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U. S. GUIDELINES FOR THE SEISMIC REHABILITATION OF EXISTING BUILDINGS

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ABSTRACT

The ongoing FEMA-sponsored program to prepare "Guidelines for Seismic Rehabilitation of Existing Buildings" has been planned and executed to provide a set of technically sound, nationally applicable and consensus-backed Guidelines and Commentary for the United States. The Guidelines will enable users, on a voluntary basis, to rehabilitate buildings to meet specified performance levels such as Collapse Prevention, Life Safety, and Immediate Occupancy, and performance ranges such as Limited Safety and Damage Control, for specifically defined ground motion levels. The Guidelines include "Simplified Rehabilitation" and "Systematic Rehabilitation" methods, new Linear Static and Nonlinear Static analysis procedures, procedures for determining acceptability of existing components/elements, and procedures for incorporating emerging technologies.

KEYWORDS

seismic rehabilitation; seismic retrofit; seismic strengthening; building standards; seismic performance levels.

INTRODUCTION

Model codes and standards for the seismic design of new buildings have been adopted and enforced throughout the United States for decades. To date, however, only a few communities in the United States, such as the City of Los Angeles, have adopted regulations for the seismic strengthening of existing buildings. In those instances where regulations have been adopted, they have focused on one or two of the most vulnerable local building types (e.g., unreinforced masonry) and have been limited primarily to "risk reduction" measures, as opposed to higher performance levels, such as life safety. One of the primary barriers to widespread implementation of seismic strengthening/upgrading in the United States has been the absence of consensus-backed, professionally accepted, nationally applicable standards for the seismic rehabilitation (retrofit/strengthening) of existing buildings.

In 1989, as a capstone project in a major, multi-year Federal program for mitigating earthquake hazards of existing (non-Federal) buildings, the Federal Emergency Management Agency (FEMA) initiated a two-

phase effort to prepare a set of technically sound, nationally applicable guidelines for the seismic rehabilitation of buildings. Phase I, conducted by the Applied Technology Council (ATC) and completed in 1992, focused on the identification and resolution of a wide range of issues that should be considered during the actual preparation of guidelines in Phase II. The results of the Phase I project, published in FEMA Report 237, *Seismic Rehabilitation of Buildings - Phase I, Issues Identification and Resolution* (ATC, 1992), established the initial conceptual decisions for the Phase II guidelines writers and provided a comprehensive set of recommendations intended to guide, but not bind, the writers. Among the numerous Phase I recommendations was the recommendation that the guidelines provide performance based design procedures that would enable designers to achieve specific levels of building performance, such as life safety and damage control, for given levels of ground shaking.

The Phase II effort commenced in 1992 with the establishment of a five-year, $8-million Cooperative Agreement (No. EMW-91-K-3602) between FEMA and the National Institute of Building Sciences (NIBS) for preparation of *Guidelines for the Seismic Rehabilitation of Buildings* (Guidelines Project). NIBS, through its Building Seismic Safety Council (BSSC), has overall management responsibility for the Guidelines Project as well as direct technical responsibility for performance of a consensus review of the *Guidelines* and several other specific tasks. ATC, as a subcontractor to BSSC, has responsibility for preparing the *Guidelines* and related companion documents and for revising the documents as appropriate following the consensus review process. The American Society of Civil Engineers (ASCE), as another subcontractor to BSSC, has responsibility for conducting Users Workshops, capturing relevant research results, and resolving issues raised (but not resolved) in Phase I.

A team of approximately 60 consultants (practitioners and researchers) from various regions of the United States have been engaged by ATC to develop the *Guidelines* (ATC-33 project). End users are participating in ASCE-conducted "Users Workshops" at the 25%, 50%, and 75% complete stages to evaluate and comment on the utility and user-friendliness of the *Guidelines*. Approximately one year prior to completion, which is scheduled for September 1997, the *Guidelines* will undergo a consensus review by the BSSC.

The *Guidelines* are based on current research knowledge and practice methods. Although no new research is being conducted to support the development process, an effort has been undertaken to identify and summarize relevant research results for use by the *Guidelines* writers. In addition, the new analysis methods developed in the project are being evaluated in case studies of 25 buildings damaged by the January 17, 1994 Northridge, California, earthquake.

PURPOSE

The *Guidelines for Seismic Rehabilitation of Buildings* (ATC, 1995) are intended to serve as a tool for design professionals, a reference document for building regulatory officials, and a foundation for the future development and implementation of building code provisions and standards. The *Guidelines* do not presume that rehabilitation will necessarily be mandated by a state or local code; rather, they are intended to be of use to owners and their design professionals for voluntary rehabilitation efforts.

The document is intended to be used primarily by the technical community responsible for developing and using building codes and standards and for carrying out the design and analysis of buildings. This primary user group includes architects, engineers, and building officials. Parts of the *Guidelines* and companion *Commentary* will also be useful and informative beyond the primary technical audience to building owners, government agencies, and policy makers.

The engineering expertise of a design professional (architect, engineer, code official) is a prerequisite to the appropriate use of the *Guidelines*, and most of the provisions of the document presume the expertise of a structural engineer experienced in building design.

The document is neither a code nor a standard. It is intended to be suitable both for voluntary use by owners and design professionals as well as for adaptation and adoption into model building codes and standards.

SIGNIFICANT NEW FEATURES

The document contains several new features that depart significantly from previous seismic codes.

1. Criteria and methods for achieving various performance levels at various seismicity (ground shaking) levels, defined regionally in terms of recurrence intervals. Performance levels and ranges considered include: Limited Safety; Collapse Prevention; Life Safety; Damage Control; and Immediate Occupancy. The combination of these parameters (performance level and expected level of ground shaking) enable the user to seek one of the following rehabilitation objectives:
   - Basic Safety Objective: Life Safety for ground shaking with a 10% probability of exceedance in 50 years and Collapse Prevention for ground shaking with a 2% probability of exceedance in 50 years.
   - Limited Objectives: rehabilitation objectives less stringent than the Basic Safety Objective, such as performance levels less than life safety (Limited Safety) for ground shaking with a 10% probability of exceedance in 50 years, or Life Safety for a ground shaking with a higher than 10% (e.g., 50%) probability of exceedance in 50 years.
   - Enhanced Objectives: rehabilitation objectives that call for a higher level of performance than the Basic Safety Objective, such as Immediate Occupancy, or Damage Control, for ground shaking with a 10% probability of exceedance in 50 years, or Life Safety for ground shaking with less than 10% (e.g., 5%) probability of exceedance in 50 years and "Collapse Prevention" for ground shaking with less than 2% probability of exceedance in 50 years..
2. Methods for "Simplified Rehabilitation", applicable to small regular buildings primarily, although not exclusively, in areas of low and moderate seismicity and specified as a function of model building type, ground shaking amplitude (seismicity level), and desired performance level (applicable to the performance levels/ranges of Limited Safety, and, in some cases, Life Safety).
3. Methods for "Systematic Rehabilitation", i.e., complete procedures for considering all elements necessary to reach a specified performance level for any building. These procedures address rehabilitation strategies, analysis procedures and their selection, and material acceptance criteria.
4. New methods of analysis, including (a) a new Linear Static Procedure (LSP) based on estimating maximum structural displacements, and (b) a new Nonlinear Static Procedure (NSP) (i.e., "Pushover" Analysis) that will better account for structural behavior caused by progressive yielding of structural elements.
5. Detailed procedures for determining acceptability of existing components and elements as well as designing new ones in the four major material groups: wood, concrete, steel, and masonry. These depart from standard design procedures for new buildings, which generally consider all parts of the structure to have similar characteristics.

6. Procedures for incorporating emerging technologies in the rehabilitation design, including seismic isolation and supplemental damping.

7. Criteria for seismic rehabilitation of nonstructural elements, coupled with various performance objectives and emphasizing those components important for the Basic Safety Objective. Components are divided between those that affect response and those that do not. Both prescriptive and analysis procedures are included.

SCOPE

The *Guidelines* can be applied to all buildings regardless of importance, occupancy, historic features, size, or other characteristics, that by some criteria are deficient in their ability to resist the effects of earthquake shaking. In addition to the direct effects of ground shaking, the document also includes consideration of the effects on buildings of local ground failure such as liquefaction. Excepted are non-building structures such as elevated tanks or billboards unless they are part of a building. Also excepted are buildings or structures covered by special codes or standards such as bridges and nuclear power plants.

The document also applies both to the overall structural system of a building, its elements, for example, shear walls or frames, and the constituent components of elements such as a column in a frame or a boundary member in a wall. It also applies to nonstructural components of existing buildings--ceilings partitions, and mechanical/electrical systems. Rehabilitation techniques for reducing seismic demand, e.g., the introduction of isolation or damping devices, in addition to increasing strength and ductility of systems, are also included. And, although the document is not intended to address the design of new buildings, it does cover new components or elements added to existing buildings.

While the *Guidelines* provide detailed engineering guidance on how to conduct seismic rehabilitation analysis once the decision to rehabilitate a building has been made and while the *Guidelines* could be used to conduct seismic evaluations, guidance on initial decisionmaking as to whether or not to undertake a rehabilitation project is beyond the scope of the *Guidelines*. Secondly, the question of when the *Guidelines* should be applicable in a mandatory way to a remodeling or structural rehabilitation project is also beyond the scope of the document. Finally, methods of reducing seismic risk that do not physically change the building, such as reducing the number of occupants, are not covered.

Also beyond the scope of this document are recommendations regarding what Performance Level and what severity and probability of shaking should be selected for Rehabilitation of any particular building, although a risk traditionally considered acceptable in the United States is central to this document and is termed the Basic Safety Objective (see significant new features above). Higher and lower objectives can also be defined by the user. The *Guidelines* were written under the premise that greater flexibility is required in seismic rehabilitation than in the design of new buildings. Once the rehabilitation objective is established, the *Guidelines* provide internally consistent procedures that include analysis and design specifications necessary to meet the rehabilitation objective.

Special or new mapping of expected seismic ground shaking for the United States has not been developed for the *Guidelines*. Although ground shaking can be defined for any probability of occurrence, it is intended that the seismic hazard used with this document be consistent with national mapping contained in the National Earthquake Hazards Reduction Program (NEHRP) *Provisions* for new buildings, currently the 1994 NEHRP edition (FEMA, 1995). Presently, national maps are available for ground shaking with a 10% chance of exceedance in 50 years, a 5% chance of exceedance in 50 years, and a 2% chance of

exceedance in 50 years. These probabilities correspond to shaking that is expected to occur, on average, about once every 500 (or more exactly, 474 years), 1000 and 2500 years.

Also featured in the *Guidelines* are descriptions of damage states with relation to specific Performance Levels. These descriptions are intended to aid design professionals and owners when selecting appropriate Performance Levels for rehabilitation design and in their judgments concerning design of rehabilitation measures.

CONTENTS OVERVIEW

While the Guidelines contain information that would not be included in seismic codes for new buildings, the Guidelines are organized much like codes for new buildings (Figure 1).

Table of Contents

Fig. 1. *Guidelines* Table of Contents (75% complete draft).

Chapter 1 provides an overview of the *Guidelines*, its relationship to other documents, the use of the *Guidelines* in the seismic rehabilitation process, and the use of the *Guidelines* for local or direct risk mitigation programs.

General requirements for rehabilitating existing buildings are presented in Chapter 2. The framework in which these requirements are specified is purposely broad in order to accommodate rehabilitating buildings: (1) of many different types, (2) to satisfy a broad range of performance goals, and (3) to include consideration of the variations of seismic hazards throughout the United States. Criteria for eleven general issues regarding the seismic rehabilitation of buildings are included:

- Rehabilitation (Risk Reduction) Objectives. Selection of desired performance level for given earthquake severity levels.

- Performance Levels defining the expected behavior of the building in the design earthquake(s) in terms of limiting levels of damage.

- Seismic Hazard. Determination of the design ground shaking and other site hazards, such as landsliding, liquefaction, settlement.

- As Built Characteristics. Determination of the basic construction and earthquake resistive capacity of the existing building.

- Rehabilitation Methods. Selection between simplified approaches and systematic approaches.

- Rehabilitation Strategies. Selection of a basic approach for rehabilitation, e.g., provide additional lateral load carrying elements, base isolation.

- Analysis and Design Procedures. For systematic rehabilitation approaches, selection among linear static, linear dynamic, or nonlinear methods of analysis.

- General Analysis and Design Requirements. Specification of the force actions for which given components of a building must be evaluated, and minimum design criteria for interconnection of structural components.

- Building Interaction. Guidelines for buildings that share elements with neighboring structures, and buildings with performance affected by the presence of adjacent structures.

- Quality Assurance. Guidelines for assuring that the design intent is appropriately represented by the rehabilitation construction.

- Alternative Materials and Methods. Guidelines for evaluating and designing structural components not specifically covered by other sections of the *Guidelines.*

Chapter 3 provides the analysis and design requirements for seismic rehabilitation of existing buildings. Four alternative analysis procedures are presented: (1) Linear Static Procedure; (2) Linear Dynamic Procedure; (3) Nonlinear Static Procedure; and (4) Nonlinear Dynamic Procedure. The limitation with regard to the use of these procedures are provided in Chapter 2. The Linear Static Procedure (LSP), which provides an approximate solution for the first mode dynamic response of a building to earthquake ground motions and uses a newly formulated equation to estimate base shear, is the preferred procedure for use with buildings of wood frame construction. Both the LSP and the Linear Dynamic Procedure (LDP), which is performed using specified ground motion criteria and accepted principles of structural dynamics, may be used for any of the recommended rehabilitation strategies except strategies incorporating the use of supplemental energy dissipation systems and some types of base isolation systems. Component actions resulting from application of the linear analysis procedures are categorized as being either force controlled or displacement controlled and compared against allowable capacities to determine acceptability. Linear analysis procedures (LSP and LDP) should not be used for buildings with highly irregular structural systems, unless the building is capable of responding to the design earthquake(s) in a nearly elastic manner and the earthquake ductility demands on the building are suitably low (guidelines for computing and evaluating the distribution of inelastic demands are provided in Chapter 2).

The Nonlinear Static Procedure (NSP) of Chapter 3 is a "push-over" analysis procedure whereby lateral loads in patterns that represent approximately the relative inertia forces generated at locations of substantial mass are applied to a two or three dimensional analytical model of the building. This model is deflected to displacements that are larger than the maximum displacements expected in the design earthquake, and the

resulting demands are then compared with available capacities. The Nonlinear Dynamic Procedure (NDP) is performed using specified ground motion criteria, accepted principles of structural dynamics, and computer software applications (as they become available). In the NDP, the force and inelastic deformation demands in the design earthquake(s) are also computed explicitly for each component of the structure, and acceptability is based on a comparison of computed demands and available capacities at the performance level(s) of interest. The NDP should be considered for a structure in which higher mode effects are important. Nonlinear analysis procedures (NSP and NDP) may be used for any structure and any rehabilitation strategy with the following exceptions and limitations:

- When sufficient information is available on the probable strengths of materials and configurations of components (as specified in Chapter 2).
- When the NDP is used, the project should be subject to review by an independent, third-party professional engineer with substantial experience in seismic design.

Chapter 4 presents the Simplified Rehabilitation Method, which is intended for use only on a selected group of simple buildings being rehabilitated to a limited safety design objective (i.e., to a performance level less than the basic safety objective). The Simplified Rehabilitation Method recognizes that the performance of certain common building types that meet specific limitations on height and regularity can be substantially improved by simply eliminating each of the deficiencies found using the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* (FEMA, 1992). In addition to the *NEHRP Handbook* deficiencies, the *Guidelines* define eight newly identified additional deficiencies that must be considered in the Simplified Rehabilitation Method. The design ground motion criteria in the Simplified Rehabilitation Method is the same as that specified in the *NEHRP Handbook*: 67% to 85% (depending on building period) of the ground motions having a less than 10% chance of exceedance in 50 years. In high seismic zones, the Simplified Rehabilitation Method is limited to buildings no taller than 2 or 3 stories, depending on building type; in moderate zones, it is limited to buildings no taller than 2 to 4 stories, depending on building type; and in low seismic zones, it is limited to buildings no taller than 2 to 6 stories, depending on building type. Moreover, in certain locations, the Simplified Rehabilitation Method can not be used on certain types of steel and concrete frame buildings with masonry infill walls and on certain types of precast concrete frame buildings.

Chapters 5 through 8 describe rehabilitation measures for components and elements, respectively, for the four major material groups: steel, concrete, masonry and wood. Included in these chapters are sections that provide (1) perspective on historical variations in material properties and connection details; (2) material properties for new and existing components; (3) evaluation methods for in-place materials; (4) attributes of typical system elements; and (5) stiffness and strength acceptance criteria for structural components, including foundation components. The acceptance criteria are expressed in terms of component demand modifiers that have been developed on the basis of available research data on the cyclic, force-deformation relationships of materials. The demand modifiers are used in conjunction with acceptance criteria equations and specifications provided in Chapter 3.

Guidelines for the application of seismic protective systems to building rehabilitation are provided in Chapter 9. Specific guidance is provided for seismic (base) isolation systems and for passive energy dissipation systems. Additional, limited guidance is provided for other special seismic systems, including active control systems, hybrid active and passive systems, and tuned mass and liquid dampers. The guidelines in Chapter 9 recognize that seismic isolation and energy dissipation systems include a wide variety of concepts and devices. In most cases, these systems will be implemented with some additional conventional strengthening of the structure and, in all cases, require evaluation of existing building elements. Chapter 9 supplements the guidelines of other chapters with additional criteria and methods of

analysis that are appropriate for buildings rehabilitated with seismic isolation systems and/or energy dissipation devices.

Chapter 10 provides geotechnical engineering guidance regarding building foundation and seismic-geologic sites hazards. Included are guidelines for establishing site soil characteristics and for identifying the following site geotechnical hazards: fault rupture, liquefaction, differential compaction, landslide and rock fall, and flooding. Also provided are techniques for mitigating geotechnical site hazards; criteria for establishing soil strength capacity, stiffness and soil-structure interaction parameters for making foundation design evaluations; guidance on how to estimate soil pressure on retaining walls; and criteria for enhancing foundation strength and stiffness.

Chapter 11 provides rehabilitation criteria for architectural, mechanical, and electrical components and systems that are permanently installed in buildings, including their supports and attachments. Contents introduced into buildings by owners or occupants are not within the scope of the *Guidelines*. This chapter contains a list of nonstructural components that are subject to the *Guidelines*, rehabilitation requirements related to seismic zone and the collapse prevention, life-safety and immediate occupancy performance levels; general requirements for acceptance criteria for acceleration-sensitive and deformation-sensitive components; and analysis methods. Methods for nonstructural rehabilitation, which can be accomplished through replacement, strengthening, bracing, or attachment, are provided in the *Commentary*.

SUMMARY

An extensive 6-year project to prepare *Guidelines for Seismic Rehabilitation of Existing Buildings* is currently underway in the United States. Funded by the Federal Emergency Management Agency (FEMA) and prepared by the Applied Technology Council for the Building Seismic Safety Council, the *Guidelines* (ATC, 1995) are intended to serve as a tool for design professionals, a reference document for building regulatory officials, and a foundation for the future development and implementation of building code provisions and standards. The *Guidelines* will enable users, on a voluntary basis, to rehabilitate buildings to meet specified performance levels such as Collapse Prevention, Life Safety, and Immediate Occupancy, and performance ranges such as Limited Safety and Damage Control, for specifically defined ground motion levels. The Guidelines contain significant new features, including a "Simplified Rehabilitation" method, which can be applied to certain simple, regular buildings that do not exceed specified height restrictions; a "Systematic Rehabilitation" method (the main body of the *Guidelines*), which can be applied to any type of building at any location; new Linear Static and Nonlinear Static analysis procedures; procedures for determining acceptability of existing components/elements; and procedures for incorporating emerging technologies. Seismic rehabilitation guidance is also provided for nonstructural components and systems.

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