The NEHRP Recommended Provisions: Design Examples are written to illustrate and explain the applications of the 2009 NEHRP Recommended Seismic Provisions for Buildings and Other Structures, ASCE 7-10 Minimum Design Loads for Buildings and Other Structures and the material design standards referenced therein and to provide explanations to help understand them. Designing structures to be resistant to major earthquake is complex and daunting to someone unfamiliar with the philosophy and history of earthquake engineering. The target audience for the Design Examples is broad. College students learning about earthquake engineering, engineers studying for their licensing exam, or those who find themselves presented with the challenge of designing in regions of moderate and high seismicity for the first time should all find this document’s explanation of earthquake engineering and the Provisions helpful.

Fortunately, major earthquakes are a rare occurrence, significantly rarer than the other hazards, such as damaging wind and snow storms that one must typically consider in structural design. However, past experiences have shown that the destructive power of a major earthquake can be so great that its effect on the built environment can be underestimated. This presents a challenge since one cannot typically design a practical and economical structure to withstand a major earthquake elastically in the same manner traditionally done for other hazards.

Since elastic design is not an economically feasible option for most structures where major earthquakes can occur, there must be a way to design a structure to be damaged but still safe. Unlike designing for strong winds, where the structural elements that resist lateral forces can be proportioned to elastically resist the pressures generated by the wind, in an earthquake the lateral force resisting elements must be proportioned to deform beyond their elastic range in a
controlled manner. In addition to deforming beyond their elastic range, the lateral force resisting system must be robust enough to provide sufficient stability so the building is not at risk of collapse.

While typical structures are designed to be robust enough to have a minimal risk of collapse in major earthquakes, there are other structures whose function or type of occupants warrants higher performance designs. Structures, like hospitals, fire stations and emergency operation centers need to be designed to maintain their function immediately after or returned to function shortly after the earthquake. Structures like schools and places where large numbers of people assemble have been deemed important enough to require a greater margin of safety against collapse than typical buildings. Additionally, earthquake resistant requirements are needed for the design and anchorage of architectural elements and mechanical, electrical and plumbing systems to prevent falling hazards and in some cases loss of system function.

Current building standards, specifically the American Society of Civil Engineers (ASCE) 7 *Minimum Design Loads for Buildings and Other Structures* and the various material design standards published by the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), the American Iron and Steel Institute (AISI), the American Forest & Paper Association (AF&PA) and The Masonry Society (TMS) provide a means by which an engineer can achieve these design targets. These standards represent the most recent developments in earthquake resistant design. The majority of the information contained in ASCE 7 comes directly from the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*. The stated intent of the *NEHRP Provisions* is to provide reasonable assurance of seismic performance that will:

1. Avoid serious injury and life loss,
2. Avoid loss of function in critical facilities, and
3. Minimize structural and nonstructural repair costs where practical to do so.

The *Provisions* have explicit requirements to provide life safety for buildings and other structures though the design forces and detailing requirements. The current provisions have adopted a target risk of collapse of 1% over a 50 year lifespan for a structure designed to the *Provisions*. The *Provisions* provide prevention of loss of function in critical facilities and minimized repair costs in a more implicit manner though prescriptive requirements.

Having good building codes and design standards is only one action necessary to make a community’s buildings resilient to a major earthquake. A community also needs engineers who can carry out designs in accordance with the requirements of the codes and standards and contractors who can construct the designs in accordance with properly prepared construction documents. The first item is what the *NEHRP Recommended Provisions: Design Examples* seeks to foster. The second item is discussed briefly later in this document in Chapter 1, Section 1.6 Quality Assurance.

The purpose of this introduction is to offer general guidance for users of the design examples and to provide an overview. Before introducing the design examples, a brief history of earthquake engineering is presented. That is followed by a history of the *NEHRP Provisions* and its role in
setting standards for earthquake resistant design. This is done to give the reader a perspective of the evolution of the *Provisions* and some background for understanding the design examples. Following that is a brief summary of each chapter.

### 1.1 EVOLUTION OF EARTHQUAKE ENGINEERING

It is helpful to understand the evolution of the earthquake design standards and the evolution of the field of earthquake engineering in general. Much of what is contained within the standards is based on lessons learned from earthquake damage and the ensuing research.

Prior to 1900 there was little consideration of earthquakes in the design of buildings. Major earthquakes were experienced in the United States, notably the 1755 Cap Ann Earthquake around Boston, the 1811 and 1812 New Madrid Earthquakes, the 1868 Hayward California Earthquake and the 1886 Charleston Earthquake. However, none of these earthquakes led to substantial changes in the way buildings were constructed.

Many things changed with the Great 1906 San Francisco Earthquake. The earthquake and ensuing fire destroyed much of San Francisco and was responsible for approximately 3,000 deaths. To date it is the most deadly earthquake the United States has ever experienced. While there was significant destruction to the built environment, there were some important lessons learned from those buildings that performed well and did not collapse. Most notable was the exemplary performance of steel framed buildings which consisted of riveted wind frames and brick infill, built in the Chicago style.

The recently formed San Francisco Section of the American Society of Civil Engineers (ASCE) studied the effects of the earthquake in great detail. An observation was that “a building designed with a proper system of bracing wind pressure at 30 lbs. per square foot will resist safely the stresses caused by a shock of the intensity of the recent earthquake.” (ASCE, 1907) That one statement became the first U.S. guideline on how to provide an earthquake resistant design.

The earthquakes in Tokyo in 1923 and Santa Barbara in 1925 spurred major research efforts. Those efforts led to the development of the first seismic recording instruments, shake tables to investigate earthquake effects on buildings, and committees dedicated to creating code provisions for earthquake resistant design. Shortly after these earthquakes, the 1927 *Uniform Building Code* (UBC) was published (ICBO, 1927). It was the first model building code to contain provisions for earthquake resistant design, albeit in an appendix. In addition to that, a committee began working on what would become California’s first state-wide seismic code in 1939.

Another earthquake struck Southern California in Long Beach in 1933. The most significant aspect, of that earthquake was the damage done to school buildings. Fortunately the earthquake occurred after school hours, but it did cause concern over the vulnerabilities of these buildings. That concern led to the Field Act, which set forth standards and regulations for earthquake
resistance of school buildings. This was the first instance of what has become a philosophy engrained in the earthquake design standards of requiring higher levels of safety and performance for certain buildings society deems more important that a typical building. In addition to the Field Act, the Long Beach earthquake led to a ban on unreinforced masonry construction in California, which in later years was extended to all areas of moderate and high seismic risk.

Following the 1933 Long Beach Earthquake there was significant activity both in Northern and Southern California, with the local Structural Engineers Associations of each region drafting seismic design provisions for Los Angeles in 1943 and San Francisco in 1948. Development of these codes was facilitated greatly by observations from the 1940 El Centro Earthquake. Additionally, that earthquake was the first major earthquake for which the strong ground motion shaking was recorded with an accelerograph.

A joint committee of the San Francisco Section of ASCE and the Structural Engineers Association of Northern California began work on seismic design provisions which were published in 1951 as ASCE Proceedings-Separate No. 66. Separate 66, as it is commonly referred to as, was a landmark document which set forth earthquake design provisions which formed the basis of US building codes for almost 40 years. Many concepts and recommendations put forth in Separate 66, such as the a period dependent design spectrum, different design forces based on the ductility of a structure and design provisions for architectural components are still found in today’s standards.

Following Separate 66, the Structural Engineers Association of California (SEAOC) formed a Seismology committee and in 1959 put forth the first edition of the Recommended Lateral Force Requirements, commonly referred to as the “The SEAOC Blue Book.” The Blue Book became the base document for updating and expanding the seismic design provisions of the Uniform Building Code (UBC), the model code adopted by most western states including California. SEAOC regularly updated the Blue Book from 1959 until 1999, with the changes made and new recommendations in each new edition of the Blue Book being incorporated into the subsequent edition of the UBC.

The 1964 Anchorage Earthquake and the 1971 San Fernando Earthquake both were significant events. Both earthquakes exposed significant issues with the way reinforced concrete structures would behave if not detailed for ductility. There were failures of large concrete buildings which had been designed to recent standards and those buildings had to be torn down. To most engineers and the public this was unacceptable performance.

Following the 1971 San Fernando Earthquake, the National Science Foundation gave the Applied Technology Council (ATC) a grant to develop more advanced earthquake design provisions. That project engaged over 200 preeminent experts in the field of earthquake engineering. The landmark report they produced in 1978, ATC 3-06, Tentative Provisions for the Development of Seismic Regulations for Buildings (1978), has become the basis for the current earthquake design standards. The NEHRP Provisions trace back to ATC 3-06, as will be discussed in more detail in the following section.
There have been additional earthquakes since the 1971 San Fernando Earthquake which have had significant influence on seismic design. Table 1 provides a summary of major North American earthquakes and changes to the building codes that resulted from them through the 1997 UBC. Of specific note are the 1985 Mexico City, 1989 Loma Prieta and 1994 Northridge Earthquakes.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>UBC Edition</th>
<th>Enhancement</th>
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<tbody>
<tr>
<td>1971 San Fernando</td>
<td>1973</td>
<td>Direct positive anchorage of masonry and concrete walls to diaphragms</td>
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<td></td>
<td>1976</td>
<td>Seismic Zone 4, with increased base shear requirements</td>
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<td></td>
<td></td>
<td>Occupancy Importance Factor I for certain buildings</td>
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<tr>
<td></td>
<td></td>
<td>Interconnection of individual column foundations</td>
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<td></td>
<td></td>
<td>Special Inspection requirements</td>
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<tr>
<td>1979 Imperial Valley</td>
<td>1985</td>
<td>Diaphragm continuity ties</td>
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<tr>
<td>1985 Mexico City</td>
<td>1988</td>
<td>Requirements for column supporting discontinuous walls</td>
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<td></td>
<td></td>
<td>Separation of buildings to avoid pounding</td>
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<td></td>
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<td>Design of steel columns for maximum axial forces</td>
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<td></td>
<td></td>
<td>Restrictions for irregular structures</td>
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<td></td>
<td></td>
<td>Ductile detailing of perimeter frames</td>
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<tr>
<td>1987 Whittier Narrows</td>
<td>1991</td>
<td>Revisions to site coefficients</td>
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<td></td>
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<td>Revisions to spectral shape</td>
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<td></td>
<td></td>
<td>Increased wall anchorage forces for flexible diaphragm buildings</td>
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<tr>
<td>1989 Loma Prieta</td>
<td>1991</td>
<td>Increased restrictions on chevron-braced frames</td>
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<td></td>
<td></td>
<td>Limitations on b/t ratios for braced frames</td>
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<tr>
<td>1994 Northridge</td>
<td>1994</td>
<td>Ductile detailing of piles</td>
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<td></td>
<td>1997</td>
<td>Restrictions on use of battered piles</td>
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<td></td>
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<td>Requirements to consider liquefaction</td>
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<td>Near-fault zones and corresponding base shear requirements</td>
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<td></td>
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<td>Revised base shear equations using I/T spectral shape</td>
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<td>Redundancy requirements</td>
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<td>Design of collectors for overstrength</td>
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<td></td>
<td>Increase in wall anchorage requirements</td>
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<td></td>
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<td>More realistic evaluation of design drift</td>
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<td></td>
<td></td>
<td>Steel moment connection verification by test</td>
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Table 1: Recent North American Earthquakes and Subsequent Code Changes (from SEOAC, 2009)
The 1985 Mexico City Earthquake was extremely devastating. Over 10,000 people were killed and there was three to four billion dollars of damage. The most significant aspect of this earthquake was that while the epicenter was located over 200 miles away from Mexico City. The unique geologic nature, that Mexico City was sited on an old (ancient?) lake bed of silt and clay, generated ground shaking with a much longer period and larger amplitudes than would be expected from typical earthquakes. This long period shaking was much more damaging to mid-rise and larger structures because these buildings were in resonance with the ground motions. In current design practice site factors based on the underlying soil are used to modify the seismic hazard parameters.

The 1989 Loma Prieta Earthquake caused an estimated $6 billion in damage, although it was far less deadly than other major earthquakes throughout history. Only sixty-three people lost their lives, a testament to the over 40 years of awareness and consideration of earthquakes in the design of structures. A majority of those deaths, 42, resulted from the collapse of the Cyprus Street Viaduct, a nonductile concrete elevated freeway. In this earthquake the greatest damage occurred in Oakland, parts of Santa Cruz and the Marina District in San Francisco where the soil was soft or poorly compacted fill. As with the Mexico City experience, this indicates the importance of subsurface conditions on the amplification of earthquake shaking. The earthquake also highlighted the vulnerability of soft and weak story buildings because a significant number of the collapsed buildings in the Marina District were wood framed apartment buildings with weak first stories consisting of garages with door openings that greatly reduced the wall area at the first story.

Five years later the 1994 Northridge earthquake struck California near Los Angeles. Fifty seven people lost their lives and the damage was estimated at around $20 billion. The high cost of damage repair emphasized the need for engineers to consider overall building performance, in addition to building collapse, and spurred the movement toward Performance-Based design. As with the 1989 Loma Prieta earthquake, there was a disproportionate number of collapses of soft/weak first story wood framed apartment buildings.

The 1994 Northridge Earthquake was most significant for the unanticipated damage to steel moment frames that was discovered. Steel moment frames had generally been thought of as the best seismic force resisting system. However, many moment frames experienced fractures of the welds that connected the beam flange to the column flange. This led to a multi-year, FEMA funded problem-focused study to assess and improve the seismic performance of steel moment frames. It also led to requirements for the number of frames in a structure, and penalties for having a lateral force resisting system that does not have sufficient redundancy.

### 1.2 History and Role of the NEHRP Provisions

Following the completion of the ATC 3 project in 1978, there was desire to make the ATC 3-06 approach the basis for new regulatory provisions and to update them periodically. FEMA, as the lead agency of the National Earthquake Hazard Reduction Program (NEHRP) at the time, contracted with the then newly formed Building Seismic Safety Council (BSSC) to perform trial designs based on ATC 3-06 to exercise the proposed new provisions. The BSSC put together a
group of experts consisting of consulting engineers, academics, representatives from various building industries and building officials. The result of that effort was the first (1985) edition of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*.

Since the publication of the first edition through the 2003 edition, the *NEHRP Provisions* were updated every three years. Each update incorporated recent advances in earthquake engineering research and lessons learned from previous earthquakes. The intended purpose of the *Provisions* was to serve as a code resource document. While the SEAOC Blue Book continued to serve as the basis for the earthquake design provisions in the *Uniform Building Code*, the *BOCA National Building Code* and the *Standard Building Code* both adopted the 1991 *NEHRP Provisions* in their 1993 and 1994 editions respectively. The 1993 version of the ASCE 7 standard *Minimum Design Loads for Buildings and Other Structures* (which had formerly been American National Standards Institute (ANSI) Standard A58.1) also utilized the 1991 *NEHRP Provisions*.

In the late 1990’s the three major code organizations, ICBO (publisher of the UBC), BOCA, and SBC decided to merge their three codes into one national model code. When doing so they chose to incorporate the 1997 *NEHRP Provisions* as the seismic design requirements for the inaugural 2000 edition of the *International Building Code* (IBC). Thus, the SEAOC Blue Book was no longer the base document for the UBC/IBC. The 1997 *NEHRP Provisions* had a number of major changes. Most significant was the switch from the older seismic maps of ATC 3-06 to new, uniform hazard spectral value maps produced by USGS in accordance with BSSC Provisions Update Committee (PUC) Project 97. The 1998 edition of ASCE 7 was also based on the 1997 *NEHRP Provisions*.

ASCE 7 continued to incorporate the 2000 and 2003 editions of the *Provisions* for its 2002 and 2005 editions, respectively. However, the 2000 IBC adopted the 1997 NEHRP Provisions by directly transferring the text from the provisions into the code. In the 2003 IBC the provisions from the 2000 IBC were retained and there was also language, for the first time, which pointed the user to ASCE 7-02 for seismic provisions instead of adopting the 2000 *NEHRP Provisions* directly. The 2006 IBC explicitly referenced ASCE 7 for the earthquake design provisions, as did the 2009 and 2012 editions.

With the shift in the IBC from directly incorporating the NEHRP Provision for their earthquake design requirements to simply referencing the provisions in ASCE 7, the BSSC Provisions Update Committee decided to move the NEHRP Provisions in a new direction. Instead of providing all the seismic design provisions within the NEHRP Provisions, which would essentially be repeating the provisions in ASCE 7, and then modifying them, the PUC chose to adopt ASCE 7-05 by reference and then provide recommendations to modify it as necessary. Therefore, Part 1 of the 2009 NEHRP Provisions contains major technical modifications to ASCE 7-05 which, along with other recommendations from the ASCE 7 Seismic Subcommittee, were the basis for proposed changes that were incorporated into ASCE 7-10 and included associated commentary on those changes. The PUC also developed a detailed commentary to the seismic provisions of ASCE 7-05, which became Part 2 of the 2009 NEHRP Provisions.
In addition to Part 1 and Part 2 in the 2009 *NEHRP Provisions*, a new section was introduced – Part 3. The intent of this new portion was to showcase new research and emerging methods, which the PUC did not feel was ready for adoption into national design standards but was important enough to be disseminated to the profession. This new three part format marks a change in the *Provisions* from a code-language resource document to the key knowledge-based resource for improving the national seismic design standards and codes.

The most significant technical change to Part 1 of the 2009 *Provisions* was the adoption of a “Risk-Targeted” approach to determine the Maximum Considered Earthquake hazard parameters. This was a switch from the Uniform Hazard approach in the 1997, 2000, and 2003 editions. In the “Risk Targeted” approach, the ground motion parameters are adjusted such that they provide a uniform 1% risk of collapse in a 50 year period for a generic building, as opposed to a uniform return period for the seismic hazard. A detailed discussion of this can be found in the commentary in Part 1 of the 2009 Provisions.

Today, someone needing to design a seismically resilient building in the U.S. would first go to the local building code which has generally adopted the IBC with or without modifications by the local jurisdiction. For seismic design requirements, the IBC then points to relevant Chapters of ASCE 7. Those chapters of ASCE 7 set forth the seismic hazard, design forces and system detailing requirements. The seismic forces in ASCE 7 are dependent upon the type of detailing and specific requirements of the lateral force resisting system elements. ASCE 7 then points to material specific requirements found in the material design standards published by ACI, AISC, AISI, AF&PA and TMS for those detailing requirements. Within this structure, the NEHRP Provisions serves as a consensus evaluation of the design standards and a vehicle to transfer new knowledge to ASCE 7 and the material design standards.

1.3 **THE NEHRP DESIGN EXAMPLES**

Design examples were first prepared for the 1985 *NEHRP Provisions* in a publication entitled *Guide to Application of the NEHRP Recommended Provisions*, FEMA 140. These design examples were based on real buildings. The intent was the same as it is now, to show people who are not familiar with seismic design of how to apply the *Provisions*, the standards referenced by the *Provisions* and the concepts behind the *Provisions*.

Because of the expanded role that the *Provisions* were having as the basis for the seismic design requirements for the model codes and standards, it was felt that there should be an update and expansion of the original design examples. Following the publication of the 2003 NEHRP Provisions, FEMA commissioned a project to update and expand the design examples. This resulted in *NEHRP Recommended Provisions: Design Examples*, FEMA 451. Many of the design problems drew heavily on the examples presented in FEMA 140, but were completely redesigned based on first the 2000 and then the 2003 *NEHRP Provisions* and the materials standards referenced therein. Additional examples were created to reflect the myriad of structures now covered under the *Provisions*. 
This volume is an update of the design examples in FEMA 451 to reflect the 2009 NEHRP Provisions and the updated standards referenced therein. Many of the design examples are the same as presented in FEMA 451, with only changes made due to changes in the provisions.

The Design Examples not only covers the application of ASCE 7, the material design standards and the NEHRP Provisions, it also illustrates the use of analysis methods and earthquake engineering knowledge and judgment in situations which would be encountered in real designs. The authors of the design examples are subject matter experts in the specific area covered by the chapter they authored. Furthermore, the companion NEHRP Recommend Provisions: Training Materials provides greater background information and knowledge, which augment the design examples.

It is hoped that with the Part 2 Expanded Commentary in the 2009 NEHRP Provisions, the Design Examples and the Training Materials, an engineer will be able to understand not just how to use the Provisions, but also the philosophical and technical basis behind the provisions. Through this understanding of the intent of the seismic design requirements found in ASCE 7, the material design standards and the 2009 NEHRP Provisions, it is hoped that more engineers will find the application of those standards less daunting and thereby utilize the standards more effectively in creating innovative and safe designs.

Chapter 1 – This preceding introduction and the Guide to Use of the Provisions which follows provides background and presents a series of flow charts to walk an engineer through the use of the provisions.

Chapter 2 – Fundamentals presents a brief but thorough introduction to the fundamentals of earthquake engineering. While this section does not present any specific applications of the Provisions, it provides the reader with the essential philosophical background to what is contained within the Provisions. The concepts of idealizing a seismic dynamic load as an equivalent static load and providing ductility instead of pure elastic strength are explained.

Chapter 3 - Earthquake Ground Motion is new to this edition of the Design Examples. This chapter explains the basis for determining seismic hazard parameters used for design in the Provisions. It discusses the seismic hazard maps in ASCE 7-05 and the new Risk Targeted maps found in the 2009 NEHRP Provisions and ASCE 7-10. The chapter also discusses probabilistic seismic hazard assessment, the maximum direction response parameters and selection and scaling of ground motion histories for use in linear and nonlinear response history analysis.

Chapter 4 – Structural Analysis presents the analysis of two different buildings, a 12-story steel moment frame and a 6-story steel moment frame structure. The 12-story structure is irregular and is analyzed using the three linear procedures referenced in ASCE 7 – Equivalent Lateral Force, Modal Response Spectrum, and Linear Response History. The 6-story structure is analyzed using three methods referenced in ASCE 7 - Equivalent Lateral Force, Modal Response Spectrum and Nonlinear Response History – and two methods which are referenced in other documents – Plastic Strength (Virtual Work) and Nonlinear Static Pushover. The intent of this chapter is to show the variations in predicted response based on the chosen analysis method.
Some of the examples have been updated based on advances in the state of the practice with respect to seismic analysis.

Chapter 5 – Foundation Analysis and Design presents design examples for both shallow and deep foundations. First, a spread footing foundation for a 7-story steel framed building is presented. Second the design of a pile foundation for a 12-story concrete moment frame building is presented. Designs of the steel and concrete structures whose foundations are designed in this chapter are presented in Chapters 6 and 7 respectively.

Chapter 6 – Structural Steel Design presents the design of three different types of steel buildings. The first building is a high-bay industrial warehouse which uses an ordinary concentric braced frame in one direction and an intermediate steel moment frame in the other direction. The second example is a 7-story office building which is designed using two alternate framing systems, special steel moment frames and special concentric braced frames. The third example is new to this edition of the design examples. It is a 10-story hospital using buckling restrained braced frames (BRBF). This replaces an example using eccentrically braced frames (EBF) in the previous edition of the design examples because the profession has moved toward favoring the BRBF system over the EBF system.

Chapter 7 – Reinforced Concrete presents the designs of a 12-story office building located in moderate and high seismicity. The same building configuration is used in both cases, but in the moderate seismicity region “Intermediate” member frames are used while “Special” moment frames are used in the high seismicity region. Also in the high seismicity region, special concrete walls are needed in one direction and their design is presented.

Chapter 8 – Precast Concrete Design presents examples of four common cases where precast concrete elements are a component of a seismic force resisting system. The first example presents the design of precast concrete panels being used as horizontal diaphragms both with and without a concrete topping slab. The second example presents the design of 3-story office building using intermediate precast concrete shear walls in a region of low or moderate seismicity. The third example presents the design of a one-story tilt-up concrete industrial building in a region of high seismicity. The last example, which is new to this edition of the design examples, presents the design of a precast Special Moment Frame.

Chapter 9 – Composite Steel and Concrete presents the design of a 4-story medical office building in a region of moderate seismicity. The building uses composite partially restrained moment frames in both directions as the lateral force resisting system.

Chapter 10 – Masonry presents the design of two common types of buildings using reinforced masonry walls as their lateral force resisting system. The first example is a single-story masonry warehouse building with tall, slender walls. The second example is a five-story masonry hotel building with a bearing wall system designed in areas with different seismicity.

Chapter 11 – Wood Design presents the design of a variety of wood elements in common seismic force resisting applications. The first example is a three-story, wood-frame apartment
building. The second example illustrates the design of the roof diaphragm and wall-to-roof anchorage for the masonry building featured in the first example of Chapter 10.

Chapter 12 – Seismically Isolated Structures presents both the basic concepts of seismic isolation and then the design of an essential facility using a seismic isolation system. The example building has a special concentrically braced frame superstructure and uses double-concave friction pendulum isolators, which have become the most common type of isolator used in regions of high seismicity. In the previous edition of the design examples, high-damping rubber isolators were used.

Chapter 13 – Nonbuilding Structure Design presents the design of various types of structures other than buildings that are covered by the Provisions. First there is a brief discussion about the difference between a nonbuilding structure and a nonstructural component. The first example is the design of a pipe rack. The second example is of an industrial storage rack. The third example is a power generating plant with significant mass irregularities. The third example is a pier. The fourth examples are flat-bottomed storage tanks, which also illustrates how the Provisions are used in conjunction with industry design standards. The last example is of a tall, slender vertical storage vessel containing hazardous materials, which replaces an example of an elevated transformer.

Chapter 14 – Design for Nonstructural Components presents a discussion on the design of nonstructural components and their anchorage plus several design examples. The examples are of an architectural concrete wall panel, the supports for a large rooftop fan unit, the analysis and bracing of a piping system (which is greatly expanded from FEMA 451) and an elevated vessel (which is new).

1.4 GUIDE TO USE OF THE PROVISIONS

The flow charts that follow are provided to assist the user of the NEHRP Recommended Provisions and, by extension, the seismic provisions of ASCE 7, Minimum Design Loads for Buildings and Other Structures; and the International Building Code. The flow charts provide an overview of the complete process for satisfying the Provisions, including the content of all technical chapters.


The flow charts in this chapter are expected to be of most use to those who are unfamiliar with the scope of the NEHRP Recommended Provisions, but they cannot substitute for a careful reading of the Provisions. The level of detail shown varies, being greater where questions of applicability of the Provisions are pertinent and less where a standard process of structural analysis or detailing is all that is required. The details contained in the many standards referenced in the Provisions are not included;
therefore, the actual flow of information when proportioning structural members for the seismic load effects specified in the Provisions will be considerably more complex.

Cited section numbers (such as Sec. 11.1.2) refer to sections of the Standard. Where reference is to a Provisions Part 1 modification to the Standard, the citation indicates that (such as Provisions Sec. 11.1.2). In a few rare instances, the Provisions Update Committee deferred to the ASCE 7 committee to make needed technical changes; in those cases reference is made specifically to ASCE 7-10 (such as ASCE 7-10 Sec. 12.12.3).

On each chart the flow generally is from a heavy-weight box at the top-left to a medium-weight box at the bottom-right. User decisions are identified by six-sided cells. Optional items and modified flow are indicated by dashed lines.

Chart 1.1 provides an overall summary of the process which begins with consideration of the Scope of Coverage and ends with Quality Assurance Requirements. Additions to, changes of use in and alterations of existing structures are covered by the Provisions (see Chart 1.3), but evaluation and rehabilitation of existing structures is not. Nearly two decades of FEMA-sponsored development of technical information to improve seismic safety in existing buildings has culminated in a comprehensive set of codes, standards and guidelines. The International Existing Building Code references the ASCE 31 Standard, Seismic Evaluation of Existing Buildings; and the ASCE 41 Standard, Seismic Rehabilitation of Existing Buildings.
Chart 1.2
Scope of Coverage

Determine if structure falls in scope of the Standard (Sec. 11.1.2).

Is structure a vehicular bridge, electrical transmission tower, hydraulic structure, buried utility line, or nuclear reactor?

Yes → Standard not applicable.

No → Is the use agricultural storage with only incidental human occupancy?

Yes → No requirements.

No → Determine $S_S$ and $S_I$ (Sec. 11.4.1).

$S_I \leq 0.04$ and $S_S \leq 0.15$?

Yes → Assign to Seismic Design Category A. Go to Chart 1.5.

No → Is it a detached 1- or 2-family dwelling?

Yes → $S_S \leq 0.4$ or SDC A, B, or C?

Yes → Wood frame dwelling with not more than 2 stories and compliant with the IRC?

Yes → No additional requirements.

No → Go to Chart 1.3.

No → No → Go to Chart 1.4.
**Chart 1.3**

**Application to Existing Structures**

*Addition to existing structure (Sec. 11B.2 and 11B.3).*

Is addition structurally independent from existing structure?

- Yes: Only addition or alteration designed as new structure. Go to Chart 1.4.
- No:
  * Is any element's seismic force increased by more than 10% or its seismic resistance decreased?
    - No
    * Do the affected elements still comply with the *Standard*?
      - Yes: Entire structure designed as new structure. Go to Chart 1.4.
      - No
  * Change to higher Occupancy Category?
    - No: No requirements.
    - Yes:
      * Change from Occupancy Category I or II to III and $S_{DS} < 0.33$?
        - Yes
        * Does alteration increase seismic forces to or decrease design strength of existing structural elements by more than 10 percent?
          - Yes: Such alteration not permitted.
          - No:
            * Is seismic force on existing structural elements increased beyond their design strength?
              - No:
                * Does alteration create a structural irregularity or make an existing irregularity more severe?
                  - Yes
                  * Is the design strength of existing structural elements required to resist seismic forces reduced?
                    - Yes
                      * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                      - No
                    - No
                * No
              - Yes
              * Is the design strength of existing structural elements required to resist seismic forces reduced?
                - Yes
                  * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                - No
            * No
          - Yes
        * *Alteration of existing structure (Sec. 11B.4).*
          * Does alteration increase seismic forces to or decrease design strength of existing structural elements by more than 10 percent?
            - Yes
            * Is seismic force on existing structural elements increased beyond their design strength?
              - No:
                * Does alteration create a structural irregularity or make an existing irregularity more severe?
                  - Yes
                  * Is the design strength of existing structural elements required to resist seismic forces reduced?
                    - Yes
                      * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                      - No
                    - No
                  - No
                * No
              - Yes
              * Is the design strength of existing structural elements required to resist seismic forces reduced?
                - Yes
                  * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                - No
            - No
          - Yes
        * *Change of use (Sec. 11B.5).*
          * Change to higher Occupancy Category?
            - No: No requirements.
            - Yes:
              * Change from Occupancy Category I or II to III and $S_{DS} < 0.33$?
                - Yes
                * Does alteration increase seismic forces to or decrease design strength of existing structural elements by more than 10 percent?
                  - Yes: Such alteration not permitted.
                  - No:
                    * Is seismic force on existing structural elements increased beyond their design strength?
                      - No:
                        * Does alteration create a structural irregularity or make an existing irregularity more severe?
                          - Yes
                          * Is the design strength of existing structural elements required to resist seismic forces reduced?
                            - Yes
                              * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                              - No
                            - No
                          - No
                        - Yes
                        * Is the design strength of existing structural elements required to resist seismic forces reduced?
                          - Yes
                            * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                            - No
                          - No
                        - No
                      - Yes
                      * Is the design strength of existing structural elements required to resist seismic forces reduced?
                        - Yes
                          * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                          - No
                        - No
                      - No
                    - Yes
                    * Is the design strength of existing structural elements required to resist seismic forces reduced?
                      - Yes
                        * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
                        - No
                      - No
                    - No
                  - No
                - No
              * No
            - Yes
            * Is the design strength of existing structural elements required to resist seismic forces reduced?
              - Yes
                * New structural elements and new or relocated nonstructural elements must be detailed and connected as required by the *Standard*.
              - No

* The *Standard* applies to existing structures only in the cases of additions to, changes of use in, and alterations of such structures.
Chart 1.4
Basic Requirements

Determine Occupancy Category (Sec. 1.5.1) and Importance Factor (Sec. 11.5.1).

Using mapped acceleration parameters and risk coefficients (from Fig. 22-1 through 22-6, or online application), determine the Maximum Considered Earthquake (MCE\textsubscript{R}) spectral response acceleration at short periods (S\textsubscript{S}) and at 1 second (S\textsubscript{1}).

$S_S \leq 0.15$ and $S_1 \leq 0.04$?

Yes

Assign structure to Seismic Design Category A. Go to Chart 1.5.

No

Soil properties known in sufficient detail to determine Site Class?

No

Use Site Class D unless authority having jurisdiction determines that Site Class E or F is present at the site.

Yes

Classify the site (Ch. 20).

Site Class E or F?

Yes

Fulfill site limitation (Sec. 11.8.1).

No

$S_1 > 0.6$ and seismically isolated or with damping system?

Yes

Perform ground motion hazard analysis (Sec. 21.2).

No

Site Class F?

Yes

Adjust MCE\textsubscript{R} acceleration parameters for site class (Sec. 11.4.3).

No

Calculate design earthquake acceleration parameters $S_{DS}$ and $S_{D1}$ (Sec. 11.4.4).

Perform site response analysis (Sec. 21.2).

Determine design response spectrum (Sec. 21.3) and design acceleration parameters (Sec. 21.4).

Calculate design response spectrum (Sec. 11.4.5).

Determine Seismic Design Category (Sec. 11.6).

Go to Chart 1.6 for structural requirements.

Go to Chart 1.24 for nonstructural components.

Go to Chart 1.25 for quality assurance requirements.
Determine static lateral forces and apply them independently in two orthogonal directions (Sec. 11.7.2).

Provide a continuous lateral load path and connect each smaller portion of the structure to the remainder of the structure with elements having a design strength of at least 5 percent of the portion's weight (Sec. 11.7.3).

For each beam, girder, or truss, provide positive connections with a design strength of at least 5 percent of the dead plus live load reaction for a horizontal force acting parallel to the member (Sec. 11.7.4).

Opt to perform a more involved analysis?

Classify the effects due to the loads described above as $E$ and combine with the effects of other loads in accordance with Sec. 2.3 or 2.4 (Sec. 11.7.1).

* The requirement to reclassify Seismic Design Category A structures to Seismic Design Category B has been declared editorially erroneous and will be removed via errata for ASCE 7-13.
Chart 1.6
Structural Design

1. Satisfy limitations of and choose to use Simplified Design Procedure? (Sec. 12.14.1.1)
   - Yes: Go to Chart 1.8.
   - No: Comply with the stated design basis (Sec. 12.1).

2. Select the seismic force-resisting system (including requirements for height limits, combinations of framing systems, dual systems, cantilevered column systems, and inverted pendulum systems, as applicable) and note R, Ω₀, and C_d for later use (Sec. 12.2 and Table 12.2-1).

3. Classify diaphragm flexibility (Sec. 12.3.1). Examine plan and vertical regularity (Sec. 12.3.2) and meet minimum requirements for irregular structures (Sec. 12.3.3).

4. Assign redundancy factor, ρ, (per Sec. 12.3.4.2) using Chart 1.7.

5. Moment frame assigned to Seismic Design Category D, E, or F?
   - Yes: Requirements for special moment frame continuity (Sec. 12.2.5.5). Note modified drift limits for moment frames (Sec. 12.12.1.1).
   - No: Determine seismic load effects and load combinations applicable to design (Sec. 12.4).

6. Determine applicable direction of loading criteria (Sec. 12.5).

7. Seismically isolated?
   - Yes: Go to Chart 1.13.
   - No: Damping system?
     - Yes: Go to Chart 1.12 for response history analysis.
     - No: Go to Chart 1.9 for ELF analysis. Go to Chart 1.11 for modal analysis.
Chart.7  
Redundancy Factor

Perform linear analysis with all elements

Define story $X_p$ above which no more than 35% of base shear is resisted

Yes

Below $X_p$ is item b of Section 12.3.4.2 satisfied?

No*

Yes

Extreme torsional irregularity?

No

Yes

Does the seismic force-resisting system comprise only shear walls or wall piers with a height-to-length ratio not greater than 1.0?

No

Yes

Prioritize elements based on highest force or force/story shear

Select an element (below $X_p$) to remove, and perform linear analysis without that element

Yes

Extreme torsional irregularity?

No

Yes

Does the demand in any remaining element (below $X_p$) increase by more than 50%?

No

Yes*

Does plastic mechanism analysis show that element removal decreases story strength by more than 33%?

No

Yes

Have all likely elements been considered?

No*

Yes

$ho = 1.0$

$ho = 1.3$

* or not considered
Chart 1.8
Simplified Design Procedure

1. Comply with the stated design basis (Sec. 12.14.2), including interconnection (Sec. 12.14.7.1).

2. Select the seismic force-resisting system (including requirements for combinations of framing systems, as applicable) and note R for later use (Sec. 12.14.4 and Table 12.14-1).

3. Classify diaphragm flexibility (Sec. 12.14.5).

4. Determine seismic load effects and load combinations applicable to design (Sec. 12.14.3).

5. Determine applicable direction of loading criteria (Sec. 12.14.6).

6. Perform simplified lateral force analysis (Sec. 12.14.8).

7. Satisfy deformation requirements (Sec. 12.14.8.5).

8. Design diaphragms, including appropriate detailing at openings (Sec. 12.14.7.2 and 12.14.7.4). Provide collector elements to transfer seismic forces (Sec. 12.14.7.3).

9. Determine out-of-plane forces for design of structural walls and their anchorage, interconnect wall elements, and satisfy requirements for diaphragm crossties, subdiaphragm aspect ratio, and detailing of wood or metal deck diaphragms (Sec. 12.14.7.5 and 12.14.7.6).

For various materials, go to these charts:
- Steel Chart 1.17
- Concrete Chart 1.18
- Composite Chart 1.19
- Masonry Chart 1.20
- Wood Chart 1.21
Introduction

Chart 1.9
Equivalent Lateral Force (ELF) Analysis

Determine fundamental period of vibration for the structure, carefully noting the upper limit placed on periods calculated from analytical models of the structure (Sec. 12.8.2).

Determine the seismic response coefficient, \( C_s \), and the total base shear (Sec. 12.8.1).

Consider soil-structure-interaction? (Optional)

Yes

Go to Chart 1.10 to calculate reduced base shear.

No

Distribute the base shear to the stories of the structure (Sec. 12.8.3).

To determine the internal forces, perform a linear elastic analysis with an appropriate distribution of forces within stories due to the relative lateral stiffnesses of vertical elements and diaphragms (Sec. 12.8.4). Include inherent torsion (Sec. 12.8.4.1) and amplified accidental torsion (Sec. 12.8.4.2 and 12.8.4.3). Calculate the overturning effects caused by seismic forces (Sec. 12.8.5).

Determine the story drifts. A re-analysis based upon a period larger than the upper limit is permitted for calculating deformations (Sec. 12.8.6).

Check the first order deformation for stability. If the stability coefficient, \( \theta \), exceeds 0.10, redesign the structure or demonstrate its stability using nonlinear static or nonlinear response history analysis (Provisions Sec. 12.8.7).

Go to Chart 1.15.
**Chart 1.10**  
**Soil-Structure Interaction (SSI)**

**ELF Analysis:** Follow this procedure (Sec. 19.2).

Calculate the foundation stiffnesses $K_y$ and $K_\theta$ (possibly using equations in *Provisions* Part 2 Sec. C19.2.1.1) at the expected strain level (Table 19.2-1).

Calculate effective gravity load, $\bar{W}$ (as a fraction of $W$), effective height, $\bar{h}$ (as a fraction of $h$), and effective stiffness, $\bar{k}$, of the fixed base structure.

Calculate effective period using Eq. 19.2-3.

Read foundation damping factor from Figure 19.2-1.

Point bearing piles?  
Yes  
No

*or*  
Uniform soft soils over a stiff deposit?

Yes  
Use Eq. 19.2-12 to modify foundation damping factor.

No

Calculate effective damping using Eq. 19.2-9. Effective damping is not taken less than 5 percent or more than 20 percent of critical.

Calculate reduced base shear, $\bar{V}$, per Sec. 19.2.1, which cannot be less than $0.7\bar{V}$.

Revise deflections to include foundation rotation (Sec. 19.2.3).

Return to Chart 1.9.

**Modal Analysis:** Follow SSI procedure for ELF analysis (Sec. 19.2) with these modifications (Sec. 19.3).

This SSI procedure applies only to the fundamental mode of vibration (Sec. 19.3.1). Therefore, substitute $W_f$ for $W$, $T_f$ for $T$, $V_f$ for $V$, etc.

Calculate the effective seismic weight of the fundamental period of vibration, $\bar{W}_f$.

Use Eq. 19.3-2 to calculate $\bar{h}$.

Calculate effective period using Eq. 19.2-3.

Read foundation damping factor from Figure 19.2-1.

Point bearing piles?  
Yes  
No

*or*  
Uniform soft soils over a stiff deposit?

Yes  
Use Eq. 19.2-12 to modify foundation damping factor.

No

Calculate effective damping using Eq. 19.2-9. Effective damping is not taken less than 5 percent or more than 20 percent of critical.

Calculate reduced base shear for the first mode, $\bar{V}_f$, per Sec. 19.3.1, which cannot be less than $0.7\bar{V}_f$. Use standard modal combination techniques (Sec. 19.3.3).

Return to Chart 1.10.
Chart 1.11
Modal Response Spectrum Analysis

Use linear elastic analysis to determine periods and mode shapes, including enough modes to obtain at least 90 percent mass participation (Sec. 12.9.1).

Consider soil-structure-interaction? (Optional)

Yes

Go to Chart 1.10 to calculate reduced base shear.

No

Determine story forces, individual member forces, displacements, and drifts in each mode (Sec. 12.9.2) and combine modal quantities using either the SRSS or the CQC technique* (Sec. 12.9.3).

Where the base shear is less than 85 percent of that computed using Sec. 12.8 with $T = C_s T_a$, amplify design forces. Where the base shear is less than 85 percent of that computed using Sec. 12.8 with $C_s$ determined using Eq. 12.8-6, amplify drifts (ASCE 7-10 Sec. 12.9.4.2).

To determine the internal forces, perform a linear elastic analysis. Include inherent and accidental torsions. Amplify torsions that are not in the dynamic model (Sec. 12.9.5).

Check the first order deformation for stability (Sec. 12.9.6). If the stability coefficient, $\theta$, exceeds 0.10, redesign the structure or demonstrate its stability using nonlinear static or nonlinear response history analysis (Provisions Sec. 12.8.7).

Go to Chart 1.15.

*As indicated in the text, use of the CQC technique is required where closely spaced periods in the translational and torsional modes will result in cross-correlation of the modes.
Chart 1.12
Response History Analysis

**Linear Response History Analysis**: Follow this procedure (Sec. 16.1).

- Model structure as for other analyses (Sec. 16.1.2).
- Select and scale ground motions based on spectral values in the period range of interest (Sec. 16.1.3), as follows. For 2-D analysis, the average is not less than the design spectrum. For 3-D analysis, the average of the SRSS spectra computed for each pair of ground motions is not less than the design spectrum. A narrower period range of interest is used for seismically isolated structures and for structures with damping systems (Sec. 17.3.2).
- Scale analysis results so that the maximum base shear is consistent with that from the ELF procedure (Sec. 16.1.4).
- Determine response parameters for use in design as follows. If at least seven ground motions are analyzed, may use the average value. If fewer than seven are analyzed, must use the maximum value (Sec. 16.1.4).

**Nonlinear Response History Analysis**: Follow this procedure (Sec. 16.2).

- Global modeling requirements are similar to those for other analyses. Modeling of hysteretic behavior of elements must be consistent with laboratory test results and expected material properties (Sec. 16.2.2).
- Select and scale ground motion as for linear response history analysis (Sec. 16.2.3).
- Nonlinear analyses must directly include dead loads and not less than 25 percent of required live loads.
- Analysis results need not be scaled.
- As for linear response history analysis, use average or maximum values depending on number of ground motions analyzed (Sec. 16.2.4).

Subsequent steps of the design process change. For instance, typical load combinations and the overstrength factor do not apply (Sec. 16.2.4.1), member deformations must be considered explicitly (Sec. 16.2.4.2), and story drift limits are increased (Sec. 16.2.4.3). The design must be subjected to independent review (Sec. 16.2.5).

Go to Chart 1.15.
Chart 1.13
Seismically Isolated Structures

Do the structure and isolation system satisfy the criteria of Sec. 17.4.1?

Yes

Opt to perform dynamic analysis?

Yes

Perform ELF analysis (see Chart 1.9) and satisfy the provisions of Sec. 17.5.

No

Site Class A, B, C, or D? and isolation system meets the criteria of Sec. 17.4.1, item 7?

Yes

Opt to perform response-history analysis?

Yes

Perform modal analysis (see Chart 2.11) and satisfy the appropriate provisions of Sec. 17.6.

No

Perform response-history analysis as described in Sec. 17.6.

No

Satisfy detailed requirements for isolation system (Sec. 17.2.4) and structural system (Sec. 17.2.5). Satisfy requirements for elements of structures and nonstructural components (Sec. 17.2.6).

Yes

Perform design review (Sec. 17.7).

Satisfy testing requirements (Sec. 17.8).

Go to Chart 1.15.
Chart 1.14
Structures with Damping Systems

Is the structure located at a site with $S_I < 0.6$?

No

Do the structure and damping system satisfy the criteria of Sec. 18.2.4.3?

No

Opt to perform ELF analysis?

No

Perform ELF analysis (see Chart 1.9) and satisfy the provisions of Sec. 18.5.

Perform nonlinear response-history analysis as described in Sec. 18.3.1.

Yes

Do the structure and damping system satisfy the criteria of Sec. 18.2.4.2?

No

Opt to perform response-history analysis?

No

Perform modal analysis (see Chart 1.11) and satisfy the appropriate provisions of Sec. 18.4.

Yes

Opt to perform ELF analysis?

Yes

Perform ELF analysis (see Chart 1.9) and satisfy the provisions of Sec. 18.5.

Modify the response of the structure for the effects of the damping system (Sec. 18.6). It is permitted to use the nonlinear static procedure to calculate the effective ductility demand (Sec. 18.3.2).

Determine seismic load conditions and acceptance criteria (Sec. 18.7). Satisfy general requirements for damping system (Sec. 18.2.2.2 and 18.2.5) and structural system (Sec. 18.2.2.1).

Perform design review (Sec. 18.8).

Satisfy testing requirements (Sec. 18.9).

No

Yes

Yes Yes

No No

Go to Chart 1.15.
Introduction

Chart 1.15
Deformation Requirements

Enter with story drifts from the analysis of seismic force effects. These drifts must include the deflection amplification factor, $C_{td}$, given in Table 12.2-1 (Sec. 12.2).

Compare with the limits established in Table 12.12-1, including reduction by the redundancy factor for systems with moment frames in Seismic Design Category D, E, or F (Sec. 12.12.1.1).

Confirm that diaphragm deflections are not excessive (Sec. 12.12.2).

Separations between adjacent buildings (including at seismic joints) must be sufficient to avoid damaging contact (Sec. 12.12.3).

Consider deformation compatibility for Seismic Design Category D, E, or F structural components that are not part of the seismic force-resisting system (Sec. 12.12.4).

Go to Chart 1.16.
Chart 1.16
Design and Detailing Requirements

1. Determine diaphragm design forces, including application of the redundancy factor to transfer forces (Sec. 12.10.1.1).

2. Design diaphragms, including appropriate detailing at openings (Sec. 12.10.1). Provide collector elements to transfer seismic forces (Sec. 12.10.2).

3. Determine out-of-plane forces for design of structural walls and their anchorage, and interconnect wall elements (Sec. 12.11.1 and 12.11.2).

4. **Seismic Design Category B?**
   - Yes
     - Apply overstrength factor to loads used in design of collector elements, splices, and their connections (Sec. 12.10.2.1).
     - Use larger forces for wall anchorage to flexible diaphragms (Sec. 12.11.2.1).
   - No

5. Continuous diaphragm crossties required. Limit on subdiaphragm aspect ratio. Special detailing for wood diaphragms, metal deck diaphragms, and embedded straps. Resolve anchorage eccentricity and consider pilaster effects (Sec. 12.11.2.2), with some exceptions for light-frame construction (Provisions Sec. 12.11.2.2.1 and 12.11.2.2.3).

For nonbuilding structures, go to Chart 1.22. For various materials, go to these charts:
- Steel Chart 1.17
- Concrete Chart 1.18
- Composite Chart 1.19
- Masonry Chart 1.20
- Wood Chart 1.21
Chart 1.17
Steel Structures

Seismic Design Category B or C?

Yes

No

Using a "structural steel system not specifically detailed for seismic resistance?"

Yes

No

Select an $R$ value from Provisions Table 12.2-1 for the appropriate steel system.

From Provisions Table 12.2-1, $R = 3$.

The system must be designed and detailed in accordance with AISC 341 for structural steel or AISI S110 for cold-formed steel or AISI Lateral for light-framed, cold-formed steel construction.

Any of the reference documents in Provisions Sec. 14.1.1 may be used for design.

Provisions Sec. 14.1.4.1 modifies AISI S110.
Sec. 14.1.6 applies to steel deck diaphragms.
Sec. 14.1.7 applies to steel cables.
Sec. 14.1.8 sets forth additional detailing requirements for steel piles in Seismic Design Categories D, E, and F.

Go to Chart 1.23.
Chart 1.18
Concrete Structures

Modifications to ACI 318 to add definitions and requirements for detailed plain concrete structural walls, ordinary precast structural walls, and wall piers. Additional requirements for intermediate precast structural walls. Revision of requirements for ties at anchor bolts and for size limits on anchors. (*Provisions Sec. 14.2.2*)

Requirements for concrete piles in Seismic Design Category C, D, E, or F (*Provisions Sec. 14.2.3*).

Acceptance criteria for special precast structural walls based on validation testing (*Provisions Sec. 14.2.4*).

Go to Chart 1.23.
Select an $R$ value from Table 12.2-1 for the appropriate composite system.

The system must be designed and detailed in accordance with the AISC 341 Parts I and II, ACI 318 excluding Ch. 22, and AISC 360.

Go to Chart 1.23.
Chart 2.20
Masonry Structures

Must construct in accordance with TMS 402 and use materials in conformance to TMS 602.

Clarifications for classification of shear walls (*Provisions* Sec. 14.4.3) and anchorage forces (*Provisions* Sec. 14.4.4).

Modifications to TMS 402 for separation joints, flanged shear walls, stress increase, reinforcement details, walls with high axial stress, coupling beams, deep flexural members, shear keys, anchor bolts, and corrugated sheet metal anchors (*Provisions* Sec. 14.4.5 through 14.4.8).

Modifications to TMS 602 concerning grout placement and control of shrinkage (*Provisions* Sec. 14.4.9).

Go to Chart 1.23.
Chart 1.21
Wood Structures

Must satisfy quality, testing, design, and construction requirements of AF&PA NDS and AF&PA SDPWS (Sec. 14.5.1).

Additional requirements for end bearing of columns and posts, continuity of wall top plates, and detailing of walls at offsets (Sec. 14.5.2).

Modification of AF&PA SDPWS for calculation of shear values for walls with multiple shear panels applied to the same or opposite faces (Sec. 14.5.3).

Go to Chart 1.23.
Chart 1.22
Non-building Structures

1. Nonbuilding structure supported by another structure?
   - Yes
     - Is weight of nonbuilding structure less than 25 percent of combined weight of nonbuilding structure and supporting structure?
       - Yes
         - Treat nonbuilding structure as nonstructural component (using Chart 2.24) and design supporting structure as a building or nonbuilding structure (Sec. 15.3.1).
       - No
         - Classify system, determine importance factor, and calculate design forces per Sec. 15.4.
   - No
     - Go to Chart 1.23.

2. Dynamic response similar to that of building structures?
   - Yes
     - Structures Similar to Buildings
       - Specific provisions for: pipe racks; steel storage racks; electrical power generating facilities; structural towers for tanks and vessels; and piers and wharves (Sec. 15.5).
   - No
     - Structures Not Similar to Buildings
       - Specific provisions for: earth-retaining structures; stacks and chimneys; amusement structures; special hydraulic structures; and secondary containment systems (Sec. 15.6); and for tanks and vessels (Sec. 15.7).
1. Foundations

May opt to model foundation load-deformation characteristics if bounding analyses for foundation stiffness are performed (Sec. 12.13.3).

May reduce foundation overturning effects at soil-foundation interface for ELF or modal analysis (Sec. 12.13.4).

Seismic Design Category B?

Yes

Requirements for: geotechnical investigation report (Sec. 11.8.2); pole type structures; ties between piles or piers; and pile anchorage (Sec. 12.13.5).

Seismic Design Category C?

Yes

Requirements for: additional geotechnical investigation report items (Sec. 11.8.3); ties between spread footings; and other pile design requirements for deformations due to both free-field soil strains and structure response, batter piles, pile anchorage, splices, pile flexibility, and pile group effects (Sec. 12.13.6).

No

Go to Chart 1.24.

Satisfy the design basis (Sec. 12.1.5).
Chart 1.24
Nonstructural Components

Assign component importance factors (Sec. 13.1.3).

Note component exemptions in Sec. 13.1.4.

Design requirements may be satisfied by project-specific design and documentation or by manufacturer certification (Sec. 13.2.1). Option to satisfy design requirements on the basis of experience data (Sec. 13.2.6).

Special certifications required for designated seismic systems in Seismic Design Category C, D, E, or F (Sec. 13.2.2).

Must consider both flexibility and strength for components and support structures (Sec. 13.2.4). Avoid consequential damage by considering functional and physical interrelationship of components (Sec. 13.2.3).

Determine the periods of mechanical and electrical components (Sec. 13.6.2). Select \( a_p \) and \( R_p \) values from Tables 13.5-1 and 13.6-1. Calculate seismic design forces per Sec. 13.3.1, including vertical load effects. (Don't forget to consider nonseismic horizontal loads.)

Compute seismic relative displacements (Sec. 13.3.2) and accommodate such displacements.

Components require positive attachment to the structure without reliance on gravity-induced friction (Sec. 13.4).

**Architectural Components**
Specific provisions for: exterior nonstructural wall elements and connections; out-of-plane bending; suspended ceilings; access floors; partitions; and glass (Sec. 13.5).

**Mechanical and Electrical Components**
Specific provisions for: mechanical components; electrical components; component supports; utility and service lines; storage tanks; HVAC ductwork; piping systems; boilers and pressure vessels; and elevator and escalator design (Sec. 13.6).

Satisfy requirements for construction documents (Sec. 13.2.7).

Go to Chart 1.25.
Seismic-force-resisting system assigned to Seismic Design Category C, D, E, or F? or Designated seismic system in structure assigned to Seismic Design Category D, E, or F?

Yes

Satisfy exceptions in Sec. 11A.1.1? No

Yes

QA plan not required.

Registered design professional must prepare QA plan and affected contractors must submit statements of responsibility (Sec. 11A.2).

Satisfy testing and inspection requirements in the reference standards (Ch. 13 and 14).

Seismic Design Category C? Yes

Occupancy Category III or IV? or Height > 75 ft? or Seismic Design Category E or F and more than two stories?

Yes

Registered design professional must perform structural observations (Sec. 11A.3).

Done.

Special inspection is required for some aspects of the following: deep foundations, reinforcing steel, concrete, masonry, steel connections, wood connections, cold-formed steel connections, selected architectural components, selected mechanical and electrical components, isolator units, and energy dissipation devices (Sec. 11A.1.3).

Special testing is required for some aspects of the following: reinforcing and prestressing steel, welded steel, mechanical and electrical components and mounting systems (Sec. 3.4 [2.4]), and seismic isolation systems (Sec. 11A.2).

Reporting and compliance procedures are given (Sec. 11A.4).
1.5 REFERENCES

American Society of Civil Engineers, 1907, *The Effects of the San Francisco Earthquake of April 18, 1906.*, New York, NY.


