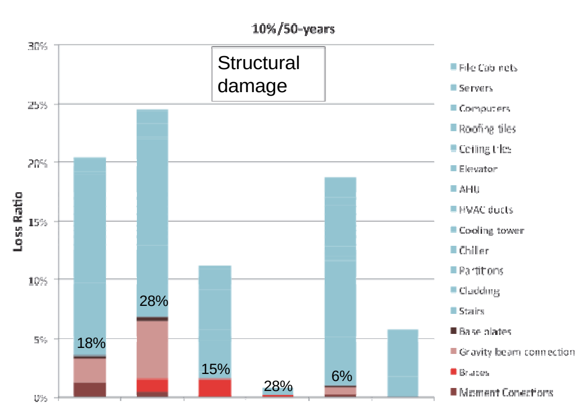
Possible Application

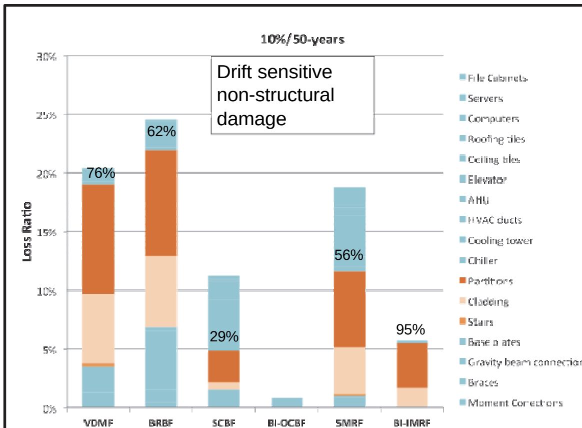
- Given the occupancy, # of stories, footage, floor mass:
  - Develop “pushover graphs” for different structural systems
  - Develop “pushover” graphs for non-structural components and content considering different drift and acceleration distributions

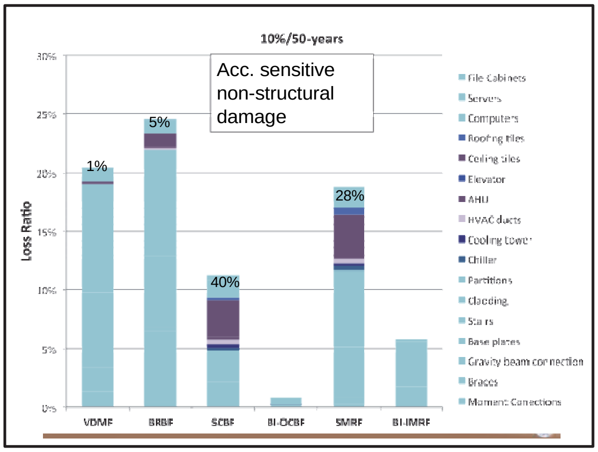


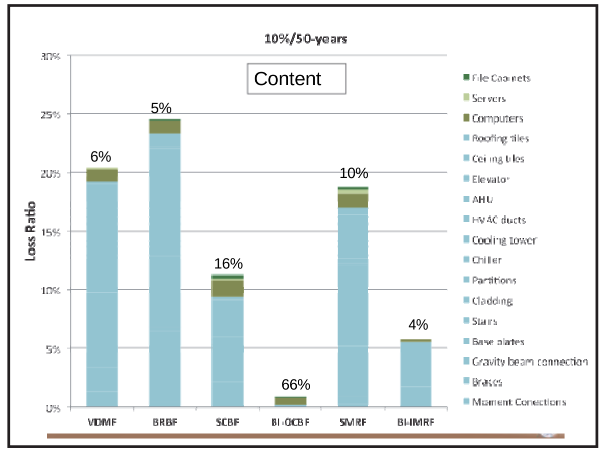
What governs selection of the system?

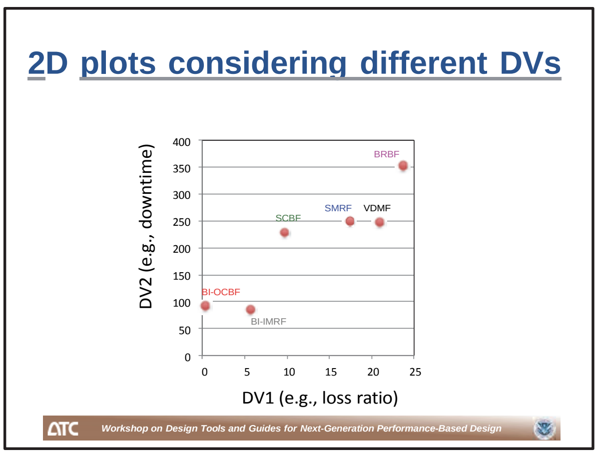
- Select the system by looking at the set of comparative plots for the same hazard level:
  - Compare DVs of different systems
  - 2D plots considering two DVs
  - Construction costs and return on investments






10%/50-years
Acc. sensitive non-structural damage
Loss Ratio
1%
5%
40%
28%
VDMF
BRBF
SCBF
BI-OCBF
SMRF
BI-IMRF
File Cabinets
Servers
Computers
Roofing tiles
Ceiling tiles
Elevator
AHU
HVAC ducts
Cooling tower
Chiller
Partitions
Cladding
Stairs
Base plates
Gravity beam connection
Braces
Moment Connections


10%/50-years
Content
Loss Ratio
6%
5%
16%
66%
10%
4%
VDMF
BRBF
SCBF
BI-OCBF
SMRF
BI-IMRF
File Cabinets
Servers
Computers
Roofing tiles
Ceiling tiles
Elevator
AHU
HVAC ducts
Cooling tower
Chiller
Partitions
Cladding
Stairs
Base plates
Gravity beam connection
Braces
Moment Connections


2D plots considering different DVs
DV2 (e.g., downtime)
DV1 (e.g., loss ratio)
BRBF
SCBF
SMRF
VDMF
BI-OCBF
BI-IMRF
ATC
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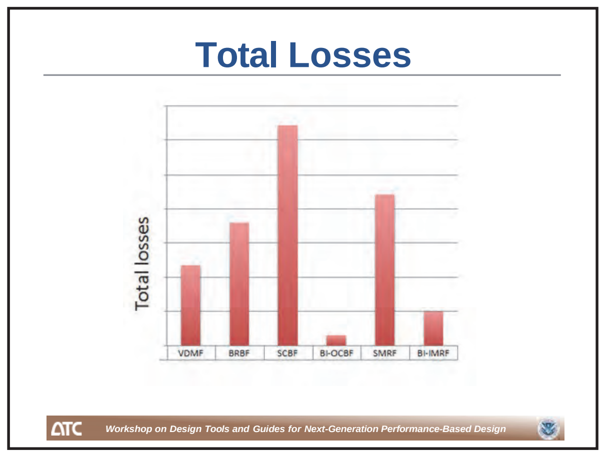
Total Losses
Total losses
VDMF
BRBF
SCBF
BI-OCBF
SMRF
BI-IMRF
ATC
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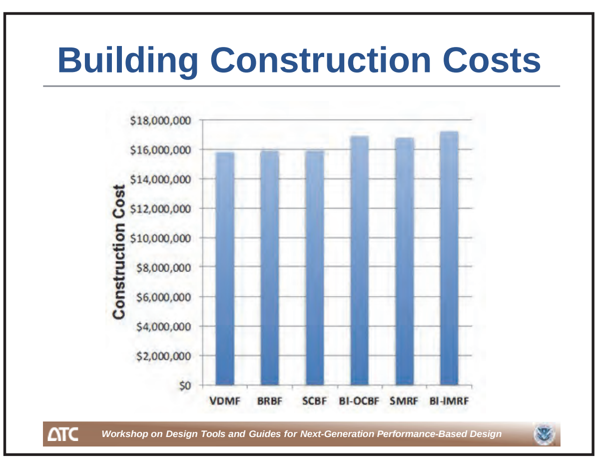
Building Construction Costs
Construction Cost
$18,000,000
$16,000,000
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
VDMF
BRBF
SCBF
BI-OCBF
SMRF
BI-IMRF
ATC
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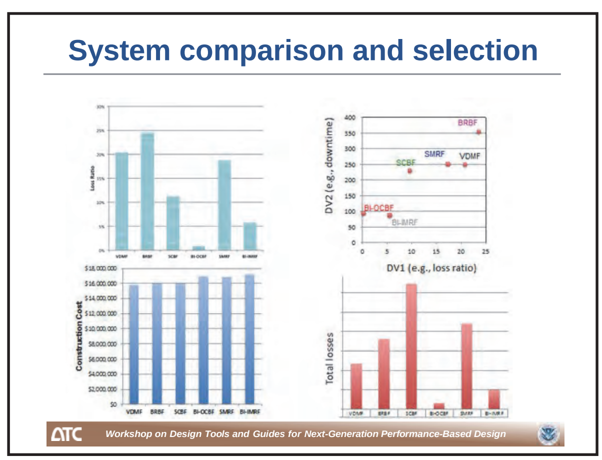
System comparison and selection
DV2 (e.g., downtime)
DV1 (e.g., loss ratio)
Total losses
ATC
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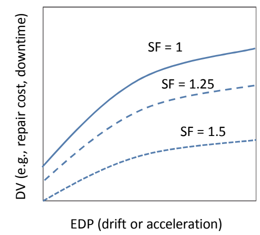
Final check

- For the selected system, after structural and nonstructural systems are designed, one can run PACT to evaluate the system's performance.

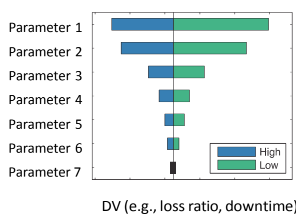
Additional graphs that may be helpful

- Design of nonstructural components



Additional graphs that may be helpful

- Change parameters such as: different system configurations, material properties, section types, nonstructural component types,…



Discussion

- What losses would be of interest to you:
  – Scenario based losses (e.g., 1906 San Francisco earthquake)
  – Multy-hazard losses (e.g., 50%/50-yrs, 10%/50-yrs, 2%/50-yrs)
  – Annualized losses

Discussion

- Would design aides make implementing performance-based design easier?

Discussion

- Would you use design aides?

Discussion

- What type of design aides would be most helpful?

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Discussion

- What types of buildings (occupancy, risk category) would design aides be used for?

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Discussion

- Would you prefer an integrated approach to design aides that: (1) guides selection of design criteria for systems and components; or (2) provides information on the performance of systems and components, given a drift or PGA?

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Discussion

- Would design aides for nonstructural performance help improve implementation of nonstructural bracing and anchorage by individuals responsible for specifying/designing such items?

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Discussion

- What type of information can be shared with non-engineers?

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Discussion

- If an owner/client is not interested in seismic performance, would you still use performance-based design aides to guide decisions?

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ATC-58-2 Project

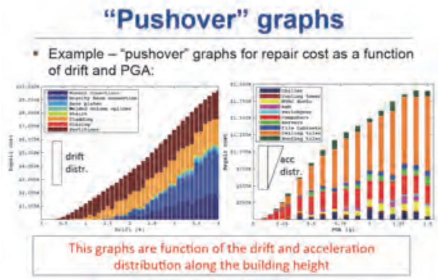
Bounding the ASCE 7-10 Design Space

David Bonneville
ATC 58-2 Performance Products Team

August 14, 2014 Workshop

ATC-58/PACT Capabilities

From Vesna Terzic



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Building Performance as Defined by ATC 58

The Building

The Structural System

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The Design Space – Defined by Strength/Stiffness

ATC 58 Performance Calculation

1. Does the Building Collapse?
   - A Function of Strength/Drift
2. Is the Building Repairable?
   - A Function of Residual Drift
3. What is the Damage and Consequence?
   - A Function of Demands Affecting Structural and Nonstructural Performance, Including:
     - Peak Story Drift Ratio
     - Floor Acceleration
     - Floor Velocity
     - Residual Drift Ratio

Thus, Seismic Performance May be Viewed as a Function of the Strength and Stiffness of the Structural System

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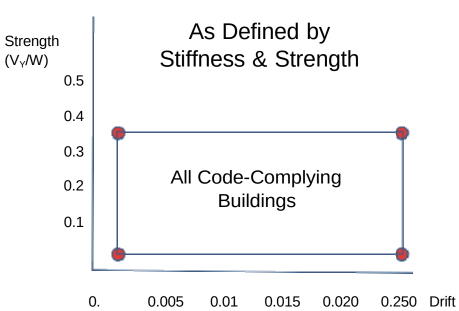
Design Space



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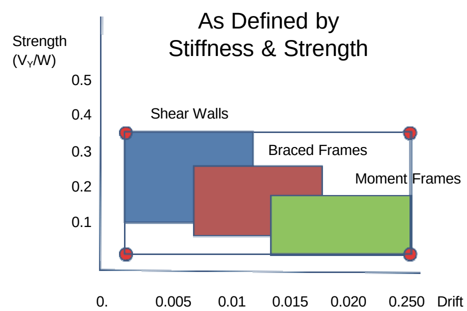
Design Space



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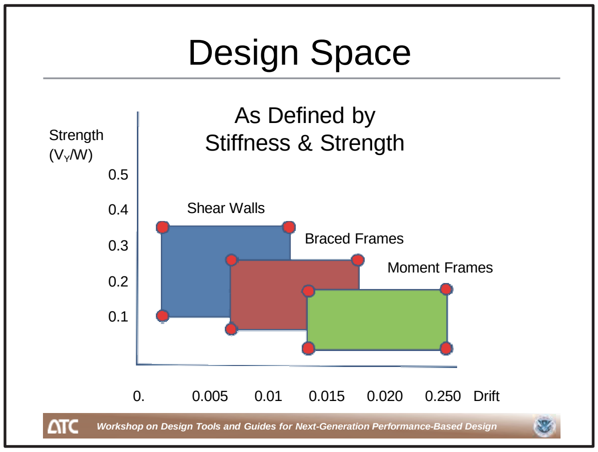
Design Space
As Defined by
Stiffness & Strength
Strength
(VY/W)
0.5
0.4
0.3
0.2
0.1
Shear Walls
Braced Frames
Moment Frames
0.
0.005
0.01
0.015
0.020
0.250
Drift
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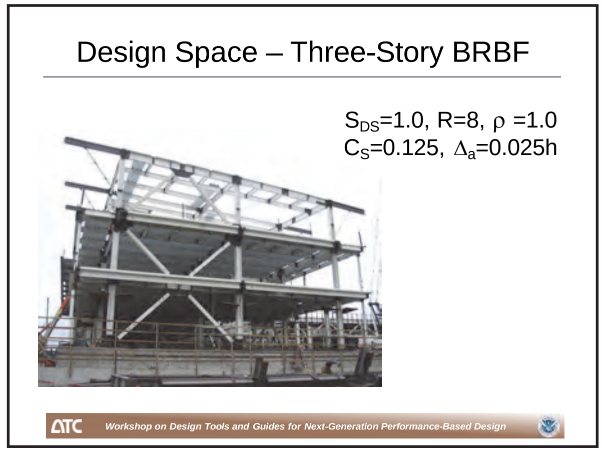
Design Space – Three-Story BRBF
S_{DS}=1.0, R=8, ρ =1.0
C_S=0.125, Δ_a=0.025h
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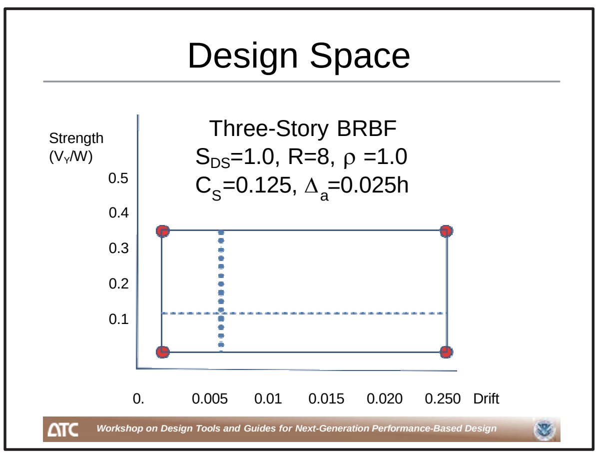
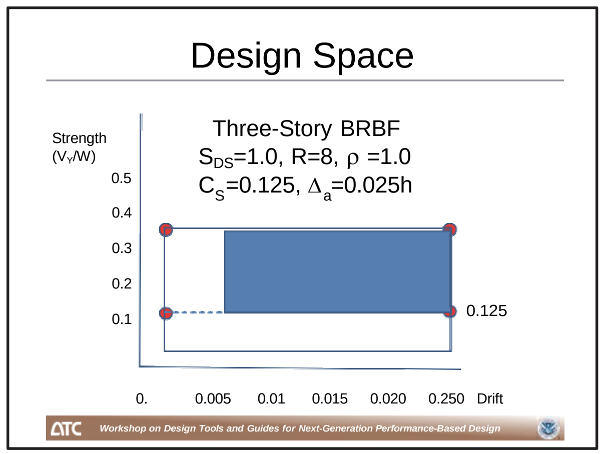

Design Space
Three-Story BRBF
S_{DS}=1.0, R=8, ρ =1.0
C_S=0.125, Δ_a=0.025h
Strength
(VY/W)
0.5
0.4
0.3
0.2
0.1
0.
0.005
0.01
0.015
0.020
0.250
Drift
Workshop on Design Tools and Guides for Next-Generation Performance-Based Design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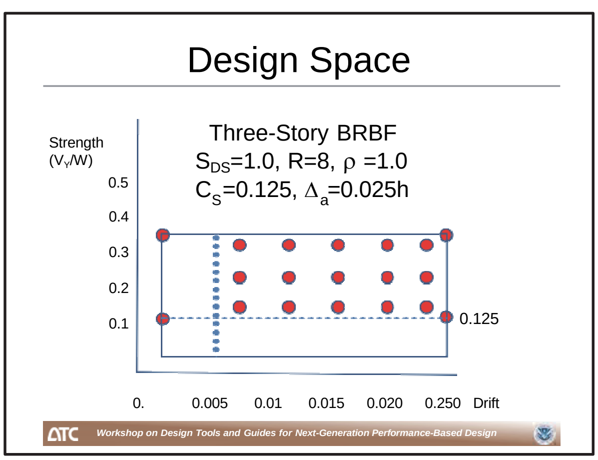
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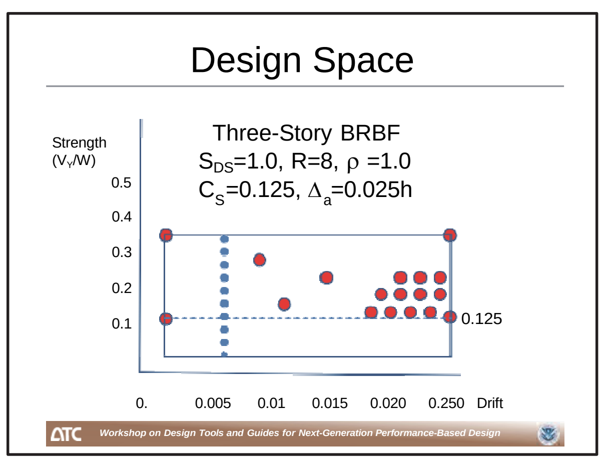
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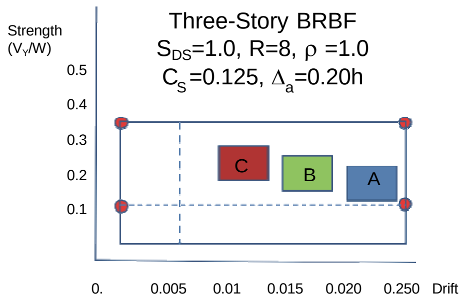
Design Space



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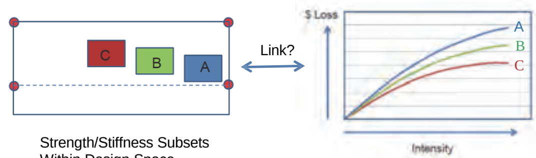
Design Space Linkage to Performance



Strength/Stiffness Subsets Within Design Space

Performance of Subsets

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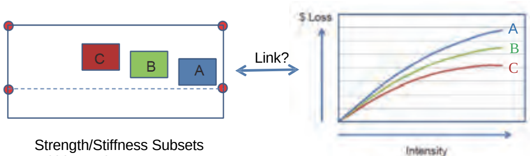
Design Space Linkage to Performance



Strength/Stiffness Subsets Within Design Space

Performance of Subsets

What is the Linkage Between System Design Space and Seismic Performance?

What is the Linkage Between Design Space Subsets and Seismic Performance?

Assuming a Linkage, How Would This Affect Our Approach to Design?

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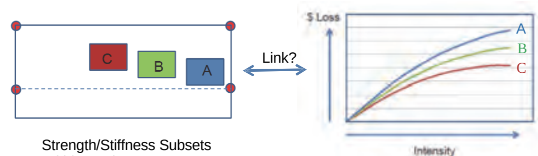
Design Space Linkage to Performance



Strength/Stiffness Subsets Within Design Space

Performance of Subsets

How much would this matter to us as designers? And to our clients?

What design parameters would you change? Which ones should you change to get max impact?

Would you change your design (system or subset) to improve performance by 20%, 40%? At what cost to the project?

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ATC 89 (NIST GCR 14-917-26) – Cost Analyses for Memphis

Table 4-1 Base Shear and Cost Comparisons between the Office Building Wind and Seismic Designs

	Wind Design	Current Local Seismic Code[1]		Current National Seismic Code[1]	
		Ratio	*Increase*	*Ratio*	*Increase*
Base Shear					
North-South Direction	1.0	4.70	-	5.34	-
East-West Direction	1.0	2.19	-	2.48	-
Structural Cost	1.0	1.144	14.4%	1.196	19.6%
Total Building Cost	1.0	1.021	2.1%	1.028	2.8%

Notes: [1] Ratios and increases are relative to wind design.

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Within the SMRF Design Space

A Collection of 21 Data Points Considering:

- Seismic Demand: SDC D, SDC C/D, I-Factor
- Layout: No. of Stories, No. of Bays, Bay Size
- Analysis Method: ELF (T_a and T_{calc}), RSA

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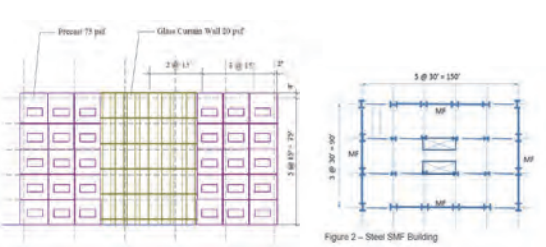

Figure 2 – Steel SMF Building

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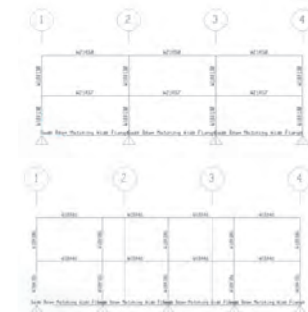
3 and 4 Bay 2-Story SMRF's



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5-Story SMRF

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12-Story SMRF

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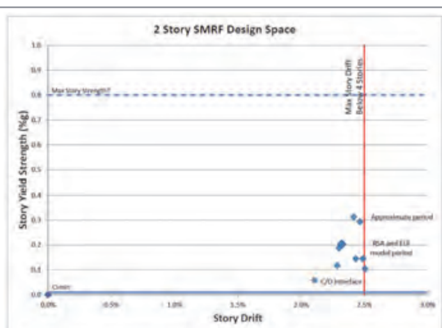

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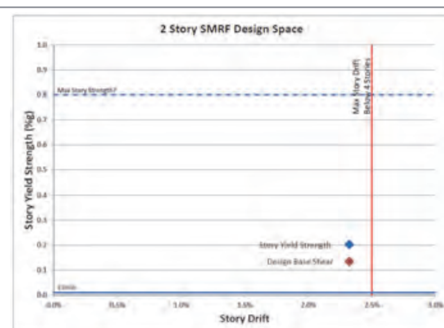

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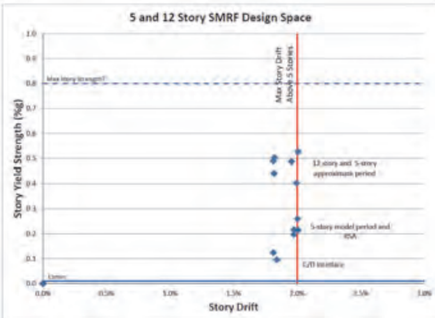

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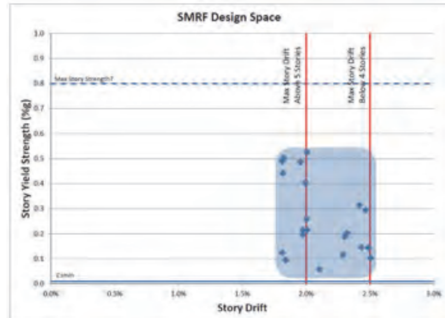

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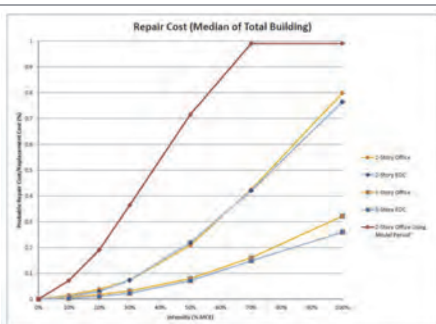
PACT Analysis Results – SMRF's



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Excerpt from 1988 UBC Section 2312 (e) 8 – Story Drift Limitation

2312 **UNIFORM BUILDING CODE**

Calculated story drift shall not exceed $0.04/R_w$ nor 0.005 times the story height for buildings less than 65 feet in height. For buildings greater in height, the calculated story drift shall not exceed $0.03/R_w$ nor 0.004 times the story height.

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Within the SCBF Design Space

A Collection of 9 Data Points Considering:

Seismic Demand: SDC D, SDC C/D, I-Factor, ρ =1.0, 1.3

Layout: No. of Stories, No. of Bays, Bay Size

Analysis Method: ELF, RSA

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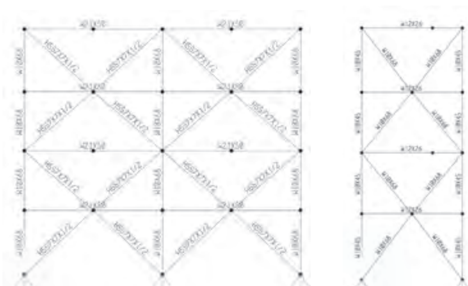

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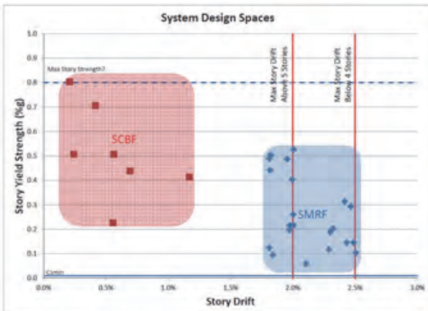
Comparing SCBF and SMRF



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Factors Affecting The Design Space

ASCE 7-Related
Engineering-Related

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ASCE 7 Provisions Affecting Seismic Performance

ASCE 7-10 Chapter 11 Provisions	Affects Strength and Stiffness?	Controlled by SE?
Risk Category and I (1.5.1 and 11.5)	Y	N
Mapped Accelerations (11.4.1)	Y	N
Site Class (11.4.2)	Y	N
Site Specific Ground Motions (11.4.7)	Y	Y

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ASCE 7 Provisions Affecting Seismic Performance

ASCE 7-10 Chapter 12 Provisions	Affects Strength and Stiffness?	Controlled by SE?
Lateral System (12.2)	Y	Y
Diaphragm Modeling (12.3.1)	Y/N	Y
Irregularities (12.3.2)	Y	Y/N
Redundancy (12.3.4)	Y	Y/N
Analysis Procedure (12.6)	Y	Y
Foundation Modeling (12.7.1)	Y	Y
Structural Modeling (12.7.3)	Y	Y
Soil Structure Interaction (12.8.1.2)	Y	Y
Max S_S for Determining C_S (12.8.1.3)	Y	Y
Period Determination (12.8.2)	Y	Y
Story Drift Determination (12.8.6)	Y	Y

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ASCE 7 Provisions Affecting Seismic Performance

ASCE 7-10 Chapter 12 Provisions	Affects Strength and Stiffness?	Controlled by SE?
Diaphragms, Chords, Collectors (12.10)	N	Y
Structural Walls and Anchorage (12.11)	N	Y
Foundation Design (12.13)	Y	Y
Simplified Design (12.14)	Y	Y

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Other Factors Affecting Seismic Performance

Other Design-Related Considerations	Affects Strength and Stiffness?	Controlled by SE?
Conservatism		
Configuration		
Soil-Structure Interaction		
Analysis Type		

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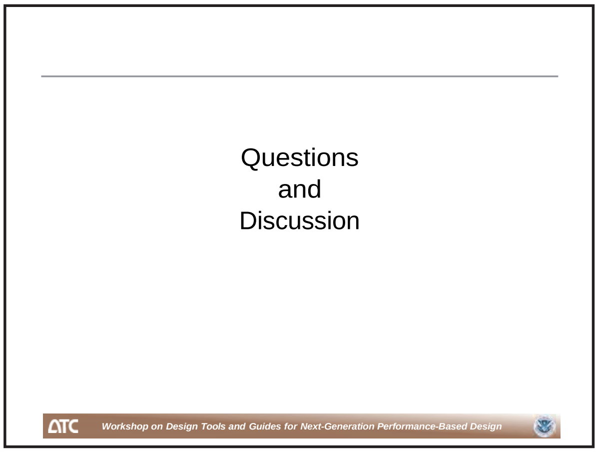
Questions
and
Discussion
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ASCE, 2010, *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers, Reston, Virginia.

ASCE, 2013, *Seismic Evaluation and Retrofit of Existing Buildings*, ASCE/SEI 41-13, American Society of Civil Engineers, Reston, Virginia.

ATC, 2014, *FEMA-Sponsored Workshop on Communicating Seismic Performance Metrics in Design Decision-Making*, ATC-58-4, Applied Technology Council, Redwood City, California.

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FEMA, 2012c, *Seismic Performance Assessment of Buildings, Volume 3 – Supporting Electronic Materials and Background Documentation*, FEMA P-58-3, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, D.C.

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Applied Technology Council Projects and Report Information

One of the primary purposes of the Applied Technology Council is to develop engineering applications and resources that translate and summarize useful information for practicing building and bridge design professionals. This includes the development of guidelines and manuals, as well as the development of research recommendations for specific areas determined by the profession. ATC is not a code development organization, although ATC project reports often serve as resource documents for the development of codes, standards and specifications.

Applied Technology Council conducts projects that meet the following criteria:

1. The primary audience or benefactor is the design practitioner in structural engineering.
2. A cross section or consensus of engineering opinion is required to be obtained and presented by a neutral source.
3. The project fosters the advancement of structural engineering practice.

Funding for projects is obtained from government agencies and tax-deductible contributions from the private sector. Brief descriptions of completed ATC projects and reports are provided below.

ATC-1: This project resulted in five papers published as part of *Building Practices for Disaster Mitigation, Building Science Series 46*, proceedings of a workshop sponsored by the National Science Foundation (NSF) and the National Bureau of Standards (NBS). Available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151, as NTIS report No. COM-73-50188.

ATC-2: The report, *An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings*, was funded by NSF and NBS and was conducted as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation. Available through ATC. (Published 1974, 270 Pages)

ATC-3: The report, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC-3-06), was funded by NSF and NBS. The tentative provisions in this report served as the basis for the seismic provisions of the 1988 and subsequent issues of the *Uniform Building Code* and the *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Building and Other Structures*. The second printing contains proposed amendments prepared by a joint committee of the Building Seismic Safety Council (BSSC) and the NBS. Available through ATC. (Published 1978, amended 1982, 505 pages plus proposed amendments)

ATC-3-2: The project, "Comparative Test Designs of Buildings Using ATC-3-06 Tentative Provisions", was funded by NSF. It consisted of a study to develop and plan a program for making comparative test designs of the ATC-3-06 Tentative Provisions. The project report was intended for use by the Building Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

ATC-3-4: The report, *Redesign of Three Multistory Buildings: A Comparison Using ATC-3-06 and 1982 Uniform Building Code Design Provisions*, was published under a grant from NSF. Available through ATC. (Published 1984, 112 pages)

ATC-3-5: The project, "Assistance for First Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council," was funded by the Building Seismic Safety Council to obtain assistance in conducting the first phase of its program to develop trial designs for buildings in Los Angeles, Seattle, Phoenix, and Memphis.

ATC-3-6: The project, "Assistance for Second Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council," was funded by the Building Seismic Safety Council to obtain assistance in conducting the second phase of its program to develop trial designs for buildings in New York, Chicago, St. Louis, Charleston, and Fort Worth.

ATC-4: The report, *A Methodology for Seismic Design and Construction of Single-Family Dwellings*, was published under a contract with the Department of Housing and Urban Development (HUD). Available through ATC. (Published 1976, 576 pages)

ATC-4-1: The report, *The Home Builders Guide for Earthquake Design*, was published under a contract with HUD. Available through ATC. (Published 1980, 57 pages)

ATC-5: The report, *Guidelines for Seismic Design and Construction of Single-Story Masonry Dwellings in Seismic Zone 2*, was developed under a contract with HUD. Available through ATC. (Published 1986, 38 pages)

ATC-6: The report, *Seismic Design Guidelines for Highway Bridges*, was published under a contract with the Federal Highway Administration (FHWA). Available through ATC. (Published 1981, 210 pages)

ATC-6-1: The report, *Proceedings of a Workshop on Earthquake Resistance of Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1979, 625 pages)

ATC-6-2: The report, *Seismic Retrofitting Guidelines for Highway Bridges*, was published under a contract with FHWA. Available through ATC. (Published 1983, 220 pages)

ATC-7: The report, *Guidelines for the Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through ATC. (Published 1981, 190 pages)

ATC-7-1: The report, *Proceedings of a Workshop on Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through ATC. (Published 1980, 302 pages)

ATC-8: The report, *Proceedings of a Workshop on the Design of Prefabricated Concrete Buildings for Earthquake Loads*, was funded by NSF. Available through ATC. (Published 1981, 400 pages)

ATC-9: The report, *An Evaluation of the Imperial County Services Building Earthquake Response and Associated Damage*, was published under a grant from NSF. Available through ATC. (Published 1984, 231 pages)

ATC-10: The report, *An Investigation of the Correlation Between Earthquake Ground Motion and Building Performance*, was funded by the U.S. Geological Survey (USGS). Available through ATC. (Published 1982, 114 pages)

ATC-10-1: The report, *Critical Aspects of Earthquake Ground Motion and Building Damage Potential*, was co-funded by the USGS and the NSF. Available through ATC. (Published 1984, 259 pages)

ATC-11: The report, *Seismic Resistance of Reinforced Concrete Shear Walls and Frame Joints: Implications of Recent Research for Design Engineers*, was published under a grant from NSF. Available through ATC. (Published 1983, 184 pages)

ATC-12: The report, *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1982, 270 pages)

ATC-12-1: The report, *Proceedings of Second Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges*, was published under a grant from NSF. Available through ATC. (Published 1986, 272 pages)

ATC-13: The report, *Earthquake Damage Evaluation Data for California*, was developed under a contract with the Federal Emergency Management Agency (FEMA). It presents expert-opinion earthquake damage and loss estimates for industrial, commercial, residential, utility and transportation facilities in California. Included are damage probability matrices for 78 classes of structures and estimates of time required to restore damaged facilities to pre-earthquake usability. Available through ATC. (Published 1985, 492 pages)

ATC-13-1: The report, *Commentary on the Use of ATC-13 Earthquake Damage Evaluation Data for Probable Maximum Loss Studies of California Buildings*, was developed with funding from the

ATC Endowment Fund. It provides guidance for using ATC-13 expert-opinion data for probable maximum loss (PML) studies of California buildings. Included are discussions of the limitations on the use of the ATC-13 expert-opinion data, and appendices containing information not included in the original ATC-13 report, such as model building type descriptions, beta damage distribution parameters for ATC-13 model building types, and PML values for ATC-13 model building types. Available through ATC. (Published 2002, 66 pages)

ATC-14: The report, *Evaluating the Seismic Resistance of Existing Buildings*, was developed under a grant from the NSF. It describes a methodology for performing preliminary and detailed seismic evaluations of buildings. A precursor to the eventual ASCE 31 Standard, *Seismic Evaluation of Existing Buildings*, it contains useful background information including a state-of-practice review; seismic loading criteria; data collection procedures; a detailed description of the building classification system; preliminary and detailed analysis procedures; and example case studies, including nonstructural considerations. Available through ATC. (Published 1987, 370 pages)

ATC-15: The report, *Comparison of Seismic Design Practices in the United States and Japan*, was published under a grant from NSF. Available through ATC. (Published 1984, 317 pages)

ATC-15-1: The report, *Proceedings of Second U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices*, was published under a grant from NSF. It includes state-of-the-practice papers and case studies of actual building designs and information on regulatory, contractual, and licensing issues. Available through ATC. (Published 1987, 412 pages)

ATC-15-2: The report, *Proceedings of Third U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes state-of-the-practice papers on steel braced frame and reinforced concrete buildings, base isolation and passive energy dissipation devices, and comparisons between U.S. and Japanese design practice. Available through ATC. (Published 1989, 358 pages)

ATC-15-3: The report, *Proceedings of Fourth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes papers on postearthquake building damage assessment; acceptable earthquake damage; repair and retrofit of earthquake-damaged buildings; base-isolated buildings, Architectural Institute of Japan recommendations for design; active damping systems; and wind-resistant design. Available through ATC. (Published 1992, 484 pages)

ATC-15-4: The report, *Proceedings of Fifth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. It includes papers on performance goals and acceptable damage; seismic design procedures and case studies; seismic evaluation, repair and upgrade; construction influences on design; isolation and passive energy dissipation; design of irregular structures; and quality control for design and construction. Available through ATC. (Published 1994, 360 pages)

ATC-16: The FEMA 90 report, *An Action Plan for Reducing Earthquake Hazards of Existing Buildings*, was funded by FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering Research Institute. Available through FEMA. (Published 1985, 75 pages)

ATC-17: The report, *Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation*, was published under a grant from NSF. It includes papers describing case studies in the United States, applications and developments worldwide, recent innovations in technology development, and structural and ground motion issues in base-isolation and passive energy-dissipation. Also included is a proposed 5-year research agenda. Available through ATC. (Published 1986, 478 pages)

ATC-17-1: The report, *Proceedings of a Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control,* was published under a grant from NCEER and NSF. Available through ATC. (Published 1993, 841 pages in two volumes)

ATC-18: The report, *Seismic Design Criteria for Bridges and Other Highway Structures: Current and Future*, was developed under a grant from

NCEER and FHWA. Available through ATC. (Published, 1997, 151 pages)

ATC-18-1: The report, *Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures***,** was developed under a contract with the Multidisciplinary Center for Earthquake Engineering Research (MCEER, formerly NCEER) and FHWA. Available through ATC. (Published, 1999, 136 pages)

ATC-19: The report, *Structural Response Modification Factors* was funded by NSF and NCEER. Available through ATC. (Published 1995, 70 pages)

ATC-20: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract with the California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. It provides procedures and guidelines for inspecting buildings that have been damaged in an earthquake, and making decisions regarding their continued use and occupancy. Written for volunteer structural engineers and building inspectors, it includes rapid and detailed evaluation procedures for posting buildings as "inspected" (apparently safe, green placard), "limited entry" (yellow) or "unsafe" (red). Available through ATC (Published 1989, 152 pages)

ATC-20-1: The report, *Field Manual: Postearthquake Safety Evaluation of Buildings, Second Edition*, was funded by Applied Technology Council. A companion to the ATC-20 report, the *Field Manual* summarizes postearthquake safety evaluation procedures in a concise format designed for ease of use in the field. Available through ATC. (Published 2004, 143 pages)

ATC-20-2: The report, *Addendum to the ATC-20 Postearthquake Building Safety Procedures* was published under a grant from the NSF and funded by the USGS. It provides updated assessment forms, placards, and evaluation procedures based on application and use in five earthquake events that occurred after the initial release of the ATC-20 report. Available through ATC. (Published 1995, 94 pages)

ATC-20-3: The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R.P. Gallagher Associates. Containing over 50 case studies using the ATC-20 Rapid Evaluation procedure, the report is intended for use as a training and reference manual. It describes how buildings are inspected and evaluated, and is illustrated with photos and completed safety assessment forms and placards. Available through ATC. (Published 1996, 295 pages)

ATC-20-T: The *Postearthquake Safety Evaluation of Buildings Training CD* was developed in cooperation with FEMA. The 4½-hour training seminar includes photographs, schematic drawings, and textual information. Available through ATC. (Published 2002, 230 PowerPoint slides with Speakers Notes)

ATC-21: The FEMA 154 report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, *Second Edition*, was developed under a contract with FEMA. It describes a rapid visual screening procedure for identifying buildings that might pose serious risk of loss of life and injury in the event of a damaging earthquake. The screening procedure utilizes an approach that involves identification of the primary structural load-resisting system and materials of construction, and assignment of a structural hazard score based on observed building characteristics. It identifies those buildings that are potentially hazardous and should be analyzed in more detail by an experienced professional engineer. Available through ATC and FEMA. (Published 2002, 161 pages)

ATC-21-1: The FEMA 155 report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation*, *Second Edition*, was developed under a contract with FEMA. It provides the technical basis for the updated rapid visual screening procedure. Available through ATC and FEMA. (Published 2002, 117 pages)

ATC-21-2: The report, *Earthquake Damaged Buildings: An Overview of Heavy Debris and Victim Extrication*, was developed under a contract with FEMA. (Published 1988, 95 pages)

ATC-21-T: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual, Second Edition,* was developed under a contract with FEMA. Training materials include120 slides in PowerPoint format and companion narrative coordinated with the presentation. Available through ATC. (Published

2004, 148 pages and PowerPoint presentation on companion CD)

ATC-22: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, was developed under a contract with FEMA in 1989. Based on the information originally developed in ATC-14, this report was revised by BSSC and published as the FEMA 178 report, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* in 1992, revised by ASCE and published as the FEMA 310 report, *Handbook for the Seismic Evaluation of Buildings – a Prestandard* in 1998. Currently available through the American Society of Civil Engineers as the ASCE 31 Standard, *Seismic Evaluation of Existing Buildings*.

ATC-22-1: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract with FEMA. (Published 1989, 160 pages)

ATC-23A: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part A: Survey Description, Summary of Results, Data Analysis and Interpretation*, was developed under a contract with the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through ATC. (Published 1991, 58 pages)

ATC-23B: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part B: Raw Data*, was developed under a contract with the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through ATC. (Published 1991, 377 pages)

ATC-24: The report, *Guidelines for Seismic Testing of Components of Steel Structures*, was jointly funded by the American Iron and Steel Institute (AISI), American Institute of Steel Construction (AISC), National Center for Earthquake Engineering Research (NCEER), and NSF. Available through ATC. (Published 1992, 57 pages)

ATC-25: The report, *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States*, was developed under a contract with FEMA. Available through ATC. (Published 1991, 440 pages)

ATC-25-1: The report, *A Model Methodology for Assessment of Seismic Vulnerability and Impact of Disruption of Water Supply Systems*, was developed under a contract with FEMA. Available through ATC. (Published 1992, 147 pages)

ATC-26: This project, "U.S. Postal Service National Seismic Program," was funded under a contract with the U.S. Postal Service (USPS), and resulted in the following interim documents:

ATC-26 Report, *Cost Projections for the U. S. Postal Service Seismic Program* (Completed 1990)

ATC-26-1 Report, *United States Postal Service Procedures for Seismic Evaluation of Existing Buildings (Interim)* (Completed 1991)

ATC-26-2 Report, *Procedures for Post-disaster Safety Evaluation of Postal Service Facilities (Interim)*. Available through ATC. (Published 1991, 221 pages)

ATC-26-3 Report, *Field Manual: Post-earthquake Safety Evaluation of Postal Buildings (Interim)*. Available through ATC. (Published 1992, 133 pages)

ATC-26-3A Report, *Field Manual: Post Flood and Wind Storm Safety Evaluation of Postal Buildings (Interim)*. Available through ATC. (Published 1992, 114 pages)

ATC-26-4 Report, *United States Postal Service Procedures for Building Seismic Rehabilitation (Interim)* (Completed 1992)

ATC-26-5 Report, *United States Postal Service Guidelines for Building and Site Selection in Seismic Areas (Interim)* (Completed 1992)

ATC-28: The report, *Development of Recommended Guidelines for Seismic Strengthening of Existing Buildings, Phase I: Issues Identification and Resolution*, was developed under a contract with FEMA. Available through ATC. (Published 1992, 150 pages)

ATC-29: The report, *Proceedings of a Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, was developed under a grant from NCEER and NSF. It includes papers describing current practice, codes and regulations; earthquake performance; analytical and experimental investigations; development of new seismic qualification methods; and research, practice, and code development needs for nonstructural elements and systems. Available through ATC. (Published 1992, 470 pages)

ATC-29-1: The report, *Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, was developed under a grant from NCEER and NSF. It includes papers on observed performance in recent earthquakes; seismic design codes, standards, and procedures for commercial and institutional buildings; design issues relating to industrial and hazardous material facilities; and seismic evaluation and rehabilitation of components in conventional and essential facilities. Available through ATC. (Published 1998, 518 pages)

ATC-29-2: The report, *Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities*, was developed under a grant from MCEER (formerly NCEER) and NSF. It includes papers on seismic design, performance, and retrofit of nonstructural components in critical facilities including current practices and emerging codes; seismic design and retrofit; risk and performance evaluation; system qualification and testing; and advanced technologies. Available through ATC. (Published 2003, 574 pages)

ATC-30: The report, *Proceedings of Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of 1985 Chile and Mexico Earthquakes*, was developed under a grant from the NSF. Available through ATC. (Published 1991, 113 pages)

ATC-31: The report, *Evaluation of the Performance of Seismically Retrofitted Buildings*, was developed under a contract with the National Institute of Standards and Technology (NIST, formerly NBS) and funded by the USGS. Available through ATC. (Published 1992, 75 pages)

ATC-32: The report, *Improved Seismic Design Criteria for California Bridges: Provisional Recommendations,* was funded by the California Department of Transportation (Caltrans). Available through ATC. (Published 1996, 215 pages)

ATC-32-1: The report, *Improved Seismic Design Criteria for California Bridges: Resource Document,* was funded by Caltrans. Available through ATC. (Published 1996, 365 pages; also available on CD-ROM)

ATC-33: The project, funded under a contract with the Building Seismic Safety Council, was initiated by FEMA to develop nationally applicable, state-of-the-art guidance for performance-based seismic rehabilitation of buildings. Work resulted in the publication of:

> FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (Published 1997, 440 pages). Revised by ASCE and published as the FEMA 356 report, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* in 2000. Currently available through the American Society of Civil Engineers as the ASCE 41 Standard, *Seismic Rehabilitation of Existing Buildings*.
>
> FEMA 274, *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings*. Available through ATC and FEMA. (Published 1997, 492 pages)
>
> FEMA 276, *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings*. Available through ATC and FEMA. (Published 1997, 295 pages)

ATC-34: The report, *A Critical Review of Current Approaches to Earthquake Resistant Design***,** was developed under a grant from NCEER and NSF. Available through ATC. (Published, 1995, 94 pages)

ATC-35: The report, *Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice* was developed under a cooperative agreement with the USGS. Available through ATC. (Published 1994, 120 pages)

ATC-35-1: The report, *Proceedings of Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, was developed under a cooperative agreement with USGS. It includes papers describing state-of-the-art information on regional earthquake risk; new techniques for estimating strong ground motions as a function of earthquake source, travel path, and site parameters; and new developments applicable to geotechnical engineering. Available through ATC. (Published 1994, 478 pages)

ATC-35-2: The report, *Proceedings: National Earthquake Ground Motion Mapping Workshop*, was developed under a cooperative agreement with USGS. It includes papers on ground motion parameters; reference site conditions; probabilistic versus deterministic basis; and the treatment of uncertainty in seismic source characterization and ground motion attenuation. Available through ATC. (Published 1997, 154 pages)

ATC-35-3: The report, *Proceedings: Workshop on Improved Characterization of Strong Ground Shaking for Seismic Design,* was developed under a cooperative agreement with USGS. It includes papers on identifying needs and developing improved representations of earthquake ground motion for use in seismic design practice and building codes. Available through ATC. (Published 1999, 75 pages)

ATC-37: The report, *Review of Seismic Research Results on Existing Buildings***,** was developed in conjunction with the Structural Engineers Association of California (SEAOC) and California Universities for Research in Earthquake Engineering (CUREe) under a contract with the California Seismic Safety Commission (SSC). Available through the Seismic Safety Commission as Report SSC 94-03. (Published, 1994, 492 pages)

ATC-38: The report, *Database on the Performance of Structures near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*, was developed with funding from the USGS, the Southern California Earthquake Center (SCEC), OES, and the Institute for Business and Home Safety (IBHS). Available through ATC. (Published 2000, 260 pages, with CD-ROM containing complete database).

ATC-40: The report, *Seismic Evaluation and Retrofit of Concrete Buildings***,** was developed under a contract with the California Seismic Safety Commission. It provides guidance on performance objectives, hazard characterization, identification of deficiencies, retrofit strategies, nonlinear static analysis procedures, modeling rules, foundation effects, and response limits for seismic evaluation and retrofit of concrete buildings. Available through ATC. (Published, 1996, 612 pages in two volumes)

ATC-41 (SAC Joint Venture, Phase 1): The project, "Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 1," was funded by FEMA and OES and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under Phase 1 the following documents were prepared:

SAC-94-01, *Proceedings of the Invitational Workshop on Steel Seismic Issues, Los Angeles, September 1994*. Available through ATC. (Published 1994, 155 pages)

SAC-95-01, *Steel Moment-Frame Connection Advisory No. 3*. Available through ATC. (Published 1995, 310 pages)

SAC-95-02, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment-Frame Structures* (FEMA 267 report) (Published 1995, 215 pages; superseded by FEMA 350 to 353)

SAC-95-03, *Characterization of Ground Motions During the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 179 pages)

SAC-95-04, *Analytical and Field Investigations of Buildings Affected by the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 900 pages in two volumes)

SAC-95-05, *Parametric Analytical Investigations of Ground Motion and Structural Response, Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 274 pages)

SAC-95-06, *Surveys and Assessment of Damage to Buildings Affected by the Northridge Earthquake of January 17, 1994*. Available through ATC. (Published 1995, 315 pages)

SAC-95-07, *Case Studies of Steel Moment Frame Building Performance in the Northridge Earthquake of January 17, 1994* (Published 1995, 260 pages, Available through ATC)

SAC-95-08, *Experimental Investigations of Materials, Weldments and Nondestructive Examination Techniques*. Available through ATC. (Published 1995, 144 pages)

SAC-95-09, *Background Reports: Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame systems, Behavior* (FEMA 288 report). Available through ATC and FEMA. (Published 1995, 361 pages)

SAC-96-01, *Experimental Investigations of Beam-Column Subassemblages, Part 1 and 2*. Available through ATC. (Published 1996, 924 pages, in two volumes)

SAC-96-02, *Connection Test Summaries* (FEMA 289 report). Available through ATC and FEMA. (Published 1996, 144 pages)

ATC-41-1 (SAC Joint Venture, Phase 2): The project, "Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 2," was funded by FEMA and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under Phase 2 the following documents were prepared:

SAC-96-03, *Interim Guidelines Advisory No. 1 Supplement to FEMA 267 Interim Guidelines* (FEMA 267A report) (Published 1997, 100 pages; superseded by FEMA 350 to 353)

SAC-99-01, *Interim Guidelines Advisory No. 2 Supplement to FEMA 267 Interim Guidelines* (FEMA 267B report, superseding FEMA 267A). (Published 1999, 150 pages; superseded by FEMA 350 to 353)

FEMA 350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 190 pages)

FEMA 351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 210 pages)

FEMA 352, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*. Available through ATC and FEMA. (Published 2000, 180 pages)

FEMA 353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*. Available through ATC and FEMA. (Published 2000, 180 pages)

FEMA 354, *A Policy Guide to Steel Moment-Frame Construction*. Available through ATC and FEMA. (Published 2000, 27 pages)

FEMA 355A, *State of the Art Report on Base Materials and Fracture*. Available through ATC and FEMA. (Published 2000, 107 pages; in print and on CD-ROM).

FEMA 355B, *State of the Art Report on Welding and Inspection*. Available through ATC and FEMA. (Published 2000, 185 pages; in print and on CD-ROM).

FEMA 355C, *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. Available through ATC and FEMA. (Published 2000, 322 pages; in print and on CD-ROM).

FEMA 355D, *State of the Art Report on Connection Performance*. Available through ATC and FEMA. (Published 2000, 292 pages; in print and on CD-ROM).

FEMA 355E, *State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*. Available through ATC and FEMA. (Published 2000, 190 pages; in print and on CD-ROM).

FEMA 355F, *State of the Art Report on Performance Prediction and Evaluation of Steel Moment-Frame Structures*. Available through ATC and FEMA. (Published 2000, 347 pages; in print and on CD-ROM).

ATC-43: The reports, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual* (FEMA 306), *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources* (FEMA 307), and *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308)**,** were developed for FEMA under a contract with the Partnership for Response and Recovery, a Joint Venture of Dewberry & Davis and Woodward-Clyde. Available through ATC and FEMA. (Published, 1998 in print and on CD-ROM; *Basic Procedures Manual*, 270 pages; *Technical Resources*, 271 pages; *Repair Manual*, 81 pages)

ATC-44: The report, *Hurricane Fran, North Carolina, September 5, 1996: Reconnaissance Report***,** was funded by the Applied Technology Council. Available through ATC. (Published 1997, 36 pages)

ATC-45: The report, *Field Manual*, *Safety Evaluation of Buildings After Wind Storms and Floods*, was developed with funding from the ATC Endowment Fund and the Institute for

Business and Home Safety (IBHS). It provides rapid and detailed evaluation procedures for inspecting buildings that have been damaged in wind storms and floods, and making decisions regarding their continued use and occupancy. Presented in a concise format designed for ease of use in the field, it is intended for use by volunteer structural engineers and building inspectors in posting buildings as "inspected" (apparently safe, green placard), "restricted use" (yellow) or "unsafe" (red). Available through ATC. (Published 2004, 132 pages)

ATC-48 (ATC/SEAOC Joint Venture Training Curriculum): The training curriculum, *Built to Resist Earthquakes, The Path to Quality Seismic Design and Construction for Architects, Engineers, and Inspectors*, was developed under a contract with the California Seismic Safety Commission and prepared by a Joint Venture partnership between ATC and SEAOC. Available through ATC. (Published 1999, 314 pages)

ATC-49: The 2-volume report, *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges; Part I: Specifications* and *Part II: Commentary and Appendices*, were developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, *Part I*, 164 pages and *Part II*, 294 pages)

ATC-49-1: The document, *Liquefaction Study Report, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges,* was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, 208 pages)

ATC-49-2: The report, *Design Examples, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*, was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through ATC. (Published 2003, 316 pages)

ATC-51: The report, *U.S.-Italy Collaborative Recommendations for Improved Seismic Safety of Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey). Available through ATC. (Published 2000, 154 pages)

ATC-51-1: The report, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey, NSS). Available in English and Italian through ATC. (Published 2002, 120 pages)

ATC-51-2: The report, *Recommended U.S.-Italy Collaborative Guidelines for Bracing and Anchoring Nonstructural Components in Italian Hospitals*, was developed under a contract with the Department of Civil Protection, Italy. Available in English and Italian through ATC. (Published 2003, 164 pages)

ATC-52: The project, "Development of a Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco", was conducted under a contract with the San Francisco Department of Building Inspection. The following reports were prepared:

ATC-52-1, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Potential Earthquake Impacts*. Available through ATC. (Published 2010, 78 pages)

ATC-52-1A, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Potential Earthquake Impacts Technical Documentation*. Available through ATC. (Published 2010, 160 pages)

ATC-52-2, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: A Community Action Plan for Seismic Safety*. Available through ATC. (Published 2010, 92 pages)

ATC-52-3, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Earthquake Safety for Soft-Story Buildings*. Available through ATC. (Published 2009, 60 pages)

ATC-52-3A, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Earthquake Safety for Soft-Story Buildings Documentation Appendices*. Available through ATC. (Published 2009, 206 pages)

ATC-52-4, *Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco: Post-Earthquake Repair and*

Retrofit Requirements. Available through ATC. (Published 2010, 130 pages)

ATC-53: The report, *Assessment of the NIST 12-Million-Pound (53 MN) Large-Scale Testing Facility*, was developed under a contract with NIST. Available through ATC. (Published 2000, 44 pages)

ATC-54: The report, *Guidelines for Using Strong-Motion Data and ShakeMaps in Postearthquake Response*, was developed under a contract with the California Geological Survey. Available through ATC. (Published 2005, 222 pages)

ATC-55: The FEMA 440 report, *Improvement of Nonlinear Static Seismic Analysis Procedures*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2005, 152 pages)

ATC-56: The report, FEMA 389, *Primer for Design Professionals: Communicating with Owners and Managers of New Buildings on Earthquake Risk*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2004, 194 pages)

ATC-56-1: The report, FEMA 427, *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks – Providing Protection to People and Buildings*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2003, 106 pages)

ATC-57: The report, *The Missing Piece: Improving Seismic Design and Construction Practices*, was developed under a contract with NIST. It provides a framework for eliminating the technology transfer gap that has emerged within the National Earthquake Hazards Reduction Program (NEHRP) that limits the adaptation of basic research knowledge into practice. Available through ATC. (Published 2003, 102 pages)

ATC-58/ATC-58-1: This series of projects, "Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings," was a multi-year, multi-phase effort funded by FEMA that has resulted in the publication of the following**:**

ATC-58-1, *Proceedings of a FEMA-Sponsored Workshop on Communicating Earthquake Risk*. Available through ATC. (Published 2002, 87 pages).

ATC-58-2, *Preliminary Evaluation of Methods for Defining Performance*. Available through ATC. (Published 2003, 99 pages).

ATC-58-3, *Proceedings of a FEMA-Sponsored Workshop on Performance-Based Design*. Available through ATC. (Published 2003, 146 pages).

FEMA 445, *Next-Generation Performance-Based Seismic Design Guidelines, Program Plan for New and Existing Buildings*. Available through ATC and FEMA. (Published 2006, 131 pages).

FEMA 461, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components*. Available through ATC and FEMA. (Published 2007, 113 pages).

FEMA P-58-1, *Seismic Performance Assessment of Buildings, Volume 1 – Methodology*. Available through ATC and FEMA. (Published 2012, 319 pages).

FEMA P-58-2, *Seismic Performance Assessment of Buildings, Volume 2 – Implementation Guide*. Available through ATC and FEMA. (Published 2012, 365 pages).

FEMA P-58-3, *Seismic Performance Assessment of Buildings, Volume 3 – Supporting Electronic Materials and Background Documentation*. Available through ATC and FEMA. (Published 2012, on CD).

ATC-60: The 2-volume report, *SEAW Commentary on Wind Code Provisions, Volume 1* and *Volume 2 - Example Problems,* was developed by the Structural Engineers Association of Washington (SEAW) in cooperation with ATC. Available through ATC. (Published 2004; *Volume 1*, 238 pages; *Volume 2*, 245 pages)

ATC-61: The 2-volume report, *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities, Volume 1 – Findings, Conclusions, and Recommendations*, and *Volume 2 – Study Documentation,* was prepared for the Multihazard Mitigation Council (MMC) of the National Institute of Building Sciences, with funding provided by FEMA. Available through ATC and the MMC. (Published 2005; *Volume 1*, 11 pages; *Volume 2*, 366 pages)

ATC-62: The report, FEMA P-440A, *Effects of Strength and Stiffness Degradation on Seismic Response*, was developed under a contract with FEMA. Developed as a supplement to the FEMA 440 report, it provides additional guidance on modeling of nonlinear degrading response. Available through ATC and FEMA. (Published 2009, 310 pages)

ATC-63: The report, FEMA P-695, *Quantification of Building Seismic Performance Factors*, was developed under a contract with FEMA. It describes a methodology for establishing seismic performance factors (R , Ω_0, and C_d) that involves the development of detailed system design information and probabilistic assessment of collapse risk. It utilizes nonlinear analysis techniques, and explicitly considers uncertainties in ground motion, modeling, design, and test data. The technical approach is a combination of traditional code concepts, advanced nonlinear dynamic analyses, and risk-based assessment techniques. Available through ATC and FEMA. (Published 2009, 420 pages)

ATC-63-1: The report, FEMA P-795, *Quantification of Building Seismic Performance Factors: Component Equivalency Methodology*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2011, 264 pages)

ATC-64: The reports, *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* (FEMA P-646), and *Vertical Evacuation from Tsunamis: A Guide for Community Officials* (FEMA P-646A), were developed under a contract with FEMA. Available through ATC and FEMA. (*Design Guidelines*, Published 2008, 174 pages; *Guide for Community Officials*, Published 2009, 62 pages)

ATC-65: The FEMA P-455 report, *Handbook for Rapid Visual Screening of Buildings to Evaluate Terrorism Risks*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 174 pages)

ATC-66: The report, FEMA P-774, *Unreinforced Masonry Buildings and Earthquakes, Developing Successful Risk Reduction Programs*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 194 pages)

ATC-68: The FEMA P-420 report, *Engineering Guideline for Incremental Seismic Rehabilitation*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2009, 94 pages)

ATC-69: The report, *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2008, 144 pages)

ATC-69-1: The electronic document, FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage, A Practical Guide*, was developed under a contract with FEMA. Available through ATC and FEMA. (Published 2011, 750 pages)

ATC-70: The report, NIST Technical Note 1476, *Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report*, was developed under a contract with NIST. Available through NIST. (Published 2006, 222 pages)

ATC-71: The reports, *Workshop on Meeting the Challenges of Existing Buildings, Part 1 Workshop Proceedings; Part 2: Status Report on Seismic Evaluation and Rehabilitation of Existing Buildings;* and *Part 3: Action Plan for the FEMA Existing Buildings Program*, were developed under a contract with FEMA. Available through ATC and FEMA. (*Part 1*, Published 2008, 142 pages; *Part 2*, Published 2009, 140 pages; *Part 3*, Published 2009, 118 pages)

ATC-72: The report, *Proceedings of Workshop on Tall Building Seismic Design and Analysis Issues* (ATC-72) was prepared for the Building Seismic Safety Council of the National Institute of Building Sciences, with funding provided by FEMA. The report, *Modeling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings* (PEER/ATC-72-1) was prepared for the Pacific Earthquake Engineering Research Center. Available through ATC and PEER. (*Proceedings*, Published 2007, 84 pages; *Modeling and Acceptance Criteria*, Published 2010, 242 pages)

ATC-73: The report, *NEHRP Workshop on Meeting the Challenges of Existing Buildings, Prioritized Research for Reducing the Seismic Hazards of Existing Buildings,* was developed under a grant from NSF. Available through ATC. (Published 2007, 22 pages)

ATC-74: The report, *Collaborative Recommended Requirements for Automatic Natural Gas Shutoff Valves in Italy,* was funded by the Department of Civil Protection, Italy. Available through ATC. (Published 2007, 76 pages)

ATC-75: The report, *Improvements to BIM Structural Software Interoperability*, was developed under a contract with the Charles Pankow Foundation. Available through ATC and CPF. (Published 2013, 155 pages)

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