



*Risk Management Series*

# Engineering Guideline for Incremental Seismic Rehabilitation

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**FEMA**



**Cover Photo:** Courtesy of University of California, Berkeley.

Steel Braced Frames were added to Hildebrand Hall at the University of California, Berkeley as part of a seismic rehabilitation for this building, which houses the College of Chemistry. The University received funding through FEMA's Hazard Mitigation Grant Program to complete this and other seismic rehabilitation projects on the Berkeley campus.

# Engineering Guideline for Incremental Seismic Rehabilitation



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# Foreword

Initial cost and loss of normal building use have been cited as major obstacles to implementation of seismic rehabilitation. The Federal Emergency Management Agency (FEMA) has published a series of occupancy-specific manuals for building owners that presents incremental strengthening of buildings in discrete stages as a way of managing costs and minimizing disruption associated with seismic rehabilitation projects.

Incremental strengthening was initially conceptualized for school buildings under a grant from the National Science Foundation to Building Technology Incorporated. The FEMA manuals are the result of a series of projects funded by FEMA and others dating back to the 1980s, which investigated financial incentives for seismic rehabilitation of existing hazardous buildings, physical seismic rehabilitation potential, and institutional capacity for mitigation investment. Work was conducted by a team of consultants led by the World Institute for Disaster Risk Management in association with Virginia Polytechnic Institute and State University, Building Technology Incorporated, Melvyn Green Associates, EQE Incorporated, and George Washington University. Early on, these projects concluded that a strategy for integrating the planning and implementation of seismic strengthening into the overall facility maintenance and capital improvement process was needed.

The strategy was referred to as incremental seismic rehabilitation, and the resulting manuals present seismic rehabilitation within the context of the specific facility management, risk management, and financial management needs and practices of building owners. At present these manuals include:

- FEMA 395, *Incremental Seismic Rehabilitation of School Buildings (K-12)*
- FEMA 396, *Incremental Seismic Rehabilitation of Hospital Buildings*

- FEMA 397, *Incremental Seismic Rehabilitation of Office Buildings*
- FEMA 398, *Incremental Seismic Rehabilitation of Multifamily Apartment Buildings*
- FEMA 399, *Incremental Seismic Rehabilitation of Retail Buildings*
- FEMA 400, *Incremental Seismic Rehabilitation of Hotel and Motel Buildings*

The technical feasibility and economic viability of incremental seismic rehabilitation has been studied and validated. This *Engineering Guideline for Incremental Seismic Rehabilitation* is intended as a technical resource for design professionals who are implementing incremental seismic rehabilitation on their projects or advocating the use of an incremental approach to seismic rehabilitation in practice. It explains the concept of incremental seismic rehabilitation as a strategy, discusses owner maintenance, capital improvement and decision-making processes as a basis for communicating with decision-makers on seismic rehabilitation opportunities, summarizes available engineering resource documents, and outlines the overall engineering process for incremental seismic rehabilitation of buildings.



# Chapter 1 Introduction to Incremental Seismic Rehabilitation

## 1.1 Background

The Federal Emergency Management Agency (FEMA) has published a series of occupancy-specific manuals for building owners that presents incremental strengthening of buildings in discrete stages as a way of managing costs and minimizing disruption associated with seismic rehabilitation projects. This series is based on the postulate that incremental improvement is better than delayed improvement or no improvement at all, and that seismic rehabilitation in existing buildings would occur more frequently if initial costs and functional disruption could be reduced.

The concept of “incremental seismic rehabilitation” has been applied in various situations for different building types and occupancies around the country. It offers a way of eliminating some of the barriers to implementation of seismic rehabilitation, and innovative structural engineers have developed and implemented various aspects of this concept in practice. The purpose of the FEMA Incremental Seismic Rehabilitation Series is to elevate this occasional, ad hoc practice to the level of a general strategy for reduction of earthquake risk in existing buildings and expansion of seismic rehabilitation activities throughout the United States.

## 1.2 What is Incremental Seismic Rehabilitation?

Incremental seismic rehabilitation is an approach to seismic rehabilitation that integrates an ordered series of discrete rehabilitation actions into

### In Brief

This chapter:

- Defines incremental seismic rehabilitation
- Explains where incremental seismic rehabilitation is being used
- Describes the manuals in the FEMA Incremental Seismic Rehabilitation Series
- Outlines the scope, organization, and content of this manual

ongoing facility maintenance and capital improvement activities over an extended period of time. The process involves a series of projects that are planned around regularly scheduled building maintenance, repairs, or renovations, and are timed to coincide with periods of reduced occupancy or use.

Initial cost and loss of normal building use have been cited as major obstacles to investment in seismic rehabilitation. The concept of incremental seismic rehabilitation is specifically designed to remove these obstacles. The underlying assumption is that integration of seismic rehabilitation work into normal building operation and maintenance cycles significantly reduces cost and disruption because scaffolding and other construction equipment are in place, work surfaces are exposed, occupants are already displaced, and interruptions in use are already accommodated.

### ***1.3 Are Incremental Seismic Rehabilitation Approaches Currently Being Used?***

Incremental seismic rehabilitation was initially conceptualized for school buildings. An incremental approach to seismic rehabilitation has been practiced by Seattle Public Schools in Seattle, Washington for more than 25 years. This program was studied in detail, and contributed significantly to the approach described in the FEMA Incremental Seismic Rehabilitation Series. The Seattle Public Schools program is presented as a case study in Appendix A.

Incremental seismic rehabilitation has also been utilized by schools in other areas, such as the Jordan and Davis County School Districts in Utah. In these school districts, rehabilitation measures that can be accomplished over the summer months have been implemented in many older school buildings.

For the most part, use of incremental seismic rehabilitation to date has been the result of individual creative efforts on the part of innovative design professionals and building owners on a project-by-project basis. One such individual project is presented as a case study in Appendix B. In some jurisdictions incremental approaches have been written into seismic strengthening ordinances, such as the Earthquake Hazard Reduction Ordinance (City of Los Angeles, 1981) addressing unreinforced masonry buildings in the City of Los Angeles, California.

### ***1.4 The FEMA Incremental Seismic Rehabilitation Series***

Each manual in the FEMA Incremental Seismic Rehabilitation (ISR) Series addresses seismic rehabilitation within the context of the specific facility management, risk management, and financial management needs and practices within a particular type of occupancy. The manuals are written for building owners, operators, and other decision-makers, and provide guidance on how to integrate seismic rehabilitation into the overall building maintenance and capital improvement process.

At present, the FEMA ISR Series includes the following manuals:

- FEMA 395, *Incremental Seismic Rehabilitation of School Buildings (K-12)* (FEMA, 2003)
- FEMA 396, *Incremental Seismic Rehabilitation of Hospital Buildings* (FEMA, 2003)
- FEMA 397, *Incremental Seismic Rehabilitation of Office Buildings* (FEMA, 2003)
- FEMA 398, *Incremental Seismic Rehabilitation of Multifamily Apartment Buildings* (FEMA, 2004)
- FEMA 399, *Incremental Seismic Rehabilitation of Retail Buildings* (FEMA, 2004)
- FEMA 400, *Incremental Seismic Rehabilitation of Hotel and Motel Buildings* (FEMA, 2004)

## **1.5 Scope, Organization, and Content**

This guide is a companion to the FEMA ISR Series of occupancy manuals. It is intended as a technical resource for design professionals who are implementing incremental seismic rehabilitation on their projects or advocating the use of an incremental approach to seismic rehabilitation in practice. It explains the concept of incremental seismic rehabilitation as a strategy, discusses owner maintenance, capital improvement and decision-making processes as a basis for communicating with decision-makers on seismic rehabilitation opportunities, summarizes available engineering resource documents, and outlines the overall engineering process for incremental seismic rehabilitation of buildings.

**Chapter 1** provides background information and introduces the concept of incremental seismic rehabilitation.

**Chapter 2** explains the incremental seismic rehabilitation process and compares it to single-stage rehabilitation.

**Chapter 3** discusses building owner perspectives on seismic rehabilitation and outlines the maintenance and capital improvement decision-making processes.

**Chapter 4** summarizes available engineering resource documents and how to use them in the context of incremental seismic rehabilitation.

**Chapter 5** outlines the basic information and overall engineering process for incremental seismic rehabilitation of buildings.

**Chapter 6** discusses future needs and possibilities for incremental seismic rehabilitation.

**Appendix A** presents a case study of how an overall program has been implemented in the Seattle Public Schools incremental seismic rehabilitation program.

**Appendix B** presents a case study illustrating how seismic rehabilitation increments were staged in an individual building located in Southern California.

**Appendix C** lists relevant existing building resource documents from the FEMA Existing Buildings Program and other sources, which could be applicable to the development and implementation of an incremental seismic rehabilitation program.

# Chapter 2 Incremental Compared to Single-Stage Seismic Rehabilitation

## 2.1 Options for Seismic Risk Reduction

In vulnerable buildings, the risk of structural collapse poses the single greatest threat in a major earthquake. Beyond collapse, additional risks include casualties, injuries to building occupants, damage to nonstructural components and systems, loss of property, and loss of use. Options for reducing seismic risk in existing buildings are shown in Figure 2-1:



Figure 2-1 Options for Seismic Risk Reduction (FEMA ISR Series).

### In Brief

This chapter:

- Compares incremental seismic rehabilitation to single-stage rehabilitation
- Highlights differences in engineering practice
- Discusses how incremental seismic rehabilitation affects liability

These options include the following actions:

**Do Nothing.** No capital investment is made in improving structural or nonstructural performance. This option can include the purchase of earthquake insurance or a plan to self-insure for capital losses.

**Replace.** Demolition and reconstruction is carried out in accordance with current building codes. This alternative is generally associated with the greatest cost and lowest overall risk. Financial constraints, historic preservation concerns, and zoning restrictions can make replacement difficult or infeasible.

**Rehabilitate.** Also referred to as “retrofit” or “strengthening,” rehabilitation involves capital investment to improve the structural performance, nonstructural performance, or both.

Consideration of cost and disruption associated with seismic rehabilitation leads to two additional options:

**Single-Stage Rehabilitation.** Rehabilitation that meets all seismic performance objectives in a single project, by incurring all costs and disruption of occupancy and use at one time.

**Incremental Rehabilitation.** Rehabilitation that eventually meets seismic performance objectives by implementing an ordered series of discrete rehabilitation actions over an extended period of time. Often such work is integrated into ongoing facility maintenance and capital improvement operations.

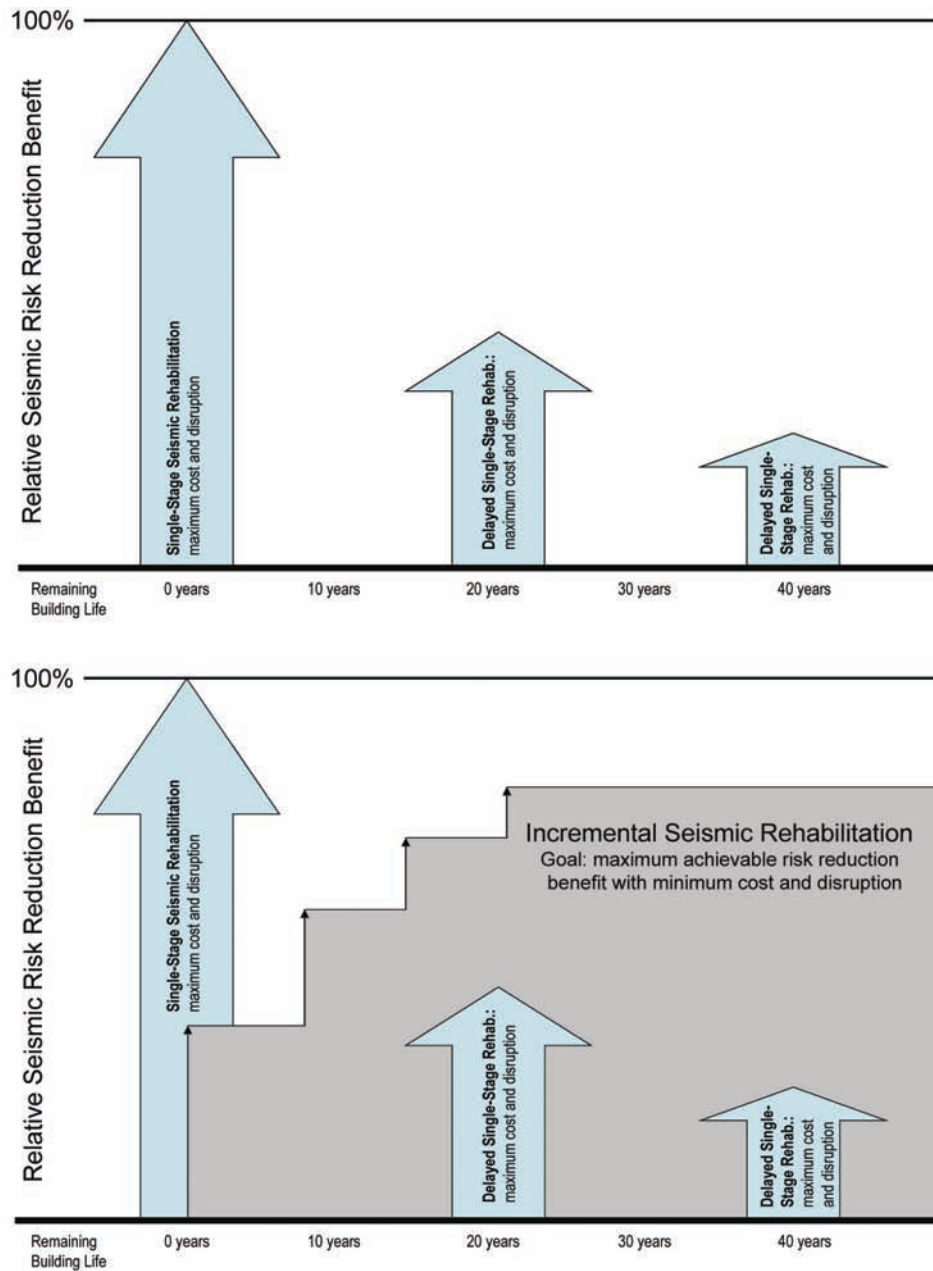
## **2.2 How Do the Benefits of Incremental and Single-Stage Seismic Rehabilitation Compare?**

Annualized losses are the result of probable damage that can occur in any year from all possible earthquakes. The primary benefit of seismic rehabilitation is a reduction in damage that is likely to occur along with a corresponding reduction in annualized losses. Using information from FEMA 227, *A Benefit-Cost Model for the Seismic Rehabilitation of Buildings* (FEMA, 1992) and FEMA 255, *Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model* (FEMA, 1994), it is possible to develop a life-cycle benefit/cost analysis that compares incremental to single-stage seismic rehabilitation.

This benefit/cost analysis postulates a series of seismic rehabilitations undertaken over a range of time periods. Expected annual damage is calculated over an arbitrary remaining building service life (e.g., 50 years) and the benefits of rehabilitation (reduced damage) are discounted to a net present value for each rehabilitation scenario. Benefits are expressed as a percentage of the benefits achieved by a full seismic rehabilitation conducted in year zero, and the results are compared on a relative basis.

Schematic diagrams in Figure 2-2 illustrate how the benefits of single-stage and incremental seismic rehabilitation scenarios vary over time. Figure 2-2 (top) shows the relative benefits of single-stage rehabilitation projects occurring at year 0, year 20, and year 40. The largest benefit is derived from a single-stage rehabilitation project completed in the near term, designated as 100%. The relative benefits of single-stage rehabilitation projects occurring in later years are only a fraction of this value.

In Figure 2-2 (bottom), the benefits of an incremental seismic rehabilitation project are overlaid on the single-stage project results. In this example, the incremental program begins in year zero, and is completed in four increments over 20 years. The benefits of incremental stages of work completed in the future are discounted, so the relative benefit of the incremental program is less than the benefit of a single-stage rehabilitation conducted in year zero. But because increments of work are completed earlier, and corresponding benefits are realized sooner, the value of an incremental seismic rehabilitation project is higher than a single-stage project completed at the same time or later.



**Figure 2-2** Comparison of generalized life-cycle benefit/cost analyses: (top) relative benefit of single-stage rehabilitation projects conducted at different times; (bottom) step-function of an incremental rehabilitation project overlaid onto single-stage rehabilitation results.

Such an analysis shows that a series of seismic rehabilitation increments conducted over a defined period of time can produce nearly as much benefit as a single-stage rehabilitation project conducted in year zero. While this example considers an incremental rehabilitation program occurring over a period of 20 years, this should not be considered a target. Reducing the overall duration of an incremental rehabilitation program will increase its benefit, and extending the duration will decrease it. There is a lasting value in overall risk reduction when work is completed early in the remaining service life of a building. Incremental seismic rehabilitation offers flexibility in the sequence and timing of rehabilitation actions, and can be more effective than a delayed, single-stage rehabilitation project.

## **2.3 The Approach to Incremental Seismic Rehabilitation**

The approach to incremental seismic rehabilitation involves identification of seismic risk and seismic vulnerabilities, development of specific actions to rehabilitate potential deficiencies, and prioritization of work into a plan that takes advantage of ongoing maintenance or capital improvement activities over time. Incremental seismic rehabilitation terms, and their use, are defined below.

*Rehabilitation measures* are specific actions that are taken to improve the seismic performance of existing structural and nonstructural components. *Integration opportunities* are ongoing maintenance and capital improvement projects that could be expanded to include seismic rehabilitation measures. *Rehabilitation increments* (or stages) are collections of rehabilitation measures that have been grouped to take advantage of integration opportunities. A *rehabilitation plan* includes all anticipated rehabilitation increments and their prioritization. *Rehabilitation objectives* are statements of the intended seismic performance level (for both structural and nonstructural components) at a specified earthquake hazard level.

A comprehensive *incremental seismic rehabilitation program* involves assessment of risk, planning and design to mitigate risk, budgeting and financing, and construction management. In such a program, rehabilitation measures are implemented in a series of rehabilitation increments, which have been scheduled based on available integration opportunities. Collectively, rehabilitation actions achieve the selected rehabilitation objective once all of the increments in a rehabilitation plan have been completed.

### **2.3.1 Elements of an Incremental Seismic Rehabilitation Program**

In the FEMA ISR Series, typical elements of an incremental seismic rehabilitation program include:

- Due Diligence Analysis
- Operator Risk Reduction Standards
- Initial Integration Opportunities
- Seismic Screening
- Seismic Evaluation



- Developing a Risk Reduction Policy
- Seismic Rehabilitation Planning for Specific Buildings
- Staging Seismic Rehabilitation Increments
- Budget Packaging
- Financial Packaging
- Seismic Rehabilitation Project Management

Most of these program elements are generally applicable within the facility management processes for all occupancy categories covered in the FEMA ISR Series. Some program elements, however, are occupancy-specific, and some occupancies have special elements. Many program elements require engineering services in order to implement.

The elements of an incremental seismic rehabilitation program that require engineering services are listed below, along with a brief description of the type of engineering services needed. Implementation of incremental seismic engineering processes is described in more detail in Chapter 5.

**Due Diligence Analysis.** Due diligence analysis is an activity required by investors, lenders, and insurance companies to identify potential risks that might be incurred in a real estate transaction. Potential risks can include seismic risk, and due diligence analysis can be used to avoid acquiring buildings with seismic deficiencies that need rehabilitation. It can also be used to factor potential seismic risk and possible seismic rehabilitation into a plan for acquiring a specific building. Procedures for conducting due diligence analyses as part of an incremental seismic rehabilitation program are the same as typical engineering practice for single-stage projects.

**Seismic Screening.** Seismic screening is a rapid, simple, preliminary assessment of potential seismic deficiencies. Typically it is used to assess and rank the seismic vulnerability of buildings within a portfolio of buildings, but it can also be used as a preliminary evaluation tool to get a sense of the possible seismic risk associated with an individual building. Procedures for conducting seismic screening as part of an incremental seismic rehabilitation program are the same as typical engineering practice for single-stage projects.

**Seismic Evaluation.** Seismic evaluation is a more detailed assessment and confirmation of potential seismic deficiencies. Typically it is conducted on individual buildings that have been identified as vulnerable by a screening process. Procedures for conducting seismic evaluation as part of an incremental seismic rehabilitation program are the same as typical engineering practice for single-stage projects.

**Seismic Rehabilitation Planning for Specific Buildings.** Incremental seismic rehabilitation differs most from typical engineering practice in this element. Planning for specific buildings involves the development of an incremental seismic rehabilitation plan, design and prioritization of rehabilitation measures, identification of integration opportunities, and definition of appropriate rehabilitation increments.

**Staging Seismic Rehabilitation Increments.** In contrast with typical engineering practice for single-stage projects, staging of seismic rehabilitation increments involves phasing of work into appropriate stages,

and development of an overall implementation timeline. Rehabilitation measures must be staged so that collectively, all seismic performance objectives are met when all increments have been completed, and that individually, no one increment leaves the building more vulnerable than when work was initiated.

**Seismic Rehabilitation Project Management.** Seismic rehabilitation project management includes support during the construction phase. Similar to construction management or construction support services for single-stage projects, this phase involves ensuring that plans, specifications, and quality assurance provisions are properly implemented in the field. Additional construction support services may be required for a project that is staged in increments over several years.

## ***2.4 How do Engineering Services for Incremental Seismic Rehabilitation Differ from Typical Engineering Practice?***

Projects undertaken in a single stage generally have a short timeframe under which commencement and completion of the work is anticipated. With incremental seismic rehabilitation, work can extend over a period of years. In the FEMA ISR Series, building owners and operators are counseled to expect that implementation of incremental seismic rehabilitation will require more effort than typical design practice for single-stage projects. Development of an incremental rehabilitation plan, design of rehabilitation increments, negotiating plan check and permit approvals, performing construction support services, coordinating with tenant improvement activities, and tracking progress and completion of the work will all likely require special effort.

In addition, there are other issues related to inevitable changes that can occur when a project is staged over an extended period of time. Similarities and differences between incremental seismic rehabilitation and typical engineering practice for single-stage projects are described below.

### ***2.4.1 Development of an Incremental Seismic Rehabilitation Plan***

An incremental seismic rehabilitation plan includes all anticipated rehabilitation increments and their prioritization. Such a plan is not part of typical engineering practice. An effective plan is one in which the rehabilitation increments are integrated into the facility management and capital improvement processes, which can vary with occupancy type. Development of an incremental seismic rehabilitation plan requires design professionals to understand the occupancy-specific facility management and decision-making processes to better identify integration opportunities.

### ***2.4.2 Analysis and Design***

The basic seismic analysis and design tools used in incremental seismic rehabilitation are the same as those used in typical engineering practice for single-stage projects. Currently available resources for seismic screening, evaluation, and rehabilitation, which have been published by FEMA and others, are described in Chapter 5 and Appendix C.

### **2.4.3 Special Design Considerations**

Because the premise of incremental seismic rehabilitation assumes that the building will be opportunistically upgraded over a period of time, there will be interim stages when the building is in a “partial” state of seismic upgrade. This requires that the design professional understand the potential consequences of prioritization and phasing of work.

The overarching design consideration for incremental seismic rehabilitation is to “do no harm” to the building. Each increment of work must improve the overall seismic performance of the building, and no increment should leave the building in a condition that is more vulnerable than it was when work was initiated. Understanding the consequences of phasing, and effectively staging rehabilitation increments for improved performance, will likely require additional analyses of the partially upgraded building and multiple iterations in the design process.

### **2.4.4 Preparation of Construction Documents**

Alternatives for the preparation of construction documents include: (1) separate documents for each rehabilitation increment; and (2) a single set of documents clearly defining the sequence and scope of work for each rehabilitation increment.

Separate sets of construction documents have advantages with regard to permitting and construction phasing. Each increment is permitted separately, and each permit is closed out at the conclusion of the construction of each increment. This provides greater flexibility in the timing and completion of future increments of work. A possible disadvantage is that documentation for the work is split up among several sets of construction documents. This may make it more difficult to coordinate work between increments and to monitor progress toward ultimate completion.

A single set of construction documents has advantages with regard to coordination and monitoring of work. With all information in one set of documents, it is more likely that rehabilitation measures in each increment are properly coordinated, and that no rehabilitation measures are inadvertently omitted. If all work is permitted under a single set of documents, it is also more likely that all increments of work will be completed. This has the possible disadvantage of reducing flexibility in the completion of future increments by forcing work to occur within the time frame of a single permit.

### **2.4.5 Plan Check and Permitting**

Whether seismic rehabilitation work is voluntary or triggered by code requirements, incremental seismic rehabilitation may require special approvals in the plan check and permitting process. Negotiation with building officials may be required in determining appropriate increments that “do no harm” to the building, and in the sequence, scheduling, and completion of future increments of work.

### **2.4.6 Implementation of an Incremental Seismic Rehabilitation Plan over Time**

As an incremental rehabilitation plan is implemented over time, potential changes from a variety of sources can affect the parameters on which a plan was based. Both owners and design professionals should be aware of the possible need to re-evaluate the elements of an incremental seismic rehabilitation plan, and make adjustments in the design and implementation of the plan, if needed. Sources of possible changes over time include:

- Revisions to seismic codes and standards
- Emerging building technologies, systems, and materials
- Changes in building occupancy and use
- Natural disasters or other events affecting the condition of the building
- New building ownership
- Owner financial status and evolving local market conditions
- Owner strategic plans and changing priorities
- Adjustments to maintenance and capital improvement plans
- Turnover in professional design staff

Changes in reference codes and standards, or in the condition of the building, have the potential to result in the need to re-design portions of the incremental seismic rehabilitation work in future years. An evolving financial climate could alter the perceived benefit/cost ratio of planned work. Changes in the status of building ownership, or in the priorities of the existing owner, can affect the implementation of future rehabilitation increments.

In prioritizing and staging rehabilitation increments, design professionals should consider the possibility that future work may be delayed. During interim stages, while a building is in a state of partial upgrade, design professionals may find themselves in the position of advocating for the eventual completion of seismic rehabilitation work. This role is particularly important since building owners and other decision makers may not have seismic rehabilitation as their highest priority at all times.

Implementation of an incremental seismic rehabilitation plan over time will be more successful if design and construction documentation is more rigorous and more easily retrievable than might otherwise be necessary for single-stage rehabilitation projects. Owners and design professionals should consider the need to carefully document each phase of incremental seismic rehabilitation work and anticipate scheduling of follow-up work. With proper documentation, institutional knowledge on a specific project will not be sensitive to turnover in professional design staff or building ownership, and changes in the plan will be easier to evaluate and implement.

## **2.5 How Does Incremental Seismic Rehabilitation Affect Liability?**

Some design professionals have been reluctant to undertake rehabilitation projects that are not in full compliance with current seismic criteria for new or existing buildings. There is a belief that additional exposure to professional liability exists when work results in a partial upgrade, or when work is conducted in increments.

While incremental seismic rehabilitation requires additional effort on the part of the design professional, the basic elements of incremental seismic design practice are the same as typical engineering practice for single-stage projects. Conduct of incremental seismic rehabilitation design in accordance with the requirements of currently available codes and standards for existing buildings, and in accordance with the standard of care for prevailing seismic design practice, should not result in an increase in professional liability.

The key to this assertion is that rehabilitation increments should be designed in such a way as to “do no harm” to the building. Work should not result in any dangerous conditions, and should not make a building less conforming to the code. Staging rehabilitation measures so that each increment of work will result in an incremental improvement in performance serves to protect the building, and the design professional, in the event that future increments of work are not completed. While the performance objectives for the full rehabilitation project may not be met, overall performance will be improved.

Design professionals must clearly document decisions and actions, what will be achieved, and what will not be achieved with each rehabilitation increment. The consequences of not completing all increments in an incremental rehabilitation plan, and the corresponding reduced benefits (increased risk), must be clearly communicated to building owners. The strategy of incremental seismic rehabilitation assumes a commitment to reduce seismic risk over time, which should be fully understood and appreciated by both parties.

Additional considerations for professional liability associated with incremental seismic rehabilitation include:

- Professional liability policy limitations
- Extended liability coverage
- Ownership (beneficiary) changes
- Insurance provider changes

Design professionals should review these and other potential risk and exposure concerns with their professional liability insurance provider.



# Chapter 3 Owner/Operator Perspectives on Incremental Seismic Rehabilitation

## **3.1 Owner/Operator Objectives: Revenue Generation, Equity, and Service Delivery**

Buildings are owned, occupied, and operated for the purpose of generating revenue, accruing equity, or delivering a service. Revenue is generated in the form of rent or lease payments, or through the sale of merchandise or manufactured products. Equity is value gained (or lost) over time. In all cases, revenue generation, equity gain, and service delivery depend upon continuous occupancy and use of a building.

At some point in their useful life, portions of buildings can evolve into a state of disrepair or become obsolete in terms of performing their intended functions. Many building owners take these opportunities to periodically invest in building improvements that serve to maintain facilities, enhance revenue generation, or improve the quality of service provided. Ongoing maintenance and capital improvement work provides an opportunity to integrate seismic rehabilitation into a facility management program at a time when other work is scheduled to occur. Because construction crews are already mobilized, finishes are removed, and occupancy is already interrupted, seismic rehabilitation work can opportunistically occur at minimal additional cost and disruption to facility operations.

Effective implementation of incremental seismic rehabilitation measures into the facility management process can remove the obstacles of initial cost and loss of normal building use associated with single-stage rehabilitation projects.

### In Brief

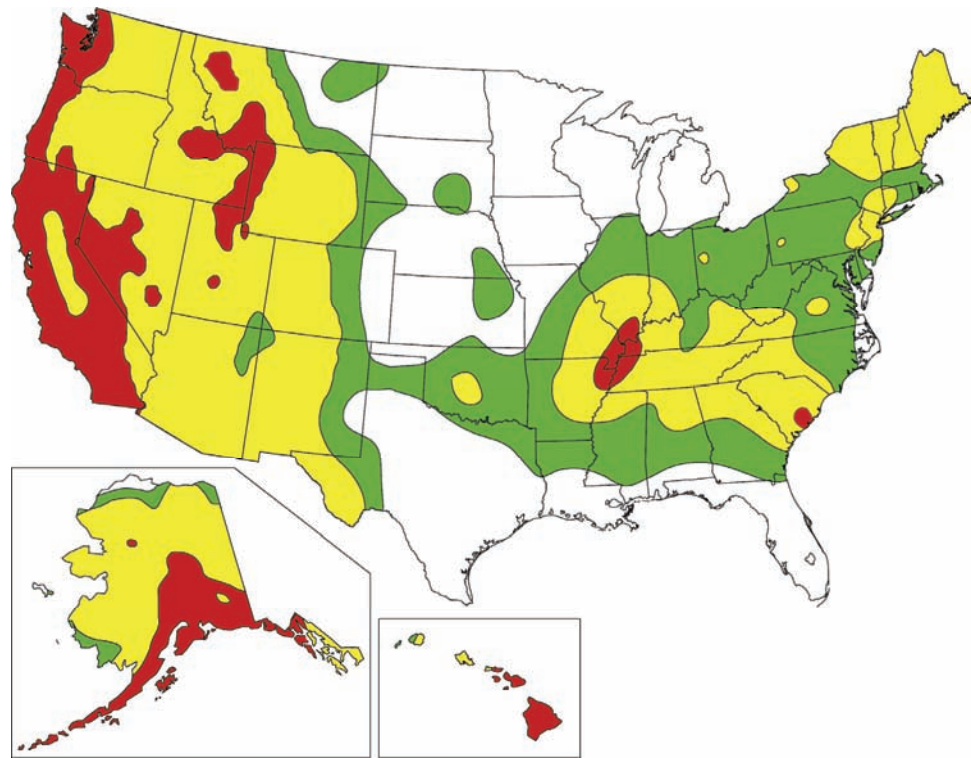
This chapter:

- Explains building owner/operator perspectives on earthquake hazard, vulnerability, and risk
- Outlines the typical facility management process as depicted in the FEMA ISR Series
- Provides guidance on communicating with multiple client audiences

## 3.2 Hazard, Vulnerability, and Risk

In the FEMA ISR Series, building owners and operators are presented with the concept that earthquake risk is a function of earthquake hazard and vulnerability. Failure to address earthquake risk can leave building owners exposed to potential losses from damage, disruption, and liability for deaths and injuries. While purchasing insurance can protect against financial losses due to damage and liability, it does not solve the problem of long-term disruption of operations. Seismic rehabilitation is presented as the best option for reducing all aspects of earthquake risk.

Earthquakes are characterized as low-probability, high consequence events. In the FEMA ISR Series, geographic variation in earthquake hazard is illustrated with the use of a simplified seismic hazard map, as shown in Figure 3-1.



**Figure 3-1** Simplified seismic hazard map showing red, yellow, and green areas indicating regions of high, moderate, and low seismicity, respectively (FEMA ISR Series).

The map in Figure 3-1 is based on United States Geological Survey (USGS) seismic hazard maps, but is a simplified representation of seismic hazard intended to explain regions of high, moderate, and low seismicity to building owners. It should be noted that engineering seismology is in a constant state of revision, and updated hazard characterization is available from the USGS. Seismic hazard characterization for use in engineering applications is explained in more detail in Chapter 5.

Owners with buildings in regions of high seismicity (red areas) are advised to take immediate action in undertaking a comprehensive vulnerability



assessment to identify buildings in need of structural and nonstructural seismic rehabilitation or replacement.

Owners with buildings in regions of moderate seismicity (yellow areas) are advised to further investigate their exposure to earthquake risk, identify vulnerable buildings for rehabilitation or replacement, and consider mitigation of risk due to potential nonstructural hazards in particular.

Owners with buildings in regions of low seismicity (green areas) are advised to consider low-cost rehabilitation strategies that protect against casualties and property loss, although the probability of an earthquake occurring might be low.

Given some level of seismic hazard, the concept of building vulnerability to damage in the event of an earthquake, including both structural and nonstructural damage, is explained. Owners are introduced to the concepts of seismic screening and seismic evaluation, and instructed to seek engineering assistance from design professionals in performing vulnerability assessments. Consequences of earthquake vulnerability are characterized as:

- Deaths and injuries to building occupants, and related liability
- Building collapse or damage to building components, including related costs for repair or replacement
- Damage to building contents, and related costs or liabilities
- Disruption of building operations and related costs or liabilities

### **3.3 Overview of the Facility Management Process**

Engineering services associated with incremental seismic rehabilitation must be integrated into the facility management process. Each occupancy category is subject to its own set of constraints on the facility management process. These constraints, along with the specific facility management, risk management, and financial management needs and practices for each occupancy, are described in more detail in the FEMA ISR Series for the following occupancy categories:

- School Buildings
- Hospital Buildings
- Office Buildings
- Multifamily Apartment Buildings
- Retail Buildings
- Hotel and Motel Buildings

Design professionals should understand the facility management process for each occupancy category and appreciate the many factors affecting how maintenance and capital improvement decisions are made. A typical facility management process includes the following phases of activity:

- Acquisition
- Redevelopment

- Use
- Planning
- Budgeting
- Funding
- Implementation

These phases of activity are generally applicable to the facility management processes for all occupancy categories covered in the FEMA ISR Series. Some activities, however, are occupancy-specific, and some occupancies have special activities. In the case of hospitals, for example, accreditation is an activity that is unique to that occupancy, and in the case of hotels and motels, change of management can be just as critical as a change in ownership, but quite different.

The facility management process is sequential, progressing from the acquisition phase through the implementation phase, as illustrated in Figure 3-2. Planning horizons for maintenance and capital improvement projects differ from one owner to the next. Some may have a one-year time frame, others may use five years, while still others may extend this horizon to 15 years. An owner with a large inventory of buildings is likely to have ongoing activities in all phases of this process within different buildings across the entire inventory.

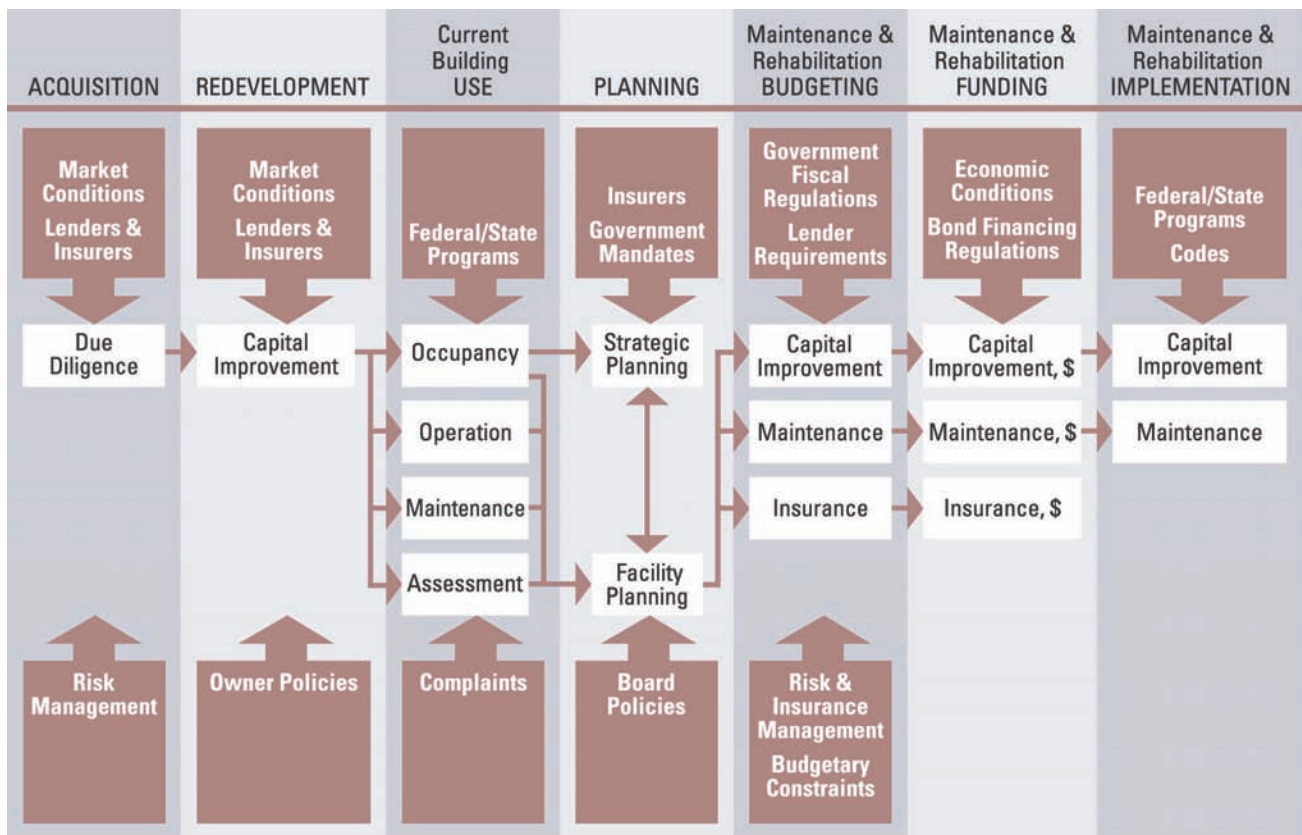


**Figure 3-2** Typical sequential facility management process (FEMA ISR Series).

Facility management processes vary with building ownership and occupancy category. They are subject to influence from a number of internal and external factors such as board of director policies, risk management policies, market conditions, economic conditions, government regulations, building code requirements, and insurance and lending requirements.

For example, in the case of commercial office buildings, internal and external influences on the facility management process are shown in Figure 3-3. This is one of a series of figures in FEMA 397 intended to illustrate the facility management process and interrelationship between internal and external factors that are specific to commercial office occupancies. In the figure, columns correspond to phases of facility management activity for commercial office occupancies, boxes identify stakeholder groups or other factors (e.g., policies, regulations, market conditions) that have the potential to influence facility management decisions in each phase, and arrows represent the flow of information or direction of influence.

Appendices in each of the FEMA ISR occupancy manuals provide a detailed explanation of the facility management processes, along with the associated internal and external influences, for each occupancy category.



**Figure 3-3 Influences on the facility management process used in commercial office buildings (FEMA 397).**

### 3.3.1 Integration of Incremental Seismic Rehabilitation Program Elements

Elements of an incremental seismic rehabilitation program extend from the acquisition phase to the implementation phase of a typical facility management process. Typical elements of an incremental seismic rehabilitation program include:

- Due Dilligence Analysis
- Operator Risk Reduction Standards
- Initial Integration Opportunities
- Seismic Screening
- Seismic Evaluation
- Developing a Risk Reduction Policy
- Seismic Rehabilitation Planning for Specific Buildings
- Staging Seismic Rehabilitation Increments
- Budget Packaging
- Financial Packaging
- Seismic Rehabilitation Project Management

Most of these program elements are generally applicable within the facility management processes for all occupancy categories covered in the FEMA

ISR Series. Some program elements, however, are occupancy-specific, and some occupancies have special elements. Figure 3-4 illustrates when the above program elements should be integrated into the phases of a typical facility management process.

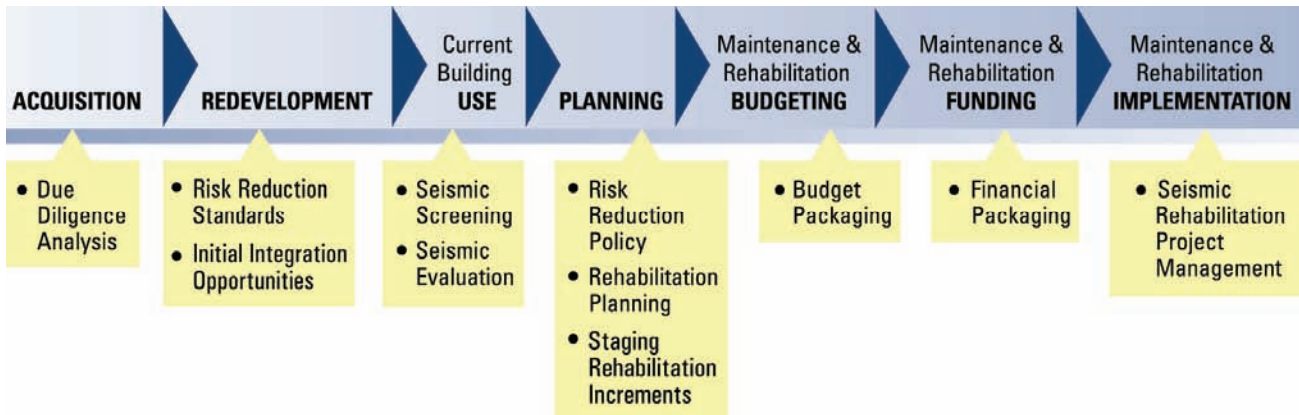


Figure 3-4 Integration of typical incremental rehabilitation program elements within the typical sequential facility management process (FEMA ISR Series).

### 3.4 The “Educated Client” Perspective

The occupancy-specific manuals of the FEMA ISR Series are intended to separately educate building owners, operators, and other stakeholders on the concepts of building vulnerability, seismic hazard, and mitigation of earthquake risk. They also lay out how incremental seismic rehabilitation can be integrated into occupancy-specific facility management processes. Owners and decision-makers that are familiar with the FEMA ISR manual for their specific occupancy have the advantage of coming to the table equipped to make informed decisions on the many choices associated with seismic evaluation and rehabilitation. With an understanding of how earthquake risk fits within their business and facility management plans, they may be more motivated to implement seismic rehabilitation in their buildings, and willing to be a collaborative partner in the seismic design process.

This educated client perspective greatly improves discussions at an early stage, and helps form the basis for mutual understanding of the many factors affecting the successful completion of incremental seismic rehabilitation projects. The design professional, however, remains an important part of the overall client education process.

### 3.5 Communicating with Multiple Client Audiences

There are many variables associated with the feasibility of a project and with choosing among various maintenance, capital improvement, and seismic rehabilitation alternatives. Some owners may have extensive management teams that include facilities, risk, and financial management functions composed of multiple departments and many personnel. Others may have combined these business concerns into a single department, or even a single person. In the simplest of organizational structures,

however, maintenance, risk, and financial considerations are still valid, and design professionals may need to address each of these individually.

Opportunities to influence the decision-making process are best afforded at the early stages of project development. The role of the design professional will be to provide both qualitative and quantitative information on seismic vulnerability and relative benefits and costs associated with seismic rehabilitation, which can then be weighed and discussed on equal footing with the other drivers for decision-making.

An owner (or ownership team) may include one or more of the following: facility manager(s), risk manager(s), and financial manager(s). Understanding the perspectives of multiple client audiences is important for clearly communicating engineering considerations associated with incremental seismic rehabilitation.

### **3.5.1 Facility Managers**

In general, facility managers are concerned about the overall condition and functionality of the assets. Facility managers carry out planning activities by considering market conditions, area demographics, physical condition, and projected useful life of existing buildings. Often they consider pressing social issues such as physical security and accessibility. Sometimes facility managers consider the risk to buildings associated with natural disasters, including earthquakes.

### **3.5.2 Risk Managers**

Risk managers carry out planning activities by considering three aspects of risk management: (1) risk identification; (2) risk reduction; and (3) risk transfer. The latter generally involves the purchase of insurance. Owner and operator risks are generally classified into the following broad areas: liability risk, larceny risk, employee risk, and facility and environmental risk. Seldom do risk managers consider risks to buildings and their occupants associated with natural disasters. Rather, they tend to assume that such risks are addressed by building codes and similar regulations.

### **3.5.3 Financial Managers**

Financial managers generally control and manage maintenance budgets, capital improvement budgets, and insurance budgets. Facility managers and risk managers present demands on these budgets to the financial managers, but the potential tradeoffs among these budgets are not often considered. The relative costs and benefits of various options for facility risk management are rarely explicitly addressed in the usual budgeting process.



# Chapter 4 Codes and Standards for Seismic Evaluation and Rehabilitation

## 4.1 *Seismic Rehabilitation in Building Codes and Standards*

In general, most states and local jurisdictions rely on model codes and standards that are developed through a national consensus process to establish building requirements. Current national model codes and standards include the following documents:

- International Code Council (ICC), *International Building Code* (ICC, 2006a)
- International Code Council (ICC), *International Existing Building Code* (ICC, 2006b)
- American Society of Civil Engineers, ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2006a)
- American Society of Civil Engineers, ASCE/SEI 31, *Seismic Evaluation of Existing Buildings* (ASCE, 2003)
- American Society of Civil Engineers, ASCE/SEI 41, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2006b)

Most jurisdictions adopt building codes that regulate the continued use of existing buildings in some way. There are three ways in which the seismic evaluation and rehabilitation of existing buildings are initiated. Efforts are mandated, triggered, or voluntarily undertaken.

### In Brief

This chapter:

- Lists current national model building codes and standards relevant to seismic evaluation and rehabilitation
- Summarizes building code requirements related to work on existing buildings
- Explains the code rationalization for incremental seismic rehabilitation

### **4.1.1 Mandated Rehabilitation**

Mandated programs are those that require seismic rehabilitation (or at least evaluation) for specified buildings regardless of action on the part of a building owner. Also called “active programs,” mandates are frequently driven by legislation or by some authority other than the building owner. The rationale for legislation varies, but it usually involves a persistent pattern of poor seismic performance along with a sizable remaining inventory of susceptible building stock.

### **4.1.2 Triggered Rehabilitation**

In triggered programs, also called “passive programs,” seismic evaluation or rehabilitation might not be intended on the part of the building owner, but is required (or triggered) based on the scope of repairs, additions, alterations, changes of occupancy, or other work that is proposed. Most triggered rehabilitation is driven by business decisions to otherwise improve a property. Once rehabilitation is triggered, it is effectively mandatory if the proposed work is to be done.

### **4.1.3 Voluntary Rehabilitation**

Voluntary rehabilitation is work initiated by the building owner (or other stakeholder) and subject to minimal outside requirements. Voluntary work is generally driven by institutional policy or the risk sensitivity of an individual building owner. Although full compliance is not required or necessary, codes and standards are often used to guide seismic evaluation and design as part of voluntary rehabilitation efforts.

## **4.2 Code Rationalizations for Incremental Seismic Rehabilitation**

Building codes allow existing buildings to remain in use without having to fully comply with the requirements for new buildings. This is generally referred to as “nonconforming rights.” The traditional language permits the legal occupancy of existing structures to continue with no change, unless deemed necessary by the building official for the safety and welfare of the occupants and the public, as long as no action on the part of the owner has triggered a requirement for compliance. State and local jurisdictions have created exceptions to this by enacting mandatory ordinances that retroactively require existing buildings to mitigate an identified hazard or become compliant with certain provisions of the code.

The primary code rationalization for incremental seismic rehabilitation is that building officials will generally permit voluntary modifications to the seismic-force-resisting system provided that the building is not made less conforming. This rationalization can be found in the language that is present in current national model building codes and standards, and similar ideas can be found in legacy (pre-2000) building code language.

Incremental seismic rehabilitation will offer the greatest flexibility if work is undertaken voluntarily, and not subject to compliance through mandatory or triggered programs. Even so, there are examples of mandatory ordinances that explicitly permit seismic strengthening to occur



in increments, such as the Earthquake Hazard Reduction Ordinance (City of Los Angeles, 1981) addressing unreinforced masonry buildings in the City of Los Angeles, California.

#### **4.2.1 Voluntary Changes to the Seismic-Force-Resisting System**

In their most recent editions, the various model codes and standards have been aligned to clearly permit voluntary changes to the seismic-force-resisting system in an existing building without full compliance with the code. In general, they all say that when voluntary work is undertaken to increase the strength or stiffness of the seismic-force-resisting system, this work need not be designed for current code-level forces provided that the following criteria are met:

- The strength of existing structural components required to resist seismic forces is not reduced
- The seismic forces on existing structural components is not increased beyond their design strength
- New structural components are designed and detailed in accordance with the code
- New nonstructural components are anchored in accordance with the code
- The work does not make a non-conforming condition in the building worse

Specific requirements on voluntary changes to the seismic-force-resisting system can be found in IBC 2006, Chapter 34, Section 3403; IEBC 2006, Chapter 8, Section 807; and ASCE 7-05, Appendix 11B, Section 11B.4.

#### **4.2.2 Repairs, Alterations, Additions, and Changes of Occupancy**

Ongoing maintenance and capital improvement work on existing buildings can include repairs, alterations, additions, and changes of occupancy. Depending on the nature and extent of this work, triggers for seismic compliance within the model codes and standards can vary somewhat. In general, triggering factors relate to the condition of the existing building, the type of work, the percentage of the building affected by the new work, and the past and future use of the building.

**Repairs.** Historically, repairs have been permitted to restore a building to its pre-damaged condition using materials and methods consistent with the original construction. Exceptions to this are based on the condition of the building. If existing structural components are found to be unsound, dangerous, or otherwise deficient, then repair work can trigger compliance with current code provisions. The IEBC 2006 further defines a term called “substantial structural damage,” which is determined by a threshold percentage of strength loss occurring in structural components over a threshold percentage of floor area. Buildings that have sustained “substantial structural damage” must be repaired to a minimum level of seismic resistance that is set somewhat below current code level forces. Buildings that have sustained less than “substantial structural damage” are permitted to be repaired using original materials and methods.

Specific requirements on repairs can be found in IBC 2006, Chapter 34, Section 3403; and IEBC 2006, Chapter 5, Section 506.

**Alterations.** Alterations made to existing buildings must comply with current code requirements. The rest of the altered building, however, does not always need to comply with the current code. Exceptions to this are based on the system that is being altered, and the extent of the alteration. Alterations to fire and life-safety systems often require upgrade of the entire system to full code compliance. Structural alterations, however, are generally permitted as long as loads on existing structural components are not increased, and capacities of existing structural components are not decreased (within certain limits). The IEBC 2006 further defines three levels of alteration depending on the extent of the work, and defines a term called “substantial structural alteration,” which is based on how much of the floor area is being structurally altered. Buildings undergoing “substantial structural alteration” must meet a minimum level of seismic resistance that is set somewhat below current code level forces.

Specific requirements on alterations can be found in IBC 2006, Chapter 34, Section 3403; IEBC 2006, Sections 606, 707, and 807; and ASCE 7-05, Appendix 11B, Section 11B.4.

**Additions.** Additions made to existing buildings must comply with current code requirements. The rest of the building, however, does not always need to comply with the current code. Exceptions to this are based on the configuration of the addition, and the effect that the addition has on the existing structural system. Vertical additions, and additions that increase loads on existing structural components (beyond certain limits), trigger compliance for the entire structure.

Specific requirements on additions can be found in IBC 2006, Chapter 34, Section 3403; IEBC 2006, Chapter 10, Section 1003; and ASCE 7-05, Appendix 11B, Section 11B.3.

**Changes of occupancy.** Changes in the occupancy and use of a building that result in reclassification to a higher occupancy category (and a correspondingly higher seismic occupancy factor) require compliance of the entire building with current code provisions applicable to the new occupancy.

Specific requirements on changes of occupancy can be found in IBC 2006, Chapter 34, Section 3406; IEBC 2006, Chapter 9, Section 907; and ASCE 7-05, Appendix 11B, Section 11B.5.

### **4.2.3 Pre-2000 Legacy Codes**

Prior to 2000, there were three organizations producing three model building codes in the United States. These were the International Conference of Building Officials (ICBO), which produced the *Uniform Building Code* (UBC), the Southern Building Code Congress International (SBCCI), which produced the *Standard Building Code*, and the Building Officials and Code Administrators International, Inc. (BOCA), which produced the *National Building Code*. In the mid-1990s, these three model code organizations formed the International Code Council (ICC) to

collaborate on the development of one model code for use throughout the United States. This effort resulted in the publication of the initial *International Building Code* (IBC) in 2000.

The organizations that developed these codes were located in different regions of the country, and each focused on criteria for natural hazards that were the most important in their respective regions. Although seismic hazards were not the highest priority in all regions, these legacy codes contain provisions that allow for incremental seismic rehabilitation of existing buildings without full code compliance.

**BOCA National Building Code (BOCA, 1999).** In the 1999 edition of the *National Building Code*, Section 3404 permits alterations to existing buildings without requiring full compliance with the current code. Section 3405 requires changes of occupancy to comply with the intent of the code for new construction. Chapter 16 requires additions and changes of occupancy that reclassify the building to a higher Seismic Hazard Exposure Group to comply with the seismic provisions of the current code.

**ICBO Uniform Building Code (ICBO, 1997).** The 1997 edition of the *Uniform Building Code* is the legacy code that most closely resembles current model codes and standards. Section 3403 permits voluntary increases to the strength and stiffness of seismic-force-resisting systems consistent with current code requirements. Section 3403 also permits additions, alterations, and repairs to be made without triggering full compliance, as long as the new work is constructed in accordance with the current code, and it does not cause the structure to be unsafe or any more hazardous than it was before the work was initiated. Section 3405 requires changes of occupancy to conform to the requirements of the new occupancy, unless the new occupancy is less hazardous.

**SBCCI Standard Building Code (SBCCI, 1999).** In the 1999 edition of the *Standard Building Code*, Section 3401 permits repairs, alterations, or rehabilitation work to be performed in any existing building without triggering full compliance with the code, as long as the new work is constructed in accordance with the current code.



# Chapter 5 Incremental Seismic Rehabilitation Engineering Process

## **5.1 Engineering Phases of an Incremental Seismic Rehabilitation Program**

The FEMA ISR Series presents information and guidance to building owners and operators that is intended to assist in the planning and completion of a successful incremental seismic rehabilitation program. As part of implementing such a program, building owners and operators are advised to seek engineering assistance from design professionals for: (1) seismic screening and evaluation; (2) incremental seismic rehabilitation planning and design; and (3) construction period support. These encompass the following elements of an incremental seismic rehabilitation program:

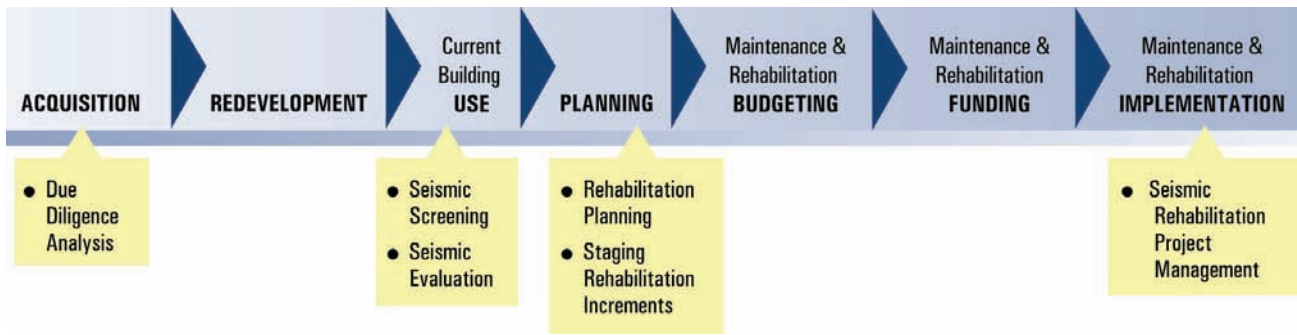
- Due Diligence Analysis (performed during the acquisition phase)
- Seismic Screening (performed during the current building use phase)
- Seismic Evaluation (performed during the current building use phase)
- Seismic Rehabilitation Planning for Specific Buildings (performed during the planning phase)
- Staging Seismic Rehabilitation Increments (performed during the planning phase)
- Seismic Rehabilitation Project Management and construction period support (performed during the implementation phase)

### In Brief

This chapter:

- Identifies the engineering phases of an incremental seismic rehabilitation program
- Describes the performance-based design process
- Explains the steps of the incremental seismic rehabilitation engineering process as depicted in the FEMA ISR Series

Figure 5-1 illustrates when engineering services are integrated into the phases of a typical facility management process.



**Figure 5-1** Integration of engineering services within the typical sequential facility management process (FEMA ISR Series).

These services, and how they relate to typical engineering practice for single-stage projects, were introduced in Chapter 2. Integration of incremental seismic rehabilitation into a facility management process was described in Chapter 3. Current national model building codes and standards, and their relation to work on existing buildings, were explained in Chapter 4. This chapter describes the specific elements of the incremental seismic rehabilitation engineering process in more detail. It identifies what services are needed when, and provides guidance on how existing building resource documents are used in providing incremental seismic rehabilitation engineering services.

## 5.2 Engineering Resources Referenced in the FEMA ISR Series

The engineering implementation of incremental seismic rehabilitation relies on the use of the following existing building resource documents, which are referenced in the FEMA ISR Series occupancy manuals and briefly described below.

Collectively, these documents define the process of screening a building inventory to identify potentially hazardous buildings, evaluating potentially hazardous buildings to confirm deficiencies and identify rehabilitation needs, and designing necessary seismic rehabilitation measures. While they do not explicitly refer to incremental seismic rehabilitation, the engineering procedures are applicable to the incremental seismic rehabilitation process, and should be used along with other applicable resources in developing and implementing an incremental seismic rehabilitation plan.

**FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Second Edition (FEMA, 2002)*.** The FEMA 154 Handbook provides a relatively simple method for quickly screening and ranking buildings that are at risk for deaths, injuries, or loss of use in the event of an earthquake. The rapid visual screening (RVS) procedure can be used by trained personnel to identify potentially hazardous buildings with a brief exterior inspection and a data collection form included in the Handbook.



The FEMA 154 Handbook is intended for use on a large group of buildings for the purpose of relative comparison of risk and prioritization for further study. With some limitations, however, it can be used to quickly assess the potential seismic performance of a single building.

**ASCE/SEI 31, *Seismic Evaluation of Existing Buildings* (ASCE, 2003).** Based on a series of predecessor documents dating back to ATC-14, *Evaluating the Seismic Resistance of Existing Buildings* (ATC, 1987), ASCE 31 is a national consensus standard for the seismic evaluation of existing buildings. It is applicable to structural and nonstructural evaluation of Life Safety and Immediate Occupancy performance levels at any level of seismicity.

ASCE 31 defines a three-tiered process in which each successive tier involves more detailed evaluation, increased effort, and greater confidence in the identification and confirmation of seismic deficiencies. The basis of the methodology is the Tier 1 checklist procedure, which utilizes a series of checklists to identify building characteristics that have exhibited poor performance in past earthquakes.

**ASCE/SEI 41, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2006b).** Based on a series of predecessor documents dating back to FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (BSSC, 1997), ASCE 41 is a national consensus standard for the seismic rehabilitation of existing buildings. Its immediate precursor, FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (FEMA, 2000), was referenced in the FEMA ISR Series, but has since been superseded by ASCE 41. It defines a performance-based approach for seismic analysis and design that can be used to achieve a desired performance objective selected from a range of performance levels (Collapse, Collapse Prevention, Life Safety, Immediate Occupancy, and Operational) at any seismic hazard level. It is intended to be generally applicable to structural and nonstructural components in buildings of any configuration and any construction type.

The performance-based methodology of ASCE 41 involves selection of a rehabilitation objective, selection of a rehabilitation method, analysis and design of rehabilitation measures, performance verification of a rehabilitation design, and preparation of construction documents. Engineering analysis is based on a series of linear, nonlinear, static, and dynamic analysis options, which involve increasing levels of effort and greater confidence in the resulting rehabilitation design.

### **5.3 Performance-Based Seismic Design**

The engineering process for incremental seismic rehabilitation is likely to include performance-based seismic design. Earthquake experience in recent years has forced recognition that damage (sometimes severe) can occur in a building designed in accordance with the code. "Performance" is used to identify levels of damage, and acceptable performance equates to acceptable levels of damage. This, in itself, represents a major change in perception. Building owners and occupants generally believe that adherence to building codes provides for a safe and habitable environment, and anticipated degrees of damage are not a normal topic of conversation between owners and design professionals.

In contrast to prescriptive design approaches, performance-based design provides a systematic methodology for assessing the performance capability of a building, system or component. It can be used to verify the equivalent performance of alternatives, deliver standard performance at a reduced cost, or confirm higher performance needed for important facilities. It also establishes a vocabulary that facilitates meaningful discussion between building owners and design professionals on the development and selection of design options. It provides a framework for determining what level of safety and what level of property protection, at what cost, are acceptable based upon the specific needs of the project.

### 5.3.1 Performance-Based Design Process

In performance-based design, identifying the performance capability of a building is an integral part of the design process, and guides the many design decisions that must be made. Figure 5-2 shows a flowchart that presents the key steps in performance-based design. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved.

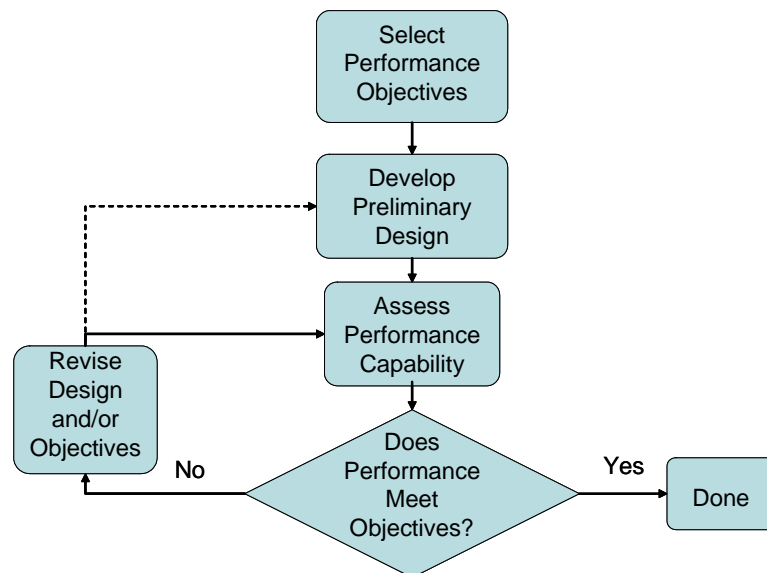


Figure 5-2 Performance-based design flowchart (ATC, 2003).

Performance-based design initiates with the selection of design criteria stated in the form of one or more performance objectives. Each performance objective is a statement of the desired performance level (acceptable level of structural and nonstructural damage) given a specified level of seismic hazard. Generally, a team of decision makers, including the building owner and design professional, will participate in selecting the performance objectives for a building. This team may consider the needs and desires of a wider group of stakeholders including prospective tenants, lenders, insurers and others who have impact on the value or use of a building, but may not directly participate in the design process.

Once the performance objectives for a project have been selected, the design professional must develop a preliminary design. For an existing



building, the preliminary design generally consists of the existing building without further modification. To assess an existing building, the following information is needed: building type, location, size and configuration, occupancy, quality and character of construction, and estimates of strength, stiffness, and ductility.

Once the preliminary design has been identified, a series of simulations (analyses of building response to loading) are performed to estimate the probable performance of the building under various scenario events. In the case of extreme loading, as would be imparted by a severe earthquake, simulations may be performed using nonlinear analysis techniques.

If the simulated performance meets or exceeds the performance objectives, the design is completed. If not, the design must be revised in an iterative process until the performance objectives are met. In some cases it may not be possible to meet the stated objective at reasonable cost, in which case, some relaxation of the original objectives may be appropriate.

The overall analysis must consider not only the frequency at which the design earthquake occurs, but the effectiveness and reliability of the entire building as a system. Any seismic analysis method should also anticipate a certain level of "uncertainty," and should address this uncertainty to the extent that available data allow.

## **5.4 Incremental Seismic Rehabilitation Basic Information**

Application of performance-based design in incremental seismic rehabilitation requires basic information in the following three categories:

- building type
- seismic hazard level
- performance objectives

This information is used in existing building resource documents for screening, evaluation, and design of rehabilitation measures. This information, however, is defined and used somewhat differently in each of the resource documents. Similarities and differences are described in the sections that follow.

### **5.4.1 Building Type**

The occupancy manuals in the FEMA ISR Series categorize buildings into seven building structural types based on the vertical load-carrying system and the floor and roof diaphragm types. These categories are used to identify integration opportunities and the relative complexity of engineering necessary to implement rehabilitation measures. The seven FEMA ISR building structural types are:

- Wood
- Unreinforced masonry

- Reinforced masonry
- Concrete with flexible diaphragms
- Concrete with rigid diaphragms
- Steel with flexible diaphragms
- Steel with rigid diaphragms

These are related to, but different from, building types as identified in FEMA 154, ASCE 31, and ASCE 41. Table 5-1 shows a comparison between the building type designations in the various FEMA ISR reference documents.

**Table 5-1 Comparison of Building Classifications in Various FEMA ISR Reference Documents**

FEMA ISR Occupancy Manuals		FEMA 154	ASCE 31/ASCE 41
Material	Diaphragm Type		
Wood	Flexible/Rigid	W1	W1 (Light Frame)
			W1A (Multi-Unit Residential)
		W2	W2 (Commercial/Industrial)
Unreinforced Masonry	Flexible	URM	URM
	Rigid		URMA
Reinforced Masonry	Flexible	RM1	RM1
	Rigid	RM2	RM2
Reinforced Concrete	Rigid	C1	C1 (Moment Frame)
	Rigid	C2	C2 (Shear Wall)
	Flexible		C2A
	Rigid	C3	C3 (Frame with Infill)
	Flexible		C3A
	Rigid	PC1	PC1A (Precast Tilt-up)
	Flexible		PC1
	Rigid	PC2	PC2 (Precast Frame/Wall)
	PC2A (Precast Frame)		
Steel	Rigid	S1	S1 (Moment Frame)
	Flexible		S1A
	Rigid	S2	S2 (Braced Frame)
	Flexible		S2A
	Flexible	S3	S3 (Light Frame)
	Rigid	S4	S4 (Frame with Concrete Walls)
	Rigid	S5	S5 (Frame with Masonry Infill)
	Flexible		S5A

In FEMA 154, 15 building types are considered. These are categorized by the construction of the primary seismic-force-resisting system. Categories are used to establish basic scores that define initial relative building vulnerabilities in the rapid visual screening procedure. Information used to categorize buildings can be obtained from a visual survey, or from a review of available drawings. If the structural system is not visible from the interior or exterior, and drawings are not available, a range of possible building types must be considered.

In ASCE 31, 24 basic building types, called common building types, are considered. They are an expansion of the building types found in FEMA 154, and are categorized by the construction of the primary seismic-force-resisting system. Classification depends on the material (e.g., wood, steel, concrete, masonry), framing type (e.g., shear wall or moment frame), and diaphragm behavior (e.g., rigid or flexible). Common building types are used to select system-specific checklists that identify building characteristics that are known to have exhibited poor performance in past earthquakes. For buildings that do not fit into one of the defined building types, ASCE 31 contains a general checklist for mixed building types.

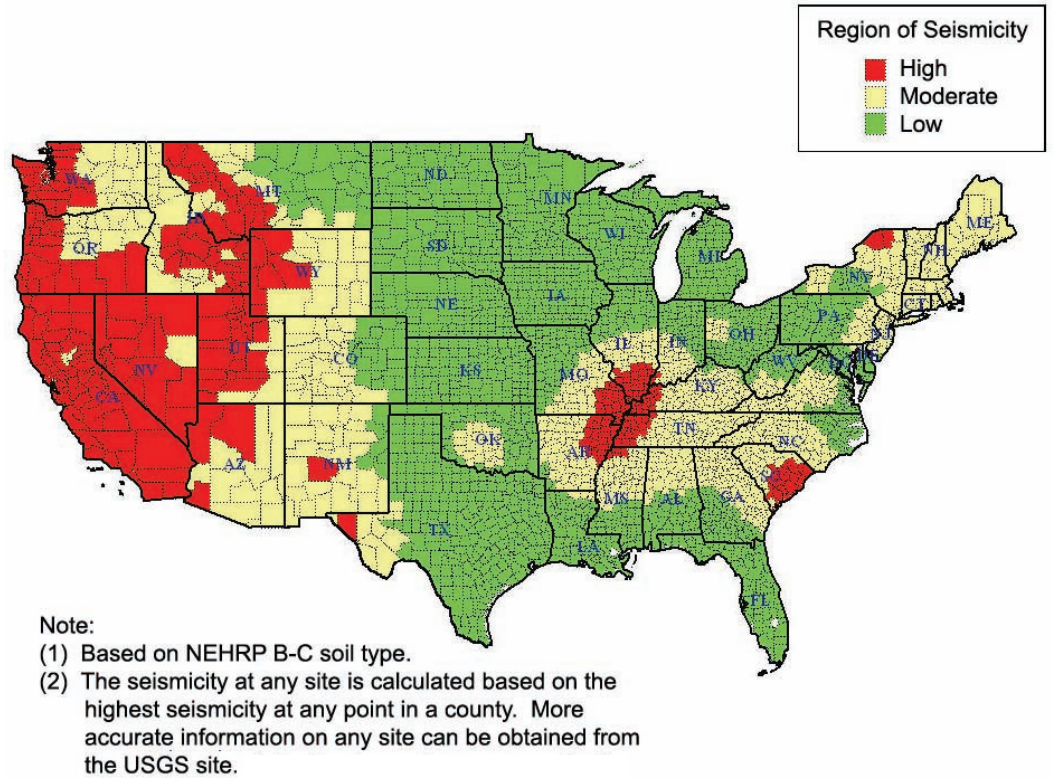
The provisions in ASCE 41 are intended to be generally applicable to all building types, system configurations, and construction materials. The Simplified Rehabilitation Procedure contained in ASCE 41 utilizes model building types that are identical to the 24 common building types found in ASCE 31.

#### **5.4.2 Seismic Hazard Level**

The United States Geological Survey (USGS) is responsible for determining the seismic hazard throughout the United States. The USGS publishes a series of seismic hazard maps, which are updated on an ongoing basis. Short period maps and one-second period maps define the short period ( $S_S$ ) and one-second period ( $S_1$ ) spectral response acceleration parameters by location. Site class (soil type) will amplify or decrease the intensity of ground shaking at a site. By knowing the location and the soil type, one can determine the expected intensity of ground shaking that a building will experience. If the soil type is not known, use of a default soil type is possible, although default soil factors may result in more conservative analysis criteria (and, potentially, more expensive rehabilitation measures).

In FEMA 154, seismic hazard level is determined by regions of seismicity. FEMA 154 uses the simplified hazard map shown in Figure 5-3 to define regions of low, moderate and high levels of seismicity. The map is based on the USGS hazard maps, and is similar to the one provided in the FEMA ISR Series, but aggregates the levels of seismicity somewhat differently. Seismic hazard characterization has evolved significantly since the time that FEMA 154 was published. Changes to earthquake source and occurrence rate models, along with new understanding of how earthquake ground motion decays with distance (attenuation relationships), have resulted in revised estimates of the hazard near known faults and other areas in the Central and Eastern United States.

In the simplified hazard map shown in Figure 5-3, regions of low seismicity include areas of the country in which no seismic design is required by current seismic design codes and standards for new buildings. For this reason, it is recommended that the relative seismic hazard at a given site be characterized using the latest seismic hazard maps available from the USGS.



**Figure 5-3 FEMA 154 simplified seismic hazard map (FEMA, 2002).**

In ASCE 31, three levels of seismicity are defined in terms of short period ( $S_{DS}$ ) and one-second period ( $S_{D1}$ ) spectral response acceleration parameters. The  $S_{DS}$  and  $S_{D1}$  parameters are based on the USGS mapped  $S_S$  and  $S_1$  spectral response acceleration parameters, modified by site class. Figure 5-4 shows the definition of ASCE 31 levels of low, moderate, and high seismicity.

Level of Seismicity <sup>1</sup>	$S_{DS}$	$S_{D1}$
Low	<0.167g	<0.067g
Moderate	≥0.167g <0.500g	≥0.067g <0.200g
High	≥0.500g	≥0.200g

<sup>1</sup> Sites with  $S_{DS}$  and  $S_{D1}$  values in different levels of seismicity shall be classified as moderate.

**Figure 5-4 ASCE 31 Levels of Seismicity Definitions (ASCE, 2003).**

In ASCE 41, three levels of seismicity are defined in terms of design short period ( $S_{XS}$ ) and design one-second period ( $S_{X1}$ ) spectral response

acceleration parameters. The  $S_{XS}$  and  $S_{X1}$  design parameters are based on the USGS mapped  $S_S$  and  $S_1$  spectral response acceleration parameters, modified by site class. The ranges of  $S_{XS}$  and  $S_{X1}$  defining low, moderate, and high levels of seismicity are identical to the ranges of  $S_{DS}$  and  $S_{D1}$  used in ASCE 31.

### 5.4.3 Performance Objectives

Performance is communicated in terms of discretely defined performance levels: Collapse, Collapse Prevention, Life Safety, Immediate Occupancy, and Operational Performance. These performance levels address damage to both structural and nonstructural components. Performance Objectives are developed by linking one of these performance levels to a specific level of earthquake hazard, as shown in Figure 5-5.

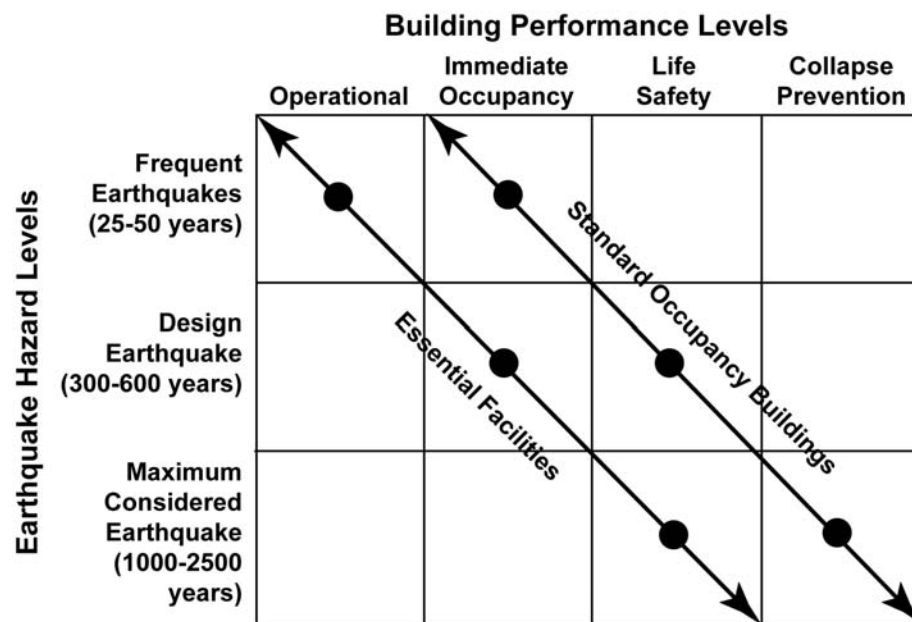


Figure 5-5 Seismic performance objectives linking building performance levels to earthquake hazard levels (adapted from SEAOC, 1995).

In FEMA 154, performance objectives are not addressed directly. The methodology does, however, identify potentially hazardous buildings that are at risk for deaths, injuries, or loss of use in the event of an earthquake.

In ASCE 31, performance objectives are defined in terms of levels of performance and levels of seismicity. ASCE 31 contains criteria for detailed evaluation of buildings for Life Safety and Immediate Occupancy levels of performance. These levels of performance can be evaluated at low, moderate, and high levels of seismicity. In the ASCE 31 methodology, the level of performance and level of seismicity affect the selection of checklists that are used for each building type.

In ASCE 41, performance objectives are defined in terms of Rehabilitation Objectives. A Rehabilitation Objective is a combination of a Target Building Performance Level and an Earthquake Hazard Level. Target

Building Performance Levels consider both structural and nonstructural component behavior.

## 5.5 Due Diligence Analysis

Due diligence analysis is performed on behalf of owners considering the acquisition of an existing building. The purpose of a due diligence analysis is to identify and quantify potential seismic risks that may exist so that they can be taken into account (or avoided) in a building acquisition plan. Seismic risks have traditionally been quantified in the due diligence process by means of Probable Maximum Loss (PML) analyses. PML analyses consist of estimating the damage that the building would experience in a major rare earthquake, expressed as a percentage of the value of the building. There are two resources offering guidance in conducting PML analyses:

- ASTM E2026, *Standard Guide for Seismic Risk Assessment of Buildings* (ASTM, 2007a)
- ASTM E2557, *Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments* (ASTM, 2007b)

These standards distinguish between *scenario losses* (SL) and *probable losses* (PL). In ASTM E2026, four levels of PML investigation are defined ranging from screening (level 0) to exhaustive investigation (level 3). Additionally, five different types of earthquake loss studies are provided, serving different financial and management needs:

- Building Stability
- Site Stability
- Damageability
- Contents Damageability
- Business Interruption

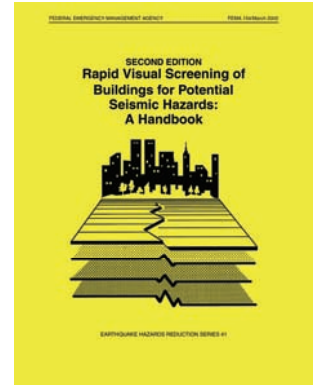
In ASTM E2557, scenario losses are expressed as either *scenario expected loss* (SEL) or *scenario upper loss* (SUL) with each related to a specified earthquake hazard level. Probable loss estimates account for the damage that a building might experience from all earthquakes that could affect the site. Owners, lenders, and insurers establish their own criteria for acceptable scenario loss or probable loss values, based on their respective tolerances for earthquake risk.

## 5.6 Seismic Screening

Seismic screening is intended to be a rapid, simple, preliminary assessment of potential seismic risk. The FEMA 154 Handbook defines a rapid visual screening process that can be used to rank the relative risk of buildings within an inventory of buildings. While intended for use on a large group of buildings, it can also be used as a preliminary evaluation tool to obtain a sense of the possible seismic risk associated with an individual building.

The rapid visual screening (RVS) procedure consists of an exterior inspection of the building to identify the seismic-force-resisting system and any building attributes that might modify the expected seismic performance of that system. The procedure is implemented using data collection forms recording the following information:

- Address or other identifying information
- Structural system type
- Building age
- Building occupancy category and number of occupants
- Building plans if available
- Soil conditions (soil type A-F)
- Presence of falling hazards (chimneys, parapets, cladding, and veneer)



The forms are shown in Figure 5-6. Based on the building structural system type, a Basic Structural Hazard (BSH) score is assigned. Scores are given for regions of low, moderate, and high levels of seismicity. For each level of seismicity, the score reflects the estimated likelihood that a typical building in that category would sustain major damage, defined as damage requiring repairs totaling approximately 60% or more of the building value. This level of damage is about the threshold where life safety begins to become a serious concern.

Basic Structural Hazard scores are then increased or decreased by Score Modifiers that account for building or site features that increase or decrease seismic vulnerability. Score Modifiers consider such attributes as:

- Number of stories
- Vertical irregularities
- Horizontal irregularities
- Pre-code buildings (designed and constructed prior to the adoption of a seismic code)
- Post-benchmark buildings (designed and constructed after significant improvements in seismic codes)
- Soil type

When Score Modifiers are combined with the Basic Structural Hazard Score, the result is a final Structural Score (S) for the building. Final Structural Scores typically range from 0 to 7, with higher scores corresponding to better expected seismic performance. For a large group of buildings, priorities for seismic evaluation can be based on the resulting Structural Scores (the lower the score, the higher the priority).

If a building receives a high score it is considered to have low risk. Structural Scores of 2 or 3 are recommended as minimum values below which buildings should be further evaluated. If a building receives a low score it should be evaluated by a design professional. Buildings identified as needing more detailed evaluation should not be considered hazardous without additional evaluation.

**LOW Seismicity**

**MODERATE Seismicity**

**HIGH Seismicity**

**PHOTOGRAPH**

BUILDING TYPE	W1		W2		S1		S2		S3		S4		S5		C1		C2		C3		PC1		PC2		RM1		RM2		URM	
	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)	(RP)	(RM)
Basic Score	4.4	3.8	2.8	3.0	3.2	2.8	2.0	2.5	2.8	1.6	2.6	2.4	2.8	2.8	1.8															
Mid Rise (4 to 7 stories)	N/A	N/A	-0.2	-0.4	N/A	-0.4	-0.4	-0.4	-0.4	-0.2	N/A	-0.2	-0.4	-0.4	N/A	-0.2	N/A	-0.2	N/A	-0.2	N/A	-0.2	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
High Rise (>7 stories)	N/A	N/A	+0.6	+0.8	N/A	+0.6	+0.8	+0.6	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8	-1.0	-0.8
Post-Benchmark	-2.4	-2.4	-1.4	-1.4	N/A	-1.6	N/A	-1.4	-2.4	N/A	-2.4	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A	-2.8	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-1.2	-0.8	-1.2	-0.8	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2	-0.8	-1.2

Figure 5-6 FEMA 154 data collection forms for Low, Moderate, and High regions of seismicity.

Because FEMA 154 is intended to be used on a large inventory of buildings, FEMA has developed a software application for portable electronic devices called *Rapid Observation of Vulnerability and Estimation of Risk* (ROVER), which can be used to rapidly gather pre-earthquake building information in the field, screen buildings for potential seismic risk, and manage the resulting large volume of data (ATC, 2009). The ROVER software application uses electronic data collection forms, and takes advantage of global positioning system (GPS) technology to determine the seismic hazard at a site automatically, using the latest USGS seismic hazard information.



## 5.7 Seismic Evaluation

Seismic evaluation is a more detailed assessment and confirmation of potential seismic deficiencies. Typically it is conducted on individual buildings that have been identified as vulnerable based on a screening process. The ASCE 31 standard defines a national consensus procedure for seismic evaluation consisting of a three-tiered process in which each successive tier involves more detailed evaluation, increased effort, and greater confidence in the identification and confirmation of seismic deficiencies. Unless otherwise triggered by local jurisdictional requirements, other established procedures for evaluating seismic deficiencies could be used.

The procedure includes consideration of “Benchmark Buildings,” which are buildings designed and constructed in accordance with certain benchmark code provisions that include relevant seismic design and detailing requirements. Benchmark Buildings need not proceed with further evaluation, but design and construction in accordance with the benchmark provisions must be verified.

Tier 1 utilizes a series of checklists and “quick check” calculations to identify building characteristics that have exhibited poor performance in past earthquakes. Based on building type, level of seismicity, and performance level, checklists are selected for use in a Tier 1 evaluation. An excerpt from one such checklist is shown in Figure 5-7. In addition to basic and supplemental structural checklists, there is a foundation-geologic hazard checklist, and nonstructural checklists covering architectural, mechanical, electrical, and plumbing components in a building. In Tier 1, the level of analysis is minimal. Evaluation is necessarily conservative as a trade-off for avoiding more detailed evaluation.

A Tier 1 evaluation is required for all buildings. At each level, one could choose to stop the evaluation process and proceed with mitigation of deficiencies. In general, it is optional to proceed to higher tiers of evaluation. For certain combinations of building type and performance level, however, a Tier 2 or Tier 3 evaluation may be required.

A Tier 2 evaluation involves simplified, but more detailed analyses to confirm or eliminate potential deficiencies identified in Tier 1. Tier 2 utilizes four analysis procedures: (1) Linear Static Procedure; (2) Linear Dynamic Procedure; (3) Special Procedure for unreinforced masonry buildings with flexible diaphragms; and (4) a procedure for nonstructural components. As a minimum, only those items found deficient under the Tier 1 analysis need to be evaluated. A Tier 2 evaluation may require more information about the building than a Tier 1 Evaluation, which may include determination of material strengths.



**3.7.9 Basic Structural Checklist For Building Type C2: Concrete Shear Wall Buildings With Rigid or Stiff Diaphragms**

This Basic Structural Checklist shall be completed where required by Table 3-2.

Each of the evaluation statements on this checklist shall be marked compliant (C), non-compliant (NC), or not applicable (N/A) for a Tier 1 Evaluation. Compliant statements identify issues that are acceptable according to the criteria of this standard, while non-compliant statements identify issues that require further investigation. Certain statements may not apply to the buildings being evaluated. For non-compliant evaluation statements, the design professional may choose to conduct further investigation using the corresponding Tier 2 evaluation procedure; the section numbers in parentheses following each evaluation statement correspond to Tier 2 evaluation procedures.

**C3.7.9 Basic Structural Checklist For Building Type C2**

These buildings have floor and roof framing that consists of cast-in-place concrete slabs, concrete beams, one-way joists, two-way waffle joists, or flat slabs. Floors are supported on concrete columns or bearing walls. Lateral forces are resisted by cast-in-place concrete shear walls. In older construction, shear walls are lightly reinforced, but often extend throughout the building. In more recent construction, shear walls occur in isolated locations and are more heavily reinforced with boundary elements and closely spaced ties to provide ductile performance. The diaphragms consist of concrete slabs and are stiff relative to the walls. Foundations consist of concrete spread footings, mat foundations, or deep foundations.

<b>Building System</b>			
C	NC	N/A	LOAD PATH: The structure shall contain a minimum of one complete load path for Life Safety and Immediate Occupancy for seismic force effects from any horizontal direction that serves to transfer the inertial forces from the mass to the foundation. (Tier 2: Sec. 4.3.1.1)
C	NC	N/A	MEZZANINES: Interior mezzanine levels shall be braced independently from the main structure, or shall be anchored to the lateral-force-resisting elements of the main structure. (Tier 2: Sec. 4.3.1.3)
C	NC	N/A	WEAK STORY: The strength of the lateral-force-resisting system in any story shall not be less than 80% of the strength in an adjacent story, above or below, for Life Safety and Immediate Occupancy. (Tier 2: Sec. 4.3.2.1)
C	NC	N/A	SOFT STORY: The stiffness of the lateral-force-resisting system in any story shall not be less than 70% of the lateral-force-resisting system stiffness in an adjacent story above or below, or less than 80% of the average lateral-force-resisting system stiffness of the three stories above or below for Life Safety and Immediate Occupancy. (Tier 2: Sec. 4.3.2.2)
C	NC	N/A	GEOMETRY: There shall be no changes in horizontal dimension of the lateral-force-resisting system of more than 30% in a story relative to adjacent stories for Life Safety and Immediate Occupancy, excluding one-story penthouses and mezzanines. (Tier 2: Sec. 4.3.2.3)
C	NC	N/A	VERTICAL DISCONTINUITIES: All vertical elements in the lateral-force-resisting system shall be continuous to the foundation. (Tier 2: Sec. 4.3.2.4)
C	NC	N/A	MASS: There shall be no change in effective mass more than 50% from one story to the next for Life Safety and Immediate Occupancy. Light roofs, penthouses and mezzanines need not be considered. (Tier 2: Sec. 4.3.2.5)

**Figure 5-7 Excerpt from the Basic Structural Checklist for Building Type C2: Concrete Shear Walls with Stiff Diaphragms (ASCE, 2003).**

A Tier 3 evaluation involves more complex nonlinear analysis procedures in an effort to further confirm, or ultimately eliminate, potential deficiencies remaining after a Tier 2 evaluation. Additional, more detailed building information is required to conduct a Tier 3 evaluation. This could require acquisition or development of as-built drawings. Site verification to determine as-built construction may require removal of finishes and physical testing to determine material strengths, types of connections, or the presence of reinforcing steel.

In general a Tier 3 evaluation refers the user to ASCE 41. Consistent with traditional engineering practice and industry consensus, however, acceptance criteria used for evaluation are relaxed in comparison with

acceptance criteria used for rehabilitation design. For this reason, a 0.75 factor is applied when utilizing ASCE 41 in an ASCE 31 Tier 3 evaluation. This is also why component modification factors (or  $m$ -factors) in ASCE 31 differ from those in ASCE 41.

This difference represents an approximate adjustment to a mean level of earthquake shaking, which is considered appropriate for existing buildings with a remaining useful life that is shorter than that of new buildings (which are designed to a mean-plus-one standard deviation level of earthquake shaking). This reduction recognizes that while new designs have an inherent conservatism that comes with only marginal additional cost, the same conservatism applied to existing buildings would identify too many buildings as deficient.

Differences in acceptance criteria between evaluation and design can make it difficult to reconcile results when moving from the evaluation phase to rehabilitation planning for specific buildings. These differences should be anticipated and considered in the implementation of an incremental seismic rehabilitation program.

## **5.8 Seismic Rehabilitation Planning for Specific Buildings**

Seismic rehabilitation planning involves design of rehabilitation measures, prioritization, identification of integration opportunities, and definition of appropriate rehabilitation increments. In the FEMA ISR Series, the development and documentation of a seismic rehabilitation plan is an essential element in the implementation of incremental seismic rehabilitation.

### **5.8.1 Incremental Seismic Rehabilitation Plan**

An incremental seismic rehabilitation plan should include all anticipated rehabilitation increments and their prioritization, and should be a written record of the goals and decisions made regarding implementation. Documentation should help guide the implementation of the overall incremental seismic rehabilitation program, and should help ensure that the building owner does not lose sight of overall rehabilitation goals during implementation of individual increments.

Since work may continue over a period of years, an incremental seismic rehabilitation plan must be periodically re-evaluated, and possibly adjusted. It must be in a form that follow-on users can readily pick up and continue with work.

An incremental seismic rehabilitation plan should include documentation of the following information:

**Building description:** the building type and its seismic-force-resisting system in as much detail as possible; any available records concerning the construction of the building, including plans, shop drawings, details, calculations, and specifications.

**Level of seismicity:** the basis for determining the level of seismicity, including seismic hazard maps and spectral response acceleration parameters, site class, geotechnical reports, and probabilistic seismic hazard assessments (if performed).

**Performance objectives:** the selected target building performance levels, including both structural and nonstructural performance, the selected seismic hazard level, and the reasons for these selections.

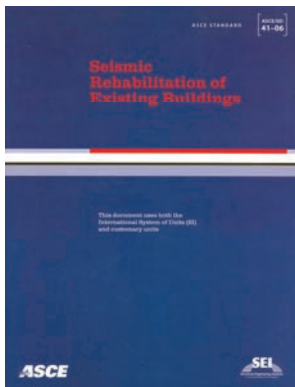
**List of deficiencies:** the results of an assessment as to whether or not the building meets the stated performance objectives; analytical results used in the evaluation; a complete list of all seismic deficiencies, including a description of the expected performance and resulting consequences of damage.

**Rehabilitation measures:** a complete list of all rehabilitation measures required to address the complete list of deficiencies; analytical results and design calculations; design drawings and construction documents.

**Rehabilitation increments:** prioritization of rehabilitation measures into discrete stages; rationale for establishing priorities; identification of integration opportunities in the maintenance and capital improvement process; explanation of performance expectations for each increment.

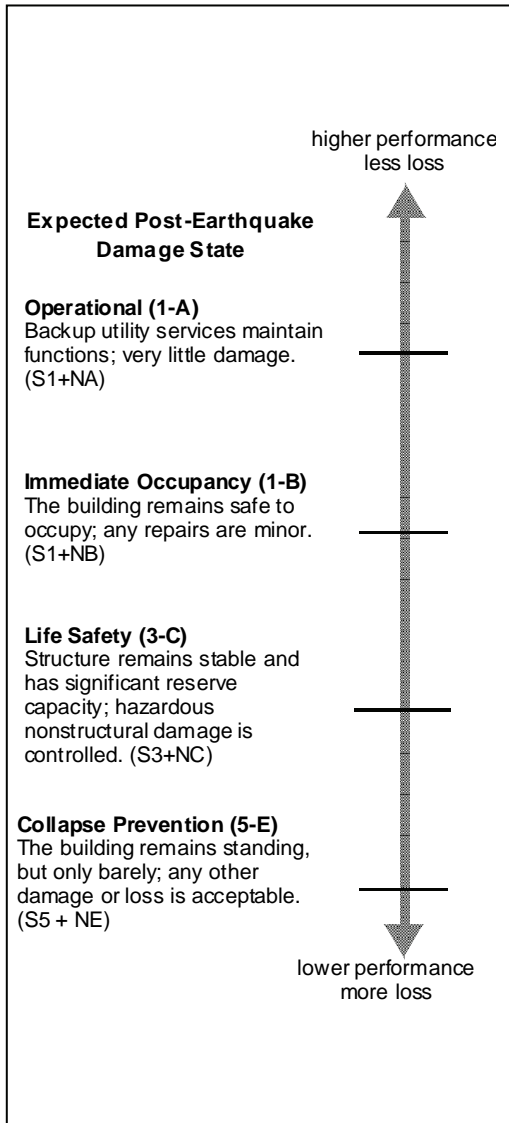
**Rehabilitation Project Schedule:** the intended sequencing of rehabilitation increments and the overall intended project timeline.

## 5.8.2 Design of Rehabilitation Measures



The ASCE 41 standard defines a performance-based design approach for achieving a desired performance objective selected from a range of performance levels (Collapse, Collapse Prevention, Life Safety, Immediate Occupancy, and Operational) at any specified seismic hazard level. The methodology involves selection of a rehabilitation objective, selection of a rehabilitation method, analysis and design of rehabilitation measures, performance verification of a rehabilitation design, and preparation of construction documents. Unless otherwise triggered by local jurisdictional requirements, other established procedures for designing rehabilitation measures could be used.

Rehabilitation Objectives are a function of Target Building Performance Levels and Earthquake Hazard Levels. Figure 5-8 shows the range of ASCE 41 Target Building Performance Levels. In the figure, alpha-numeric codes are used to identify the structural and nonstructural performance levels (e.g., the designation 3-C refers to structural performance level 3 and nonstructural performance level C). Figure 5-9 shows how Target Building Performance Levels are linked with Earthquake Hazard Levels to define Rehabilitation Objectives. A Basic Safety Objective is defined, which is intended to be generally consistent with the safety level expected in current code-conforming buildings, and other rehabilitation objectives are characterized by comparison with the Basic Safety Objective. Enhanced rehabilitation objectives exceed the performance expectations of the Basic Safety Objective, and limited rehabilitation objectives improve seismic performance, but fall below the performance expectations of the Basic Safety Objective.



**Figure 5-8 ASCE 41 Target Building Performance Levels (ASCE, 2006b).**

		<b>Target Building Performance Levels</b>									
		<b>Operational Performance Level (1-A)</b>	<b>Immediate Occupancy Performance Level (1-B)</b>	<b>Life Safety Performance Level (3-C)</b>	<b>Collapse Prevention Performance Level (5-E)</b>						
<b>Earthquake Hazard Level</b>	50%/50 year	a	b	c	d						
	20%/50 year	e	f	g	h						
	BSE-1 (~10%/50 year)	i	j	k	l						
	BSE-2 (~2%/50 year)	m	n	o	p						
<p><sup>1</sup>Each cell in the above matrix represents a discrete Rehabilitation Objective.</p> <p><sup>2</sup>The Rehabilitation Objectives in the matrix above may be used to represent the three specific Rehabilitation Objectives defined in Sections 1.4.1, 1.4.2, and 1.4.3, as follows:</p> <table style="width: 100%; border: none;"> <tr> <td style="padding-right: 20px;">Basic Safety Objective (BSO)</td> <td>k and p</td> </tr> <tr> <td>Enhanced Objectives</td> <td>k and m, n, or o p and i or j k and p and a, b, e, or f m, n, or o alone</td> </tr> <tr> <td>Limited Objectives</td> <td>k alone p alone c, d, g, h, or l alone</td> </tr> </table>						Basic Safety Objective (BSO)	k and p	Enhanced Objectives	k and m, n, or o p and i or j k and p and a, b, e, or f m, n, or o alone	Limited Objectives	k alone p alone c, d, g, h, or l alone
Basic Safety Objective (BSO)	k and p										
Enhanced Objectives	k and m, n, or o p and i or j k and p and a, b, e, or f m, n, or o alone										
Limited Objectives	k alone p alone c, d, g, h, or l alone										

**Figure 5-9 ASCE 41 Rehabilitation Objectives (ASCE, 2006b).**

Two methods of rehabilitation are provided within ASCE 41: systematic rehabilitation and simplified rehabilitation. Systematic rehabilitation is intended to be generally applicable to structural and nonstructural components in buildings of any configuration and any construction type. Engineering analysis is based on a series of four analysis options: (1) Linear Static Procedure; (2) Linear Dynamic Procedure; (3) Nonlinear Static Procedure; and (4) Nonlinear Dynamic Procedure. Each successive option involves increasing levels of effort and greater confidence in the resulting rehabilitation design.

Simplified rehabilitation is applicable to structural and nonstructural components in buildings within a specified range of building types and characteristics. Applicability depends on the number of stories and the level of seismicity. In general, simplified rehabilitation refers the user to ASCE 31, and permits a deficiency-only rehabilitation plan without an explicit requirement for a full-building analysis.

Data collection is an important consideration within ASCE 41. The extent to which material strengths and details of construction are known will have a significant effect on analytical simulations of building response, and on uncertainty in the resulting estimate of building performance. ASCE 41 encourages explicit and comprehensive investigation to maximize knowledge of the building and minimize unknowns.

Because of differences in criteria between evaluation and rehabilitation design, rehabilitation measures designed using ASCE 41 may differ somewhat from rehabilitation measures identified in an ASCE 31 evaluation. These differences should be anticipated and considered in the implementation of an incremental seismic rehabilitation program.

### **5.8.3 Prioritization of Rehabilitation Measures**

Since rehabilitation work will be staged over an extended period of time, some rehabilitation measures will be implemented sooner, and others will be implemented later. Rehabilitation measures can be prioritized based on:

- structural priority,
- use priority, and
- integration priority.

The most advantageous sequence of work will depend on the relative seismic risk reduction benefits and opportunity for performing the work. Often, priorities will begin with structural considerations and will then be adjusted based on facility use and opportunity for integration.

**Structural Priority.** Structural priority is influenced by relative impact on overall seismic performance. Deficiencies that will result in damage with a high consequence of casualties, property loss, or loss of use should be mitigated first. Similarly, rehabilitation measures that will have a large impact on reducing potential damage (and consequences resulting from that damage) should be implemented first.

The commentary in Chapter 10 of ASCE 41 provides a list of deficiencies for each model building type, ranked from highest to lowest priority in terms of the severity of the deficiency. This can be used as a general guide for establishing structural priority, although the ranking can vary somewhat for individual buildings. Examples of these tables are shown in Figure 5-10.

To assist in understanding the impact and damage reduction potential of various rehabilitation measures, the occupancy manuals in the FEMA ISR Series provide tables that list possible structural and nonstructural seismic performance improvements along with their intended purpose. These tables identify what actions could be undertaken and what the expected outcome would be, which can be used to assist in assigning structural priority within each occupancy category. Excerpts from one set of tables are shown in Figure 5-11 and Figure 5-12. A complete set of tables is provided in each occupancy manual.

Table C10-4. S1 and S1A: Steel Moment Frames with Stiff or Flexible Diaphragms	
Typical Deficiencies	
Load Path	<ul style="list-style-type: none"> <li>Redundancy</li> <li>Vertical Irregularities</li> <li>Plan Irregularities</li> <li>Adjacent Buildings</li> <li>Uplift at Pile Caps</li> </ul>
Steel Moment Frames	<ul style="list-style-type: none"> <li>Drift Check</li> <li>Frame Concerns</li> <li>Strong Column-Weak Beam</li> <li>Connections</li> </ul>
Re-entrant Corners	<ul style="list-style-type: none"> <li>Diaphragm Openings</li> <li>Diaphragm Stiffness/Strength</li> </ul>
Diaphragm/Frame Shear Transfer	
Anchorage to Foundations	<ul style="list-style-type: none"> <li>Condition of Foundations</li> <li>Overturning</li> <li>Lateral Loads</li> <li>Geologic Site Hazards</li> </ul>
Condition of Steel	

Table C10-5. S2 and S2A: Steel Braced Frames with Stiff or Flexible Diaphragms	
Typical Deficiencies	
Load Path	<ul style="list-style-type: none"> <li>Redundancy</li> <li>Vertical Irregularities</li> <li>Plan Irregularities</li> <li>Uplift at Pile Caps</li> </ul>
Stress Level	<ul style="list-style-type: none"> <li>Stiffness of Diagonals</li> <li>Chevron or K-Bracing</li> <li>Braced Frame Connections</li> </ul>
Re-entrant Corners	<ul style="list-style-type: none"> <li>Diaphragm Openings</li> <li>Diaphragm Stiffness/Strength</li> </ul>
Diaphragm/Frame Shear Transfer	
Anchorage to Foundations	<ul style="list-style-type: none"> <li>Condition of Foundations</li> <li>Overturning</li> <li>Lateral Loads</li> <li>Geologic Site Hazards</li> </ul>
Condition of Steel	

Figure 5-10 Tables of ranked deficiencies for Steel Moment Frame and Steel Braced Frame model building types (ASCE, 2006b).

### Structural Seismic Performance Improvements

Level of Seismicity			Building Element	Structural Sub-System	Definitions and Purpose		
L	M	H			Seismic Performance Improvement	Description	Purpose
	✓	✓	Foundation		Anchor Bolts	Connection between the foundation and the building	Improve load path. Prevent building from sliding off foundation.
	✓	✓	Foundation		Anchorage	Connection between the foundation and the building for larger buildings	Improves load path. Provides adequate connection between the building and the foundation.
	✓	✓	Foundation		Cripple Stud Bracing	Short wood studs between the foundation and the first floor	Cripple studs are usually not braced. They may topple causing the building to fall off the foundation.
	✓	✓	Foundation		New Foundations	New foundations to convey loads	Additional foundations may be the preferred solution in some cases.
	✓	✓	Foundation		Pile Cap Lateral Load	Piles supporting buildings may try to move laterally from building loads during earthquakes	Brace piles at their top to eliminate the chance of lateral movement.
	✓	✓	Foundation		Uplift	Under overturning type loads foundations may be pulled upward	Reduces the uplift chance by improving foundation system.

Figure 5-11 Excerpt from table of structural seismic performance improvements (FEMA 395).

## Nonstructural Seismic Performance Improvements

Rank *	Level of Seismicity			Definitions and Purpose		
	L	M	H	Seismic Performance Improvement	Description	Purpose
1	✓	✓	✓	Bracing of Parapets, Gables, Ornamentation & Appendages	Construct parapet bracing on the roof side of the parapet. Gables are braced in the attic space. Other elements are anchored in a positive manner.	Prevents parapets, gables and ornamentation from falling outward
2	✓	✓	✓	Anchorage of Canopies at Exits	Canopies or roofs over exits	Prevents collapse of canopies which would block exits and possibly injure persons
3		✓	✓	Bracing or Removal of Chimneys	Chimneys should be braced to the structure	Chimneys may topple onto yards or through roofs
4	✓	✓	✓	Bracing or Reinforcing Masonry Walls at Interior Stairs	Interior exit stairs may have unreinforced masonry enclosure walls that could collapse	Prevents collapse of walls blocking stairways
5		✓	✓	Suspension and Bracing of Lights	Lights may swing or otherwise fall in an earthquake	Falling lights could injure occupants. Lights should not be supported by a suspended ceiling in a high and moderate seismic zone. Pendant lights should have their sway limited.
6	✓	✓	✓	Anchorage and Bracing of Emergency Lighting	Positive attachment of emergency lights	Battery packs are heavy and could fall
7		✓	✓	Fastening and Bracing of Ceilings	Diagonal bracing of ceiling	Suspended ceilings should be braced against sidesway to reduce the chance of elements falling
8		✓	✓	Restraint of Hazardous Materials Containers	Chemical labs, shops, etc may have materials that could, when combined, create a fire or chemical hazard	Reduces danger of breakage and mixing of chemical

\* Rank in terms of 'life safety effectiveness'

Figure 5-12 Excerpt from table of nonstructural seismic performance improvements (FEMA 395).

An example of a code-developed approach to assigning structural priority is contained in the *International Existing Building Code (IEBC)*, Appendix Section A404. This section applies to earthquake hazard reduction in existing wood-frame residential buildings that are three or more stories in height. Phasing is intended to address the most hazardous conditions first, and to avoid leaving the building in a more vulnerable condition. As defined in the IEBC, Phase 1 includes the ground floor, Phase 2 includes intermediate levels, and Phase 3 includes the remaining levels of the building through the top story.

**Use Priority.** Use priority is influenced by the importance of current building use and occupancy. Buildings with higher occupant loads, critical functions, or high-value equipment or property should be rehabilitated first. Similarly, important portions of a building, such as assembly areas and elements of the egress system (e.g., corridors, stairs, lobbies), should be rehabilitated before other less critical areas.

Use priority could also be influenced by planned future use. Some buildings might be scheduled for significant expansion or intensification of use, which should raise the priority for seismic rehabilitation in these buildings. In adjusting priorities and scheduling work, owners may consider planning alternative uses for seismically vulnerable buildings. Some could be scheduled for early demolition and replacement, or for conversion to a lower risk category of use (e.g., storage) until rehabilitation is complete.

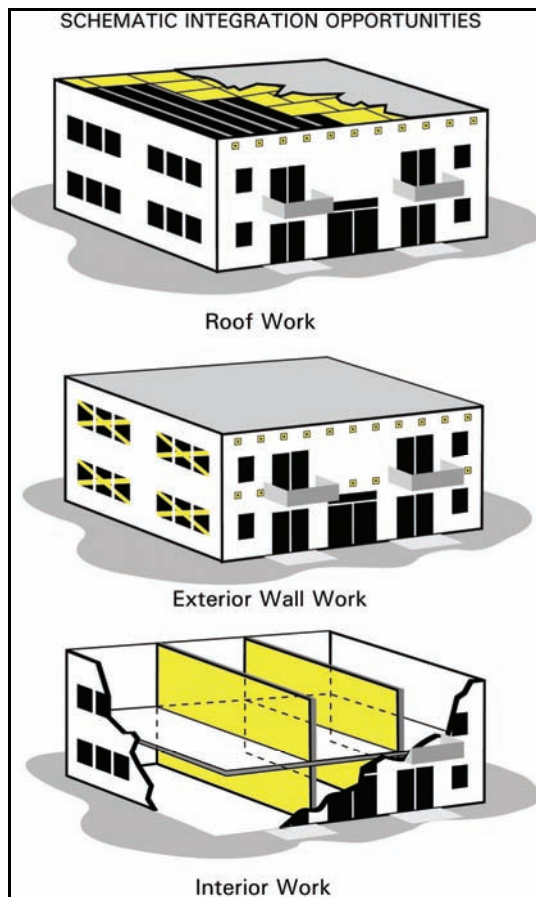
**Integration Priority.** Integration priority is influenced by the potential for integrating rehabilitation measures into other building maintenance or capital improvement projects that are routinely scheduled. Integration



priority is opportunistic in that seismic rehabilitation work is accomplished when other work is being undertaken, or when portions of the building are otherwise vacant. This reduces the cost of the seismic rehabilitation action by taking advantage of construction mobilization, access to the area of work, and disruption of occupancy and use that would have occurred anyway.

Integration priority is affected by the nature, location, and extent of work. Rehabilitation measures that can be accomplished with the lowest additional cost and least disruption to building use are generally scheduled first. Examples of integration priorities are illustrated in Figure 5-13, and described below:

- Work that can be accomplished from the exterior (roofs, exterior walls, and basements) with little or no effect on interior space use
- Work that can be accomplished in localized spaces in the interior of the building (e.g., corridors)
- Work that must be accomplished in spaces spread throughout the building (these may be tenant spaces and/or common spaces)
- Work that requires access to concealed spaces
- Work that involves mechanical, electrical, and plumbing systems



**Figure 5-13** Prioritization of work based on integration opportunities: (1) roof work; (2) exterior wall work; and (3) localized interior work (FEMA ISR Series).

### 5.8.4 Identification of Integration Opportunities

Maintenance and capital improvement activities vary by occupancy category. In general, these activities include:

- Roofing maintenance and repair/re-roofing
- Exterior walls maintenance and repair/window replacement
- Fire and life safety improvements
- Modernization/remodeling/accommodation of new technology
- Underfloor and basement maintenance and repair
- Energy conservation/weatherization/air conditioning
- Hazardous materials abatement
- Accessibility improvements

The occupancy manuals in the FEMA ISR Series include matrices showing specific structural and nonstructural seismic performance improvements that can be integrated with their occupancy-specific maintenance and capital improvement activities. An excerpt from one set of matrices is shown in Figure 5-14. A complete set of matrices is provided in each occupancy manual.

Number*	Level of Seismicity			Building Structural Element	Structural Sub-System	Seismic Performance Improvement	Vertical Load Carrying Structure						
	L	M	H				Wood	Masonry <sup>1</sup>	Concrete	Steel			
<b>Nonstructural</b>													
1	✓	✓	✓	n/a	n/a	Anchorage of Canopies at Exits	■	■	■	■	■	■	
2		✓	✓	n/a	n/a	Anchorage and Detailing of Rooftop Equipment	■	■	■	■	■	■	
5	✓	✓	✓	n/a	n/a	Bracing of Parapets, Gables, Ornamentation, and Appendages	■	■	■	■	■	■	
8		✓	✓	n/a	n/a	Attachment and Bracing of Large Ductwork	■	■	■	■	■	■	
18		✓	✓	n/a	n/a	Bracing or Removal of Chimneys	■	■	■	■	■	■	
<b>Structural</b>													
n/a		✓	✓	All Elements		Load Path and Collectors	□	□	□	□	☒	☒	
n/a		✓	✓	Horizontal Elements	Diaphragms	Attachment and Strengthening at Boundaries	■	■	■	■	☒	■	☒
n/a		✓	✓	Horizontal Elements	Diaphragms	Strength/Stiffness	■	■	■	■	☒	■	☒
n/a		✓	✓	Horizontal Elements	Diaphragms	Strengthening at Openings	□	□	□	□		□	
n/a		✓	✓	Horizontal Elements	Diaphragms	Strengthening at Re-entrant Corners	□	□	□	□	☒	□	☒
n/a		✓	✓	Horizontal Elements	Diaphragms	Topping Slab for Precast Concrete		□	□		☒		☒
n/a	✓	✓	✓	Vertical Elements	Load Path	Lateral Resisting System to Diaphragm Connection	■	■	■	■	☒	■	☒
n/a	✓	✓	✓	Vertical Elements		Out-of-Plane Anchorage of Concrete or Masonry Wall		■	■	■	□	■	□

\* Nonstructural improvements are numbered for ease of use. Structural improvements are not numbered, but rather, organized by structural element and sub-system.

- Work that may be included in the building rehabilitation/maintenance/repair project on the basis of a quick evaluation by a design professional.
- Work requiring engineering design.
- ☒ Work requiring detailed engineering analysis and evaluation of sequencing requirements. The "x" designates work that could redistribute loads, overstressing some elements.

Note 1: Masonry buildings with a concrete roof should use the concrete building, concrete diaphragm for options.

Figure 5-14 Integration opportunities for roofing maintenance and repair (FEMA 400).

These matrices classify seismic performance improvements by level of seismicity, building structural element, structural subsystem, and vertical-load-carrying structure. Depending on the building type and the specific seismic performance improvement, implementation could require one of three levels of engineering involvement: quick evaluation, engineering design, and detailed engineering analysis. These are identified by symbols in the matrices, as shown in Figure 5-15.

■	Indicates improvements that can be implemented when the integration opportunity arises, on the basis of a quick evaluation by a design professional. These types of improvements address deficiencies that may be identified in an ASCE 31, <i>Seismic Evaluation of Existing Buildings</i> , Tier 1 analysis.
□	Indicates improvements that can be implemented when the integration opportunity arises and that require engineering design. These types of improvements address deficiencies that may be identified in an ASCE 31 Tier 1 or Tier 2 analysis.
X	Indicates improvements that require engineering analysis to determine if they should be implemented when the integration opportunity arises to avoid unintentionally increasing the seismic vulnerability by redistributing loads to weaker elements of the structural system (sequencing requirements).

**Figure 5-15** Classification of integration opportunities by extent of engineering required (FEMA ISR Series).

### 5.8.5 Definition of Appropriate Rehabilitation Increments

It is possible that implementation of selected rehabilitation measures in certain portions of a building can increase seismic demands on other portions of a building, resulting in a condition that is more vulnerable or less conforming than when work was initiated. Rehabilitation measures that introduce vertical or horizontal irregularities in strength or stiffness, particularly in buildings with rigid diaphragms, should be avoided.

Rehabilitation measures should be packaged into logical increments that can fit within the scope of a maintenance or capital improvement project and result in a rational incremental improvement in seismic performance. This can result in the need for iterative design processes and additional analyses of partial rehabilitation stages to understand the potential impacts of the following:

- **Partial changes to the seismic-force-resisting system:** partial increases in strength or stiffness that create temporary irregularities and could result in instability. Work should result in balanced changes to the seismic-force-resisting system.
- **Partial strengthening in selected areas:** work done in local areas that creates a concentration of seismic demand in the area that might not have been anticipated. Work should avoid creating “hard spots” in a building that concentrate seismic demands in areas that cannot resist these demands.

- **Vertical seismic improvements:** changes in strength or stiffness in one story that create a vertical discontinuity that overloads elements in adjacent stories. Strengthening “from the ground up” helps to avoid this effect.
- **Element connection upgrades:** strengthening connections between elements (e.g., out-of-plane connections on heavy exterior walls) that delivers loads to locations in the building that may or may not be able to resist them. Rehabilitation increments should consider potential impacts along the entire seismic load path.

## **5.9 Staging Seismic Rehabilitation Increments**

Staging of seismic rehabilitation increments involves determining the number and scope of incremental stages that will be undertaken and the length of time over which the entire rehabilitation plan will be implemented. While structural priority and use priority can factor into when a rehabilitation increment should take place, staging of rehabilitation increments is primarily driven by integration opportunities.

As part of the planning process, rehabilitation measures are grouped into logical packages for effectively improving seismic performance. Staging of seismic rehabilitation increments consists of matching an increment with an appropriate maintenance or capital improvement project, and mapping out subsequent increments within occupancy-specific maintenance and capital improvement schedules.

### **5.9.1 Coordination with Tenant Work**

Specific to commercial office occupancies, major tenant improvement work offers a unique opportunity for staging of seismic rehabilitation increments. This is most likely to occur in the case of large commercial tenants with long-term leases. Large tenants conducting major improvements in their space will often have their own design professionals and contractors. Incremental seismic rehabilitation work performed by the owner in conjunction with major tenant improvement work performed by commercial tenants will require close coordination between the owner’s design professionals and contractors, and those of the tenant.

## **5.10 Seismic Rehabilitation Project Management**

Seismic rehabilitation project management primarily refers to management of seismic rehabilitation construction projects as they are implemented within other maintenance and capital improvement work. Also known as construction management or construction support services, this effort involves ensuring that plans, specifications, and quality assurance provisions are properly implemented in the construction of seismic rehabilitation measures.

# Chapter 6 Incremental Seismic Rehabilitation Needs and Possibilities

As a partner in the National Earthquake Hazards Reduction Program (NEHRP), FEMA has invested significant effort and funding in the development of guidelines and procedures to promote earthquake hazard reduction in existing buildings. Incremental seismic rehabilitation offers a way of eliminating some of the barriers to implementation of seismic rehabilitation and expanding earthquake risk reduction activities in the United States.

Validation of the basic concept of incremental seismic rehabilitation is critical to its successful implementation. The engineering and building regulatory communities must be convinced of the feasibility of the incremental approach, if it is to be used. Necessary safeguards and limitations must be defined to avoid the unintended temporary reduction of seismic resistance, and building owners must be convinced that the incremental approach offers adequate cost and use benefits to make seismic mitigation financially attractive.

## **6.1 Political, Social, and Economic Possibilities**

Public policy and regulatory issues are critical to implementation of seismic rehabilitation programs. In the 2008 NEHRP Workshop on Meeting the Challenges of Existing Buildings, held in San Francisco, California, increased political will to support mitigation measures was identified as the most valuable contribution for meeting challenges faced by our existing building stock. The biggest impediment to seismic rehabilitation was identified as the lack of market forces aligned to support such activities (ATC, 2008).

### In Brief

This chapter:

- Describes the political, social, and economic possibilities of incremental seismic rehabilitation
- Explains how incremental seismic rehabilitation can affect decision-making and program management
- Recommends actions to assist in the further development and acceptance of incremental seismic rehabilitation

Political entities are concerned with the safety of their constituents, but numerous impediments to implementation of mandated seismic rehabilitation programs exist. The economic burden of construction cost and disruption that must be borne by building owners and occupants is the most obvious impediment. Economic incentives can offset some of the cost, but incentive programs have generally not been substantial enough to overcome resistance.

Balancing seismic safety against political, social and economic factors is not easy. Incremental seismic rehabilitation offers a solution to cost and disruption disincentives for seismic rehabilitation in existing buildings, and can be an effective measure for public officials to consider.

## **6.2 How Can Incremental Seismic Rehabilitation Affect Decision-Making and Program Management?**

The FEMA ISR Series presents seismic rehabilitation within the context of occupancy-specific facility management processes. It communicates decisions on seismic risk and seismic rehabilitation investment in terms that can be related to normal maintenance and capital improvement activities and expenditures. It explains how seismic rehabilitation can be incorporated into business continuity planning.

Building owners are accustomed to making periodic investments to repair and improve existing facilities. There is also precedent for such work to trigger upgrades to certain aspects of their facilities (e.g., fire and life-safety upgrades, Americans with Disabilities Act modifications). The process of incremental seismic rehabilitation presents owners with a new paradigm in which seismic rehabilitation is a regular part of ongoing maintenance and capital improvement activities, and that reduction in earthquake risk will be in their long-term best interest. It presents an opportunity for seismic rehabilitation to be infused directly into the program management and decision-making process.

## **6.3 What is needed to Further Promote Incremental Seismic Rehabilitation?**

Development of the approach described in the FEMA ISR Series included studies on the economic and technical validity of incremental seismic rehabilitation. Further development and acceptance will be based largely on its continued use. Recommendations for possible ways to help expand the use of incremental seismic rehabilitation include:

- Advocacy at national and regional building owners' associations by occupancy type
- National advocacy at the model code development level
- Local advocacy at the local code administrative level
- Political advocacy to affect public policy on earthquake safety
- Creation of an incremental seismic rehabilitation case studies repository
- Collection of additional data on economic viability

## **6.4 Summary and Conclusions**

Incremental seismic rehabilitation offers a way of eliminating potential cost and disruption barriers to implementation of seismic rehabilitation. It offers flexibility in the sequence and timing of rehabilitation actions, and can be more cost-effective than a delayed, single-stage rehabilitation project. The concept of incrementally improving the seismic-force-resisting system of an existing building is permitted in the language contained in current national model building codes and standards, and similar ideas have been present in the history of building regulations.

Engineering procedures associated with typical engineering practice for single-stage projects are applicable to incremental seismic rehabilitation. In some cases, however, engineering services may require more effort to implement within the context of incremental seismic rehabilitation. The overall approach to incremental seismic rehabilitation utilizes owner maintenance, capital improvement and decision-making needs as a basis for effectively communicating with stakeholders on seismic rehabilitation opportunities and encouraging active mitigation of seismic risk.





# Appendix A Case Study Example – Seattle Public Schools Incremental Seismic Rehabilitation Program

This appendix presents a case study illustrating how an overall incremental seismic rehabilitation program was implemented for Seattle Public Schools in Seattle, Washington. It discusses seismic screening, seismic evaluation, rehabilitation planning, and staging of rehabilitation increments in the Seattle Public Schools building inventory, and includes budget information for reference.

## **A.1 Introduction**

The Juan de Fuca plate is located off the coast of Washington, Oregon and Northern California. It is the source of shallow earthquakes widely distributed over Washington, and deep earthquakes in the western parts of Washington and Oregon. Large earthquakes are anticipated about every 35 years, although there is some disagreement over the recurrence interval. Earthquakes of magnitude 8 or greater are suggested by the geology, but none has occurred in the past 150 years. The return period for large-magnitude earthquakes appears to be several hundred years.

Seattle Public Schools has a long history of seismic awareness dating back to 1949 when several schools were damaged in an earthquake near Olympia, Washington. Seismic surveys of schools began in Seattle in 1977. Additional surveys were carried out in 1978 and 1979. A comprehensive survey of all Seattle schools was completed in 1983 as part of a long-range capital improvement plan. It was under this plan that

## In Brief

This appendix:

- Illustrates the implementation of an incremental seismic rehabilitation program
- Shows how incremental seismic rehabilitation work was planned and staged
- Provides budget information for reference

integrated incremental seismic rehabilitation was initiated and carried out under two financing programs, the Capital Levy Program (CLP) and the Capital Improvement Program (CIP). The approach was refined with further studies in 1991 and 1992, and has continued under renewed funding to the present.

## **A.2 Regulatory Context**

In 1955, the Washington state legislature passed statewide Earthquake Resistance Standards covering hospitals, schools, public assembly buildings, and all public-owned structures. The *Uniform Building Code* (UBC) was adopted statewide, effective in 1978, and local jurisdictions were provided with the authority to adopt more stringent requirements. All buildings, including state-owned buildings, are subject to local code enforcement in Washington.

The city of Seattle has code enforcement jurisdiction over Seattle Public Schools. In the case of existing buildings undergoing “extensive rehabilitation,” as defined in the Seattle Building Code, seismic strengthening is required. In such cases, the *Uniform Code for Building Conservation* (UCBC) is one option for seismic criteria, but is not required. The Seattle Public Schools seismic rehabilitation work has been primarily voluntary.

## **A.3 Seismic Screening of the Building Inventory**

The Seattle Public Schools seismic program is based on a detailed inventory of the buildings and their components, including detailed seismic analysis results, and cost estimates. It demonstrates how a database is essential to the support of long range incremental seismic rehabilitation strategic planning.

A utilization study identified five schools as “imminent hazards” and led to the *Seismic Survey of 22 Seattle Schools*, dated November 30, 1977. Three engineering firms conducted “limited observations of structural elements and a brief design review” of buildings consisting of masonry bearing walls and wood floors and roofs. Engineers recommended three levels of work (cost estimates were provided) involving:

- Imminent hazards consisting mostly of parapets, gables, chimneys, and loose or poorly anchored masonry
- Limited floor and roof ties, diaphragm reinforcement, and added shear walls
- Present code requirements

This was followed by the *Seismic Survey of 10 Schools and Chimneys at 53 Schools*, dated September 6, 1978. Ten schools were inspected, consisting of masonry bearing walls and reinforced concrete or wood floors. Information on the chimneys at 53 schools was obtained by a questionnaire. Engineers recommended work to remove the imminent hazards, and cost estimates were provided.

This in turn was followed by *Seismic Inspections, 87 Schools*, dated August 10, 1979. This survey was carried out by a district building

inspector and a brick mason from the maintenance section. The survey found that 50 schools required no seismic work, 12 required "some attention to skylights only," and 25 had problems which could be considered "grave risk hazards." For the latter, items of corrective work were identified, but costs were not estimated. The report concluded that "with adequate funding, specifications can be prepared and work completed by the start of the 1980-81 school year."

## **A.4 Seismic Evaluation of Individual Buildings**

In 1982, the Seattle Public Schools commissioned CMB/KIM Architects & Engineers to carry out a comprehensive survey of all school buildings. A preliminary report consisting of three volumes and entitled *Comprehensive Survey of Educational Facilities, Seattle School District No. 1* was published on April 8, 1983. The study consisted of two basic parts:

- An inventory and categorization of deficiencies
- A seismic analysis of every building

The deficiency inventory was based on a field inspection of each site by a minimum of five professionals, including an architect, a structural engineer, a mechanical and electrical engineer, and a certified roofing inspector. Approximately 50 man-hours were spent at each site, and about 6,000 deficiencies were documented at 101 sites. Deficiencies were prioritized in terms of their level of risk and the potential impact of non-action. Hazardous conditions were prioritized under special procedures, and received immediate attention.

The seismic analysis for each facility consisted of seven parts:

- Field inspection and evaluation
- Reporting of major deficiencies
- Computation of ratings in terms of structural and nonstructural quality
- Establishment of probabilities of occurrence for major earthquakes
- Determination of possible site-dependent amplification due to poor soil conditions
- Computation of risks (in terms of damage and casualties)
- Comparisons with other commonly accepted risks

This report concluded that "the majority of facilities exceed an ordinary level of acceptable risk. These structures should be strengthened or retired as soon as monetary resources permit it. The methodology taken in this evaluation is directed towards establishing procedures and priorities to reduce the risks to acceptable levels."

Since 1982, the approach to seismic rehabilitation under both the Capital Levy Program and the Capital Improvement Program was periodically refined. Over this same time period, significant changes occurred in the seismic requirements of the building code, reflecting a greater understanding of building performance in earthquakes. In order to keep pace with these changes, Seattle Public Schools undertook two new engineering studies that produced two new reports in 1991.

The first study, entitled *Structural Evaluation of Seattle Public Schools* was published in early 1991 by TRA Architecture Engineering Planning Interiors of Seattle. This was a structural evaluation of the seismic resistance of all Seattle schools constructed before 1968, and was viewed as an update of the seismic portion of the 1983 report. The goal of the study was “to establish a minimum standard for seismic upgrade of all existing schools and to rate the schools relative to that standard.”

Evaluations were based on the “Rapid Analysis Procedure” of ATC-14, *Evaluating the Seismic Resistance of Existing Buildings* (ATC, 1987), first published in 1987. A numerical rating was assigned in order to rank the buildings. A rating of 100 represented a building whose allowable shear stress and required shear stress are equal, and a rating of 165 represented a new building designed to meet the 1988 Uniform Building Code. Ratings ranged from 20 to 750, for 166 separately identified buildings. Eighty-six buildings at 50 school campuses rated below 100.

The 50 school campuses with ratings below 100 were subjected to further structural analysis by Dodd Pacific Engineering, Inc. of Seattle and San Francisco. This analysis was based on a review of drawings, but without site visits. The results of the analyses were used to prepare recommendations to eliminate major structural deficiencies, eliminate major nonstructural deficiencies, and develop preliminary construction cost estimates. Each building was assigned a priority ranking from 1 (highest) to 7 (lowest). The results of this study were published in a report entitled *Abbreviated ATC-14 and ABK Seismic Evaluations, and Preliminary Construction Cost Estimates* in 1991.

## **A.5 Seismic Rehabilitation Planning and Design**

Between 1986 and 1991, the Capital Improvement Program Phase I (CIP-I) resulted in the modernization or replacement of 14 elementary schools and one high school, at a cost of about \$140 million (of which about \$40 million were State funds). The program utilized data from the 1983 CMB/KIM Architects and Engineers report.

In early 1992, Seattle Public Schools published two related reports, a *Proposed Facilities Master Plan 1992 to 2010*, and a *Proposed Phase II Capital Improvement Program*. Following extensive public review, these documents were revised and adopted by the Board of Directors, and published as *Superintendent's Final Recommendations – 2010 Facilities Master Plan and Capital Improvement Program Phase II* on July 15, 1992. The plan states that “more than a third of Seattle schools are already 60 years or older. Many are in poor condition and have outdated electrical, heating and ventilating systems. Forty percent still need significant work to improve resistance to earthquakes. Many lack the space and technology needed to educate today's students to be successful in tomorrow's competitive world.”

The Board adopted 11 goals for Seattle Public Schools facilities, including the following:

- Assure that buildings meet health and safety standards with regard to seismic, fire, and lighting
- Provide safe, secure and efficient buildings from which essential

and vital operations can be continued if a disaster occurs

Between 1992 and 2000, the Capital Improvement Program Phase II (CIP-II) included the modernization, preservation or replacement of 25 elementary schools, two middle schools, five high schools and six alternative/special education schools. The estimated cost of CIP-II was \$795 million. Approximately \$695 million was to be obtained through a 15-year bond measure, and the remaining \$100 million was to be supplemented from other sources such as interest earnings, state matching funds and possible future development impact fees. An initial bond issue of \$339 million was authorized. Capital Levy Program funds were made available for schools not included in CIP-II, but still in need of seismic and other building improvements.

The Board adopted six criteria for CIP-II project selection and prioritization. These were:

- Completion of projects left over from Capital Improvement Program Phase I
- Seismic conditions
- Condition physical systems
- Adequacy for educational uses
- Need for increased capacity to meet projected student population and desegregation goals
- Age

A *Seismic Action Plan* was developed by Seattle Public Schools staff in parallel with the *Superintendent's Final Recommendations – 2010 Facilities Master Plan and Capital Improvement Program Phase II*. The Seismic Action Plan is viewed as the culmination of all previous structural evaluations and studies. Scheduling of seismic work in the plan is based on a “worst first” approach in which schools with lower seismic ratings are upgraded first.

## **A.6 Staging of Seismic Rehabilitation Increments**

Seattle Public Schools has been carrying out seismic rehabilitation projects on existing school buildings for many years under the Capital Levy Program and the Capital Improvement Program. The Capital Levy Program consists of small to medium-sized projects that replace or upgrade existing facilities and systems to provide students with safe and secure buildings. These are generally carried out during the summer months when the schools are out of session. The Capital Improvement Program consists of major projects that involve demolition and reconstruction or substantial rehabilitation of existing schools.

### **A.6.1 Capital Levy Program (1982-1999)**

Between 1982 and 1999, about 103 schools initiated Capital Levy Program projects. Of these, 51 had at least one seismic rehabilitation project, and some had more than one. When seismic rehabilitation was coupled with other work, it was most often roofing, followed by exterior wall improvements, accessibility improvements (ADA), and corridor

improvements. Table A-1 summarizes Capital Levy Program projects that included seismic rehabilitation work between 1982 and 1999.

**Table A-1 Seattle Public Schools Capital Levy Projects 1982-1999**

School	Year	Work Description	School	Year	Work Description
Addams	1991	Seismic	Madrona*	1992	Seismic
Alki	1991	Seismic, Corridor	Magnolia	1994	Seismic, Corridor, ADA
Allen	1993	Seismic	Mann	1993	Seismic, ADA
Arbor Heights	1985	Seismic, Roof	Marshall	1993	Seismic
Bagley	1991	Seismic, Exterior	McDonald	1993, 1998	Seismic Seismic, ADA
Ballard*	1993	Seismic, Gutters & Downspouts	McGilvra	1992	Seismic
Blaine	1992	Seismic, Corridor	Meany	1991	Seismic, Roof
Boren*	1999	Seismic, Roof, Hazmat, Fire Alarms	Memorial Stad.	1994	Seismic, Roof
Brighton	1994	Seismic, Corridor, ADA	Minor	1993	Seismic, ADA
Bryant*	1989	Seismic	Monroe	1998	Seismic, ADA
Coe*	1993	Seismic	Northbeach	1989	Seismic
Columbia	1989	Seismic, Roof	Northgate	1987	Seismic, Roof
Concord*	1989, 1992	Seismic Seismic	Pinehurst	1994	Seismic, Roof, Exterior
Dearborn Park	1991	Seismic, Roofing	Rainier Beach*	1992	Seismic, Roof
Decatur	1989	Seismic	Rogers	1987, 1993	Seismic, Roof Seismic
Dunlap*	1993	Seismic	Roosevelt	1993	Seismic, Roof
Garfield	1999	Seismic, Windows, Arts/Science Improvements	Sacajawea	1997	Seismic
Genessee Hill	1985, 1997	Seismic, Roof Seismic	Schmitz Park	1991	Seismic
Greenwood*	1987	Seismic, Structural	Seward*	1984, 1991, 1993	Seismic, Windows, A/C Seismic Seismic
Hamilton	1990	Seismic, Roof, Exterior	Sharples	1994	Seismic, Roof, Exterior
Highland Park*	1993	Seismic, ADA	Stevens*	1993	Seismic, Roofing, ADA
Hughes	1998	Seismic, ADA	Whitman	1995	Seismic
Latona*	1989, 1992	Seismic Seismic	Wilson	1999	Seismic, Roof
Lowell	1993	Seismic, ADA	Van Asselt	1991	Seismic, Exterior
Loyal Heights	1991	Seismic, Exterior	West Seattle*	1993	Seismic, ADA
Madison	1994	Seismic, Roof, Exterior			

\*Schools scheduled for replacement or gut rehabilitation in the Capital Improvement Program

### **A.6.2 Buildings, Technology and Athletics Levy (1998-2004)**

In 1998, Seattle Public Schools implemented a new Capital Levy Program called the Buildings, Technology and Athletics (BTA) Levy. This was a six-year program to finance more than 465 small and large facility improvement projects at every school in the District (112 schools). Voters approved \$150 million for this program, extending through 2004. About \$139 million was budgeted for school improvements and \$11 million was budgeted for computer equipment.

Work included improvements to building systems, technology infrastructure, and athletic facilities. About \$59 million of the total was allocated to the following building system upgrades (which include seismic work):

- Completion of the seismic mitigation program started in the early 1980s
- Replacement of the most critical roofs (this work included seismic upgrade of diaphragms and improved diaphragm connections, if necessary, but was not classified as seismic work)
- Replacement of windows to protect the building and improve energy efficiency
- Provision of life safety improvements including upgrades to fire alarms, better ADA access, elevators, and selected hazards materials abatement
- Replacement of heat pumps at the end of their useful life
- Improvement of science and art facilities in all secondary schools

These improvements were planned to be implemented during the summer months while the schools were closed. The individual scopes of work were packaged into a variety of small projects to meet these goals.

Table A-2 shows a breakdown of the building system improvements with dedicated seismic work. Projects at 24 schools had dedicated seismic work in this program. Prior seismic work occurred at 11 of these schools. The absolute dollar value and percentage related to seismic work varies significantly between schools. Overall, the table shows a total budget of \$6.9 million for dedicated seismic work, and another \$6.7 million of roof work (a portion of which included seismic). In this program, seismic work on average accounted for 30% of the building budget at schools with dedicated seismic work, 12% of the total budget for building improvements, and about 5% of the budget for the overall BTA Levy program.

## ***A.7 Local Jurisdictional Issues***

Local jurisdictional problems (e.g., plan check and permit approval) in combining seismic work with other work categories have not been reported. Technical problems, such as increasing building vulnerability through partial incremental improvements, have not been reported.

## ***A.8 Legal/Liability Issues***

Incremental seismic strengthening has been practiced by Seattle Public Schools since the early 1950s. No legal problems have been reported.

**Table A-2 Buildings, Technology and Athletics Levy Projects with Dedicated Seismic Work**

School	Prior Seismic Projects	Total Building Program (\$)	Roof (\$)	Seismic (\$)	Percent Seismic (%)
Marshall	1993	1,489,676	279,120	350,000	23%
Rainier Beach	1992	2,592,847		1,021,020	39%
Roosevelt	1989/1993	2,545,206	300,000	350,000	14%
Denny		1,344,132	724,500	265,766	20%
Madison	1994	800,179		350,000	44%
McClure		869,736		556,206	64%
Meany	1991	321,048		18,018	6%
Arbor Heights	1985	1,157,910	453,338	423,191	37%
Broadview		894,584	741,526	105,105	12%
Fairmont Park		275,164	15,683	85,586	31%
King		563,162	390,829	79,580	14%
Laurelhurst		552,643	213,184	230,250	42%
Loyal Heights	1991	676,950	165,179	230,250	34%
North Beach	1989	159,920		58,559	37%
Rainier View		534,774	325,086	67,568	13%
Roxhill		655,952	482,265	22,523	3%
Sacajawea	1997	495,367		367,500	74%
Decatur	1989	829,932	456,058	373,874	45%
Boren/Cooper		1,649,550	1,200,000	173,250	11%
Hay NOMS		2,131,695	638,652	290,312	14%
Hughes		595,123	127,575	420,000	71%
Magnolia	1994	604,849		215,250	36%
McDonald	1993	908,452	190,062	614,114	68%
Monroe		568,372		247,919	44%
Totals		23,217,223	6,703,057	6,915,841	30%



# Appendix B Case Study Example – Staging of Seismic Rehabilitation Increments

This appendix presents a case study showing how seismic rehabilitation increments were staged in a privately-owned retail/office building located in Southern California. It is intended to illustrate one portion of the incremental seismic rehabilitation process in some detail (see Figure B-1), while omitting discussion on other portions of the process. In this example, mandatory compliance with specified criteria was triggered by the local jurisdiction. Seismic evaluation and rehabilitation design activities were performed (though not described here). Since there was considerable flexibility in the timeline for compliance, the owner decided on an incremental approach to performing the necessary work. An incremental seismic rehabilitation program was implemented to take advantage of scheduled maintenance (e.g., roof replacement) and occupancy turnover in the major tenant areas located throughout the building.

## ***B.1 Building Description***

The case study building is a two story unreinforced masonry (URM) bearing wall structure built in the early 1900s. It is an occupied historic building in the downtown district of the city. The first floor is used for retail sales and the second floor is used for offices. Given these uses, FEMA 397, *Incremental Seismic Rehabilitation of Office Buildings* (FEMA, 2003), and FEMA 399, *Incremental Seismic Rehabilitation of Retail Buildings* (FEMA, 2004), would be applicable.

## In Brief

This appendix:

- Explains how seismic rehabilitation increments were staged in an individual building
- Describes a set of rehabilitation measures typical of unreinforced masonry construction
- Illustrates one approach to construction phasing

The building measures approximately 29 feet wide by 90 feet long, with a single-story addition of reinforced concrete masonry block located in the rear. The walls are 13-inch unreinforced brick masonry founded on a concrete perimeter foundation. The first floor consists of wood joists spanning between wood girders supported on small concrete piers. The first floor diaphragm is a double layer of diagonal and straight wood sheathing.

The second floor consists of 2x14 wood joists spanning the width of the building, sheathed with diagonal and straight wood sheathing. The roof consists of 1x6 straight wood sheathing spanning between carpenter trusses at 24 inches on center. Unreinforced masonry parapets extend above the roof in heights ranging from 20 to 48 inches.

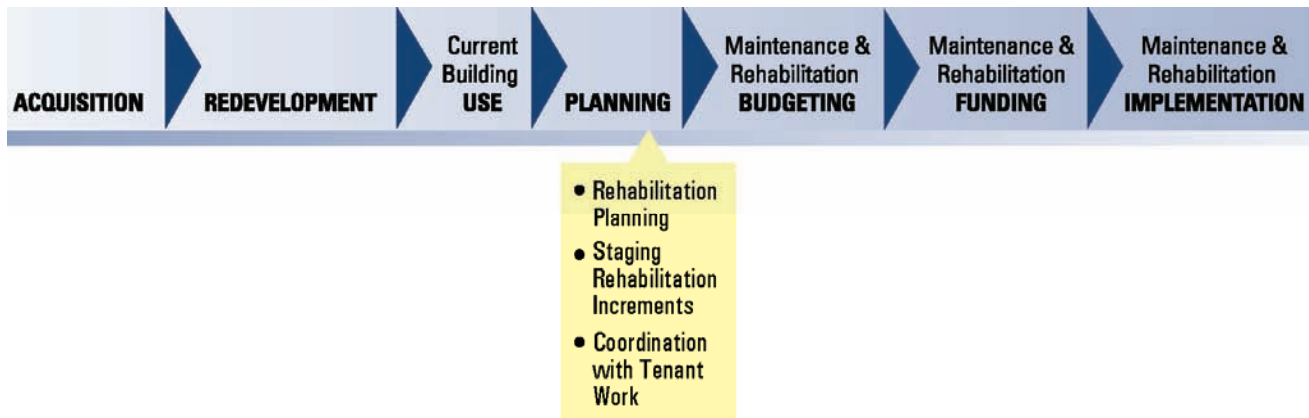


Figure B-1 Portion of the incremental seismic rehabilitation process illustrated in the case study example of Appendix B.

## B.2 Regulatory Context

Unreinforced masonry buildings have been the cause of deaths and injuries in past earthquakes. In 1987, California adopted legislation requiring all local jurisdictions in Seismic Zone 4 (the highest seismic zone) to survey and identify URM buildings, and to notify building owners of the findings. In response to this potential hazard, many local jurisdictions adopted a variety of regulations with mandatory hazard reduction measures. Many such regulations included installation of parapet bracing and out-of-plane wall anchors.

In the jurisdiction in which this case study building was located, owners were notified of their URM status and required to have seismic rehabilitation plans and calculations prepared and submitted for plan check. Seismic design work was based on the criteria contained in Appendix 1 of the *Uniform Code for Building Conservation*, which is now Appendix Chapter A-1 of the *International Existing Building Code* (ICC, 2006).

While the development of rehabilitation plans and calculations were required, no completion date for the construction work was specified at that time (1989). This flexibility in compliance opened the door to consider phasing of seismic strengthening work in increments. How eventual compliance was integrated into future tenant changes and

maintenance cycles, and how rehabilitation work was packaged to incrementally improve seismic performance, are discussed in the sections that follow.

### **B.3 Rehabilitation Measures**

A seismic evaluation was performed. The case study building was found to contain many seismic deficiencies typical of unreinforced masonry bearing wall construction. Rehabilitation designs were prepared. The following rehabilitation measures were planned to address deficiencies identified in the case study building:

**Parapet Bracing.** Due to their unbraced height, parapets on all walls required bracing. Parapet bracing consisted of a horizontal steel channel located about 12 inches below the top of the wall, braced by steel angles anchored to the roof.

**Wall-to-Roof Anchorage.** The unreinforced masonry walls required both out-of-plane anchors and in-plane shear force connections to the roof diaphragm. Anchors consisted of epoxy (adhesive) anchors installed at an angle of 22.5 degrees into the wall. Options included a through-bolt configuration, which was not selected in order to avoid impacts to the façade and disruption of an adjacent building.

**Wall Stability Bracing.** The second floor wall exceeded acceptable height/thickness ratios for stability, and thus required stability bracing. Wall stability bracing consisted of vertical steel tubes attached to the floor and roof diaphragms.

**Wall-to-Second Floor Anchorage.** Walls required both out-of-plane and in-plane anchorage at the second floor level, similar to details used at the roof.

**Lateral Bracing at Open Front.** Because of a large entry door and windows, there was no lateral bracing across the front of the building. A two-story steel frame was needed one column line inside the building to provide the necessary lateral bracing at the front of the building.

**Lateral Bracing at Rear Wall.** At the time when the one-story addition was constructed, most of the original rear wall was removed. To provide adequate lateral bracing at the back of the building, a layer of reinforced shotcrete was required on the remaining portions of the wall, and a collector was needed to deliver loads to the reinforced wall.

**Crosswalls.** The existing roof diaphragm did not have sufficient capacity to span between existing shear wall elements without excessive deformation. Wood crosswalls were needed in the second story to couple the roof diaphragm to the stiffer second floor diaphragm to minimize diaphragm deflections. This option was chosen in lieu of creating a new roof diaphragm by placing a layer of plywood over the roof.

## ***B.4 Staging of Seismic Rehabilitation Increments***

Because of flexibility in the URM compliance timeline, the building owner had two choices for scheduling the work: (1) single-stage construction; and (2) phased construction. A single-stage project would require contractor access to the entire building, forcing existing tenants to temporarily relocate or to move. Since the building was completely occupied, and generating revenue, a single stage project did not appeal to either the building owner or the tenants.

The owner decided to phase the work. Specific to the facility management process for retail/office occupancies, rehabilitation planning included coordination with tenant work. The incremental rehabilitation plan was based on the eventual expiration of tenant lease contracts, and the eventual need to perform certain maintenance work in the building. The planned rehabilitation measures were broken into phases conducted over a 10-year time frame. The resulting rehabilitation increments are shown in Figure B-1, Figure B-2, and Figure B-3.

Each phase resulted in an incremental improvement in the expected seismic performance of the building. Because of floor and roof diaphragm flexibility, incremental work in one area did not create a torsional irregularity condition in the building during intermediate phases of work.

**Phase 1.** The first phase was initiated in conjunction with a planned re-roofing project. Since re-roofing could be accomplished without disrupting the tenants, all work for this phase was detailed to be done from above the roof. Work in this phase included the installation of all parapet bracing and all wall-to-roof anchors (Figure B-3).

**Phase 2.** Several years later, the tenant on the first floor vacated the space. Work in this phase included installation of the first story of the steel frame at the front of the building, including the grade beam, columns, and beam under the second floor. Work also included shotcrete installation on the rear shearwall, and installation of all wall-to-second floor anchors from below the second floor (Figure B-1).

**Phase 3.** When the tenant located in the front portion of the second floor decided to move, this provided an opportunity to work in about half of the second floor area. Work in this phase consisted of completing the second story of the steel frame at the front of the building, installation of the wall stability braces, and installation of crosswall extensions in this area of the building (Figure B-2).

**Phase 4.** Eventually the rear portion of the second floor was vacated and the work could be completed. Work in this phase included installation of the remaining wall stability braces and the remainder of the crosswall extensions (Figure B-2).

Additional work was also done during the various phases of construction. The owner took these opportunities to update and improve the electrical system, install accessible toilets, provide new finishes on the walls and ceilings, and upgrade mechanical (HVAC) systems.

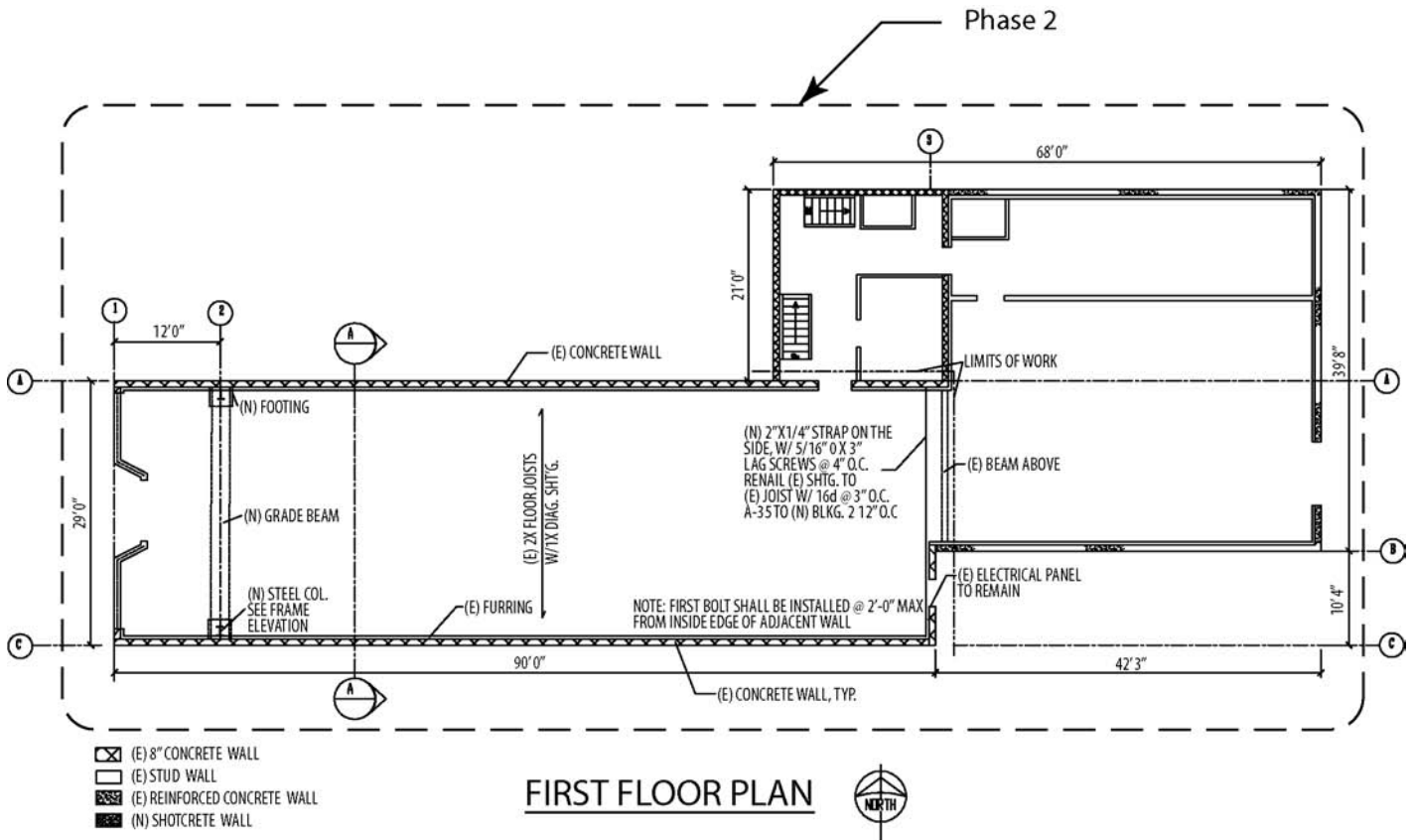


Figure B-2 First floor plan and rehabilitation increments (graphic courtesy of M. Green).

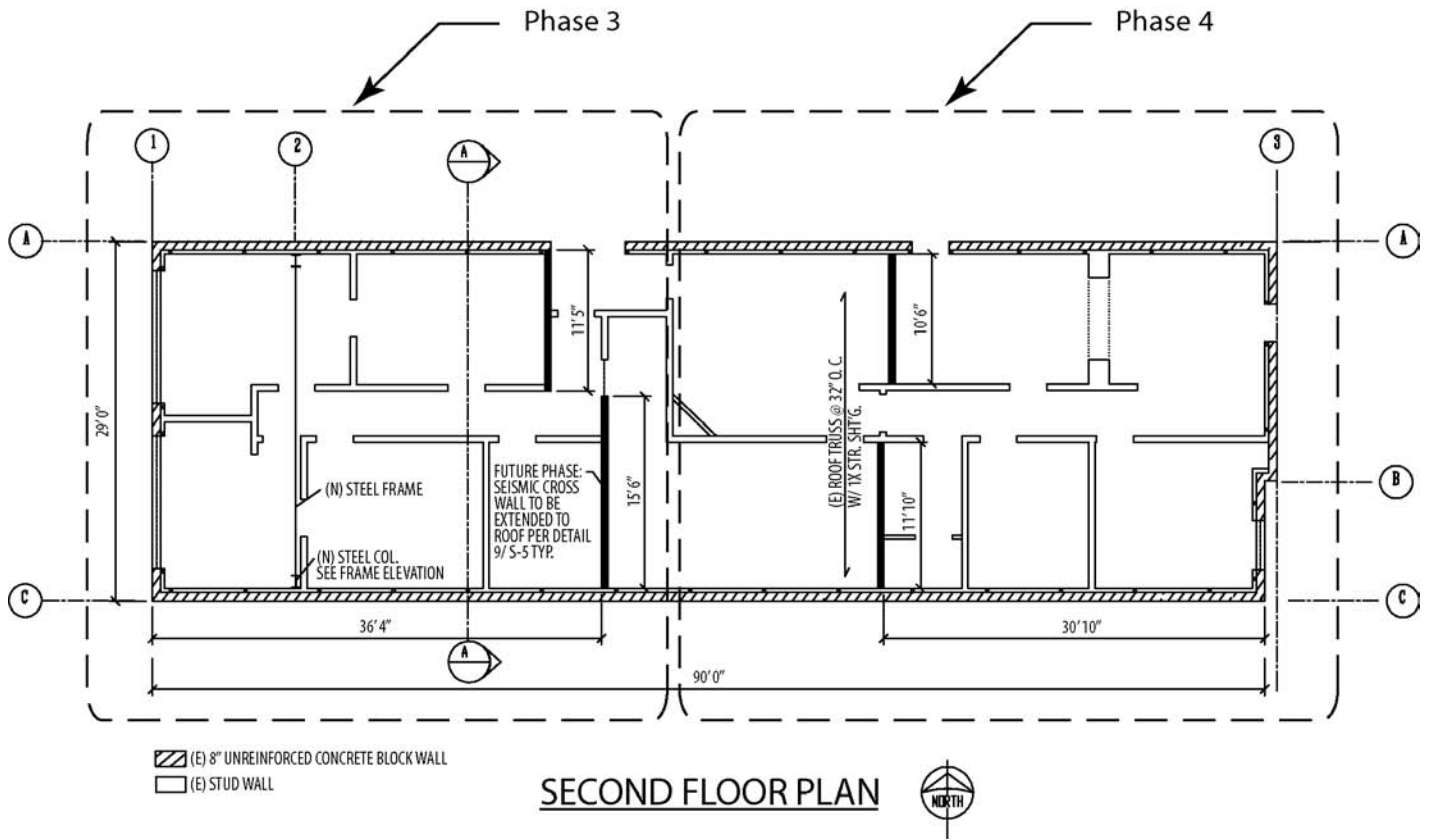


Figure B-3 Second floor plan and rehabilitation increments (graphic courtesy of M. Green).

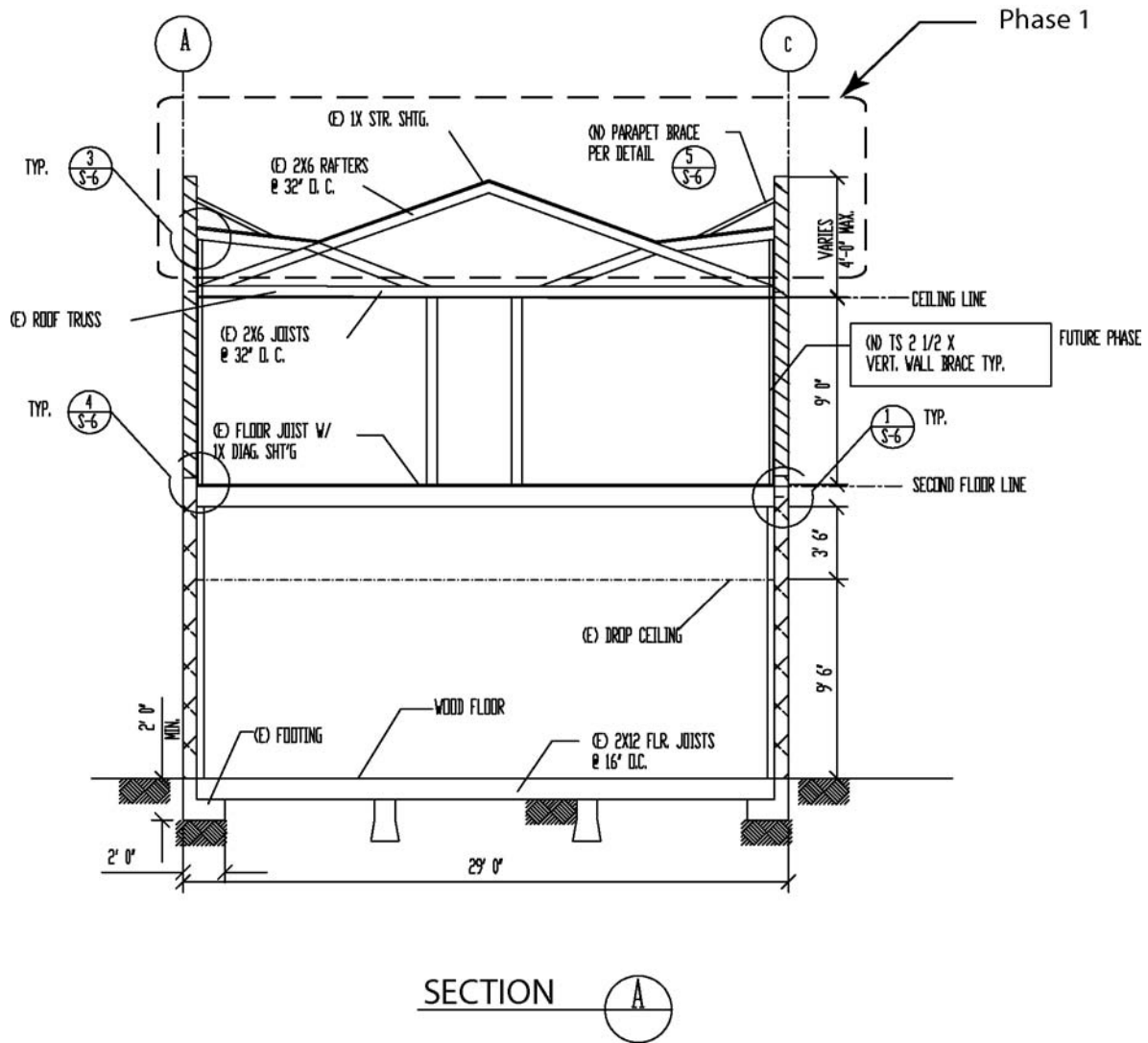


Figure B-4 Building cross-section and rehabilitation increments (graphic courtesy of M. Green).





# Appendix C Other Existing Building Resource Documents

This appendix lists other relevant existing building resource documents that could be applicable to the development and implementation of an incremental seismic rehabilitation program.

## **C.1 Relevant Resources from the FEMA Existing Buildings Program**

FEMA's Existing Buildings Program is part of the National Earthquake Hazard Reduction Program (NEHRP). Under this program, FEMA has developed a collection of documents related to earthquake hazard mitigation. Additional information is available on the FEMA website at <http://www.fema.gov/plan/prevent/earthquake/>. Other FEMA documents that could be applicable to the development of an incremental seismic rehabilitation program include:

- FEMA 74, *Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide, Third Edition, 1994*
- FEMA 156, *Typical Costs for Seismic Rehabilitation of Existing Buildings, Volume 1 - Summary (Second Edition), 1994*
- FEMA 227, *A Benefit-Cost Model for the Seismic Rehabilitation of Buildings, Volume 1: A User's Manual, 1992*
- FEMA 255, *Seismic Rehabilitation of Federal Buildings: A Benefit/Cost Model, Volume 1: A User's Manual, 1994*
- FEMA 306, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual, 1999*
- FEMA 307, *Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Technical Resources, 1999*

## In Brief

This appendix:

- Lists other relevant documents from the FEMA Existing Buildings Program
- Lists relevant documents from other sources

- FEMA 308, *Repair of Earthquake Damaged Concrete and Masonry Wall Buildings*, 1999
- FEMA 351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*, 2000
- FEMA 389, *Primer for Design Professionals, Communicating with Owners and Managers of New Buildings on Earthquake Risk*, 2004
- FEMA 412, *Installing Seismic Restraints for Mechanical Equipment*, 2002
- FEMA 413, *Installing Seismic Restraints for Electrical Equipment*, 2002
- FEMA 414, *Installing Seismic Restraints for Duct and Pipe*, 2002
- FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings*, 2006

## **C.2 Other Existing Building Resource Documents**

Additional existing building resource documents from other sources include:

- ASTM International, ASTM E2026-07, *Standard Guide for Seismic Risk Assessment of Buildings* (ASTM, 2007a)
- ASTM International, ASTM E2557-07, *Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments* (ASTM, 2007b)
- Applied Technology Council, ATC-40, *Seismic Evaluation and Retrofit of Concrete Buildings* (ATC, 1996)
- Structural Engineers Association of Northern California/ International Conference of Building Officials, *Guidelines for Seismic Evaluation and Rehabilitation of Tilt-up Buildings and Other Rigid Wall/Flexible Diaphragm Structures* (SEAONC/ICBO, 2001)

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