This Federal Emergency Management Agency (FEMA) CD contains a set of instructional materials for use with FEMA Publication 451, *NEHRP Recommended Provisions: Design Examples,* in the form of PowerPoint slides with notes. These training materials provide a means for gaining additional knowledge about earthquake engineering as presented in the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA 450). Also on the CD is NONLIN, an educational program for dynamic analysis of simple linear and nonlinear structures. The instructional materials can be presented to engineers/architects by a qualified speaker with expertise in the practice of earthquake engineering, can be used by an individual who wishes to enhance his/her understanding of earthquake engineering, or can be applied by engineering academics as the basis for classroom instruction on earthquake-resistant design. The CD contains a series of topic folders. In each folder are pdf files for the PowerPoint presentation, for the notes pages, and for student handouts. Also included is a folder for NONLIN that contains zip files for this program and a file that lists items referenced in the presentation.

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NEHRP Recommended Provisions: Instructional Materials (FEMA 451B)

- These instructional materials complement FEMA 451, *NEHRP Recommended Provisions: Design Examples*
- Needed are copies of FEMA 451 and FEMA 450, the 2003 *NEHRP Recommended Provisions for New Buildings and Other Structures (*Part 1, *Provisions,* and Part 2, *Commentary)*

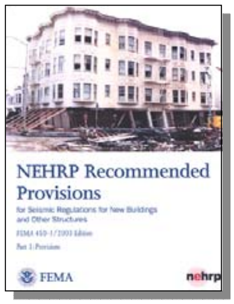
FEMA Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 2

In addition to the *Design Examples* volume, the training requires copies of FEMA Publication 450, the 2003 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.

FEMA 450 and 451

Single copies of both publications are available at no charge from the FEMA Publications Center at **1-800-480-2520**

(order by publication number)



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Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 3

Individual copies of these publications can be obtained at no charge from the FEMA Publications Center, 1-800-480-2520 (order by FEMA Publications number). If multiple copies are needed for presentation of the training materials to a group, e-mail bssc@nibs.org.

Acknowledgments

- FEMA 451 and 451B were developed for FEMA by the Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences (NIBS).
- The BSSC also manages development and updating of the *NEHRP Recommended Provisions*.
- For information about the BSSC and its member organizations or to download FEMA 451 and 451B, see

http://bssconline.org

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This CD was developed by the Building Seismic Safety Council under Contract EMW-1998-CO-0419 between the Federal Emergency Management Agency and the National Institute of Building Sciences. For further information on the Building Seismic Safety Council, see the Council's website – www.bssconline.org – or contact the Building Seismic Safety Council, 1090 Vermont, Avenue, N.W., Suite 700, Washington, D.C. 20005; phone 202-289-7800; fax 202-289-1092; e-mail bssc@nibs.org.

Acknowledgments

FEMA and the BSSC are grateful to the following individuals for their contribution to these instructional materials:

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- **James R. Harris***,* Ph.D., P.E., J. R. Harris and Company, Denver, Colorado
- **Richard E. Klingner**, Ph.D., P.E., University of Texas, Austin
- **James R. Martin**, Jr., Ph.D., Virginia Tech
- **Steve Pryor**, S.E., Simpson Strong Tie, Inc, Dublin, California
- **Michael D. Symans**, Ph.D., Rensselaer Polytechnic Institute
- **Carin Roberts-Wollmann**, Ph.D., P.E., Virginia Tech

FEMA Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 5

Much of this material was originally developed for the Multihazard Building Design Summer Course offered at FEMA's Emergency Management Institute. Managing the development of that course material for the Building Seismic Safety Council (BSSC) was Advanced Structural Concepts, Inc., Blacksburg, Virginia (Finley A. Charney, PhD., PE, President). Further, the course materials were developed in association with the Center for Extreme Load Effects on Structures, Virginia Tech (Finley A. Charney, PhD, PE, Director, and James R. Martin, Jr., Associate Director)

Motivation for Earthquake Engineering

- Minimize human death and injury
- Minimize economic loss
  - Direct (collapse and damage)
  - Indirect (loss of use, business interruption)
- Maintain lifelines

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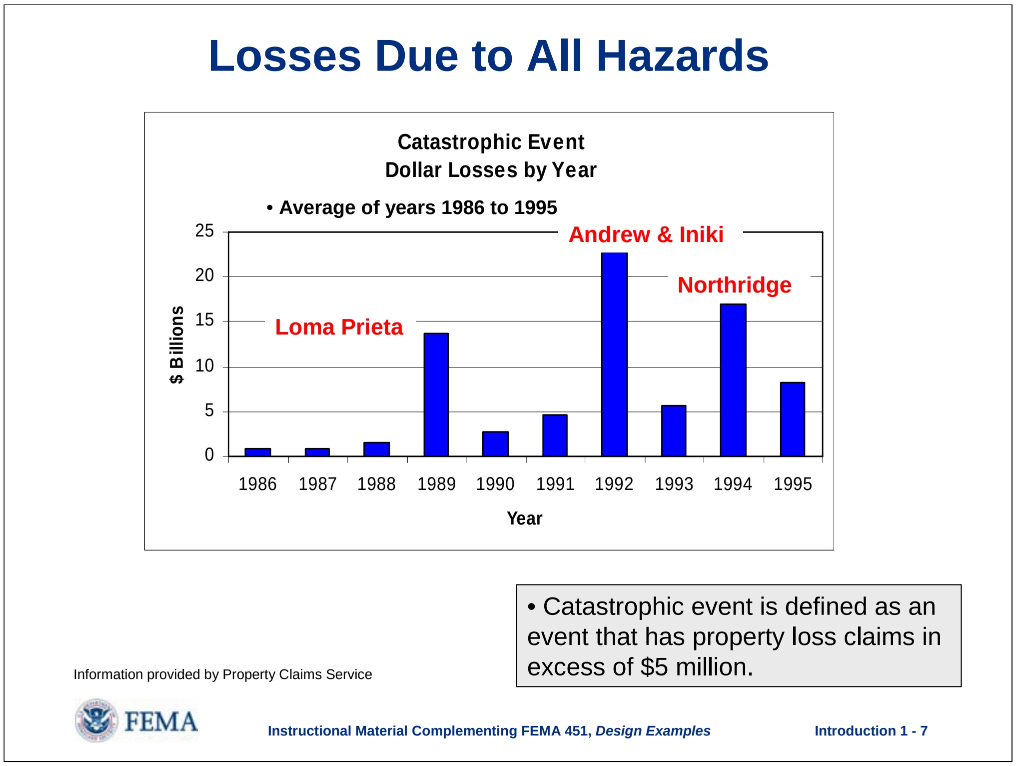
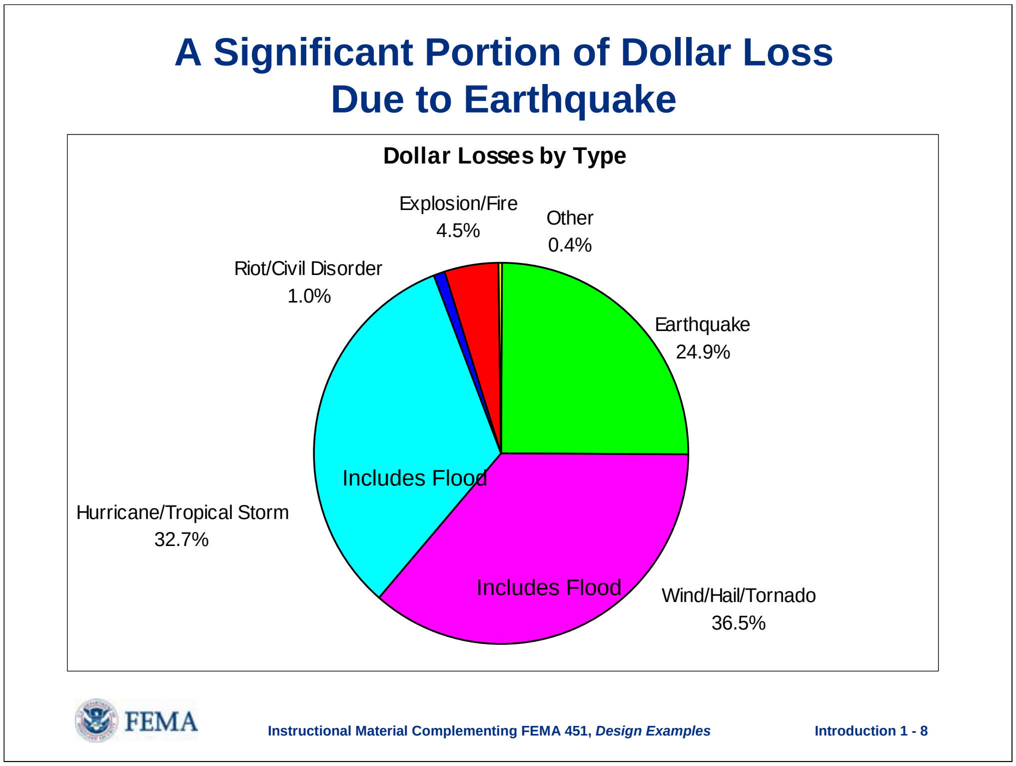
Earthquake-resistant design and construction are important in those areas of the nation at risk.

Users of this document who are also interested in residential construction are encouraged to consult FEMA Publication 232, *Homebuilders' Guide to Earthquake-Resistant Design and Construction*. This guide provides information on current best practices for earthquake-resistant home design and construction for use by builders, designers, code enforcement personnel, and potential homeowners. It incorporates lessons learned from the 1989 Loma Prieta and 1994 Northridge earthquakes as well as knowledge gained from the FEMA CUREE-Caltech Wood Frame Project. It also introduces and explains the effects of earthquake loads on one- and two-family detached houses and identifies the requirements of the 2003 *International Residential Code* (IRC) intended to resist these loads.



Natural hazards can be catastrophic to life and property. This slide indicates dollar losses for all natural hazards in the United States for the past several years. The Loma Prieta and Northridge earthquakes were matched in dollar damage by hurricanes Hugo, Andrew and Iniki and all were surpassed by the damage caused by Hurricane Katrina.



Earthquakes are a significant hazard but generally cause less dollar damage than wind, rain, and associated flooding. This slide does not break out flood damage, however, it should be emphasized that floods are one of the largest sources of losses due to natural disasters.

Nevertheless, mitigation actions to reduce the losses from these natural hazards are cost-effective. In 2006, the National Institute of Building Sciences through its Multihazard Mitigation Council completed a report to the Congress of the United States on behalf of Federal Emergency Management Agency (FEMA) that presents the results of an independent study to assess the future savings from hazard mitigation activities. This study shows that money spent on reducing the risk of natural hazards is a sound investment. On average, a dollar spent by FEMA on hazard mitigation (actions to reduce disaster losses) provides the nation about $4 in future benefits. In addition, FEMA grants to mitigate the effects of floods, hurricanes, tornados, and earthquakes between 1993 and 2003 are expected to save more than 220 lives and prevent almost 4,700 injuries over approximately 50 years. Recent disaster events painfully demonstrate the extent to which catastrophic damage affects all Americans and the federal treasury.

Those interested in reading the report of the study should see http://nibs.org/MMC/mmcactiv5.html

Examples of US Earthquake Losses

- 1906 San Francisco
- 1933 Long Beach
- 1964 Alaska
- 1971 San Fernando Valley
- 1989 Loma Prieta
- 1994 Northridge

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These are but a few of the major earthquakes occurring in the United States during the previous century. This presentation emphasizes the Loma Prieta and Northridge earthquakes.

The Northridge earthquake, like the 1971 San Fernando Valley earthquake, was a “wakeup” call to engineers and ultimately resulted in significant changes to building codes. Much of the current emphasis on performance-based engineering is due to the greater than expected damage that occurred as a result of the Northridge earthquake.

1971 Earthquake in the San Fernando Valley of California

Earth dam located about 20 km from the epicenter. Part of the upstream face lost bearing strength and slipped beneath the water.

This slide emphasizes the fact that damage occurs to nonbuilding structures as well as building structures.

1971 San Fernando Valley Earthquake

"Soft story" failure of the Olive View Hospital. The column failure caused a collapse that pinned the ambulances under the rubble, rendering them useless.

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Damage to the Olive View Hospital was particularly disturbing because the structure was relatively new and was designed according to the "modern" code at the time. The building was a complete loss and had to be demolished. Note that the ambulance canopy in the foreground is a separate structure, and was also a complete loss. Also significant is the fact that the ambulances were trapped in the collapsed canopy and were not available for use.

During the 1994 Northridge earthquake, the new Olive View Hospital structure fared rather well, but there were significant losses associated with nonstructural elements and components.

1989 Earthquake in Loma Prieta, California

Oakland Bay Bridge failure.

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Losses of transportation structures are very dramatic and can be among the most costly in terms of loss of life and property and indirect effects. This bridge was out of service for several weeks after the earthquake requiring major rerouting of traffic.

The collapse of the Oakland Cyprus Street Viaduct (not shown) was responsible for the loss of 42 lives. There were similar but less catastrophic failures of sections of the Embarcadero Freeway in San Francisco.

The Loma Prieta earthquake killed more than 60 people, injured 3,700, and left 12,000 homeless.

1994 Earthquake in Northridge, California

Bull Creek Canyon Channel Bridge on the Simi Valley freeway near the epicenter to the north. Shear failure of a flared column.

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Freeways in the Los Angeles area were not immune to damage during the Northridge earthquake. Ironically, many of the bridges that failed were scheduled for rehabilitation prior to the earthquake.

Approximately 60 people were killed by the quake.

1994 Northridge Earthquake
Gavin Canyon Undercrossing on I-5

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Another illustration of damage as a result of the Northridge earthquake.

Examples of Earthquake Losses Outside the United States

- 1923 Tokyo
- 1927 China
- 1985 Chile
- 1985 Mexico City
- 1988 Armenia
- 1993 Hokkaido
- 1995 Kobe
- 1999 Turkey, Taiwan
- 2001 India

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Earthquakes occur all over the world and often produce unimaginable destruction. Codes and enforcement in developing countries are often decades behind those of the industrialized world.

1985 Mexico City Earthquake

Pino Suarez Towers looking north -- one of the few steel frame buildings to collapse.

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The damage in Mexico City was due to an earthquake that occurred more than 350 km away from the city center. The main shock killed 10,000, left 50,000 homeless, and caused $4 billion dollars damage.

The vast destruction was attributed in large part to dynamic amplification of seismic waves through the soft soil in Mexico City. The dominant seismic waves had a period of about 2.0 seconds, wreaking havoc on buildings in the 10- to 20-story range.

1988 Leninakan, Armenia, Earthquake

Damage to a stone bearing wall building. The floor planks were not tied to the supporting bearing walls.

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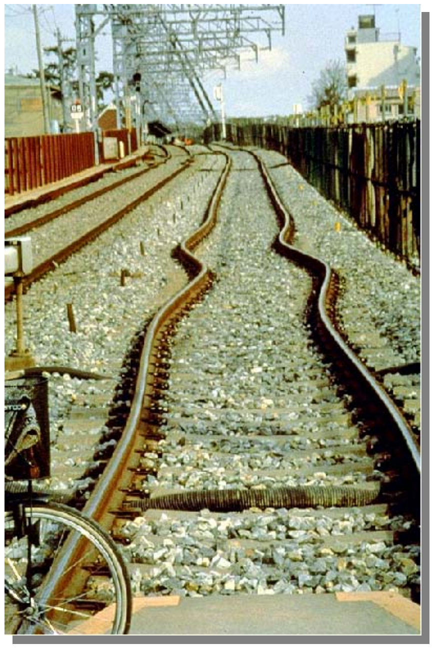
Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 17

This is an example of the devastation caused by earthquakes in countries without adequate seismic design building code requirements and/or enforcement.

Many (almost complete destruction) precast concrete frame buildings collapsed because of inadequate detailing. This earthquake killed at least 25,000 people, and left 500,000 homeless. Dollar damage was estimated in excess of 13 billion. Overall, 95% of the precast frame structures (5 to 12 stories) in Leninakan collapsed or were damaged beyond repair.



1995 Kobe, Japan, Earthquake

Distorted train tracks.

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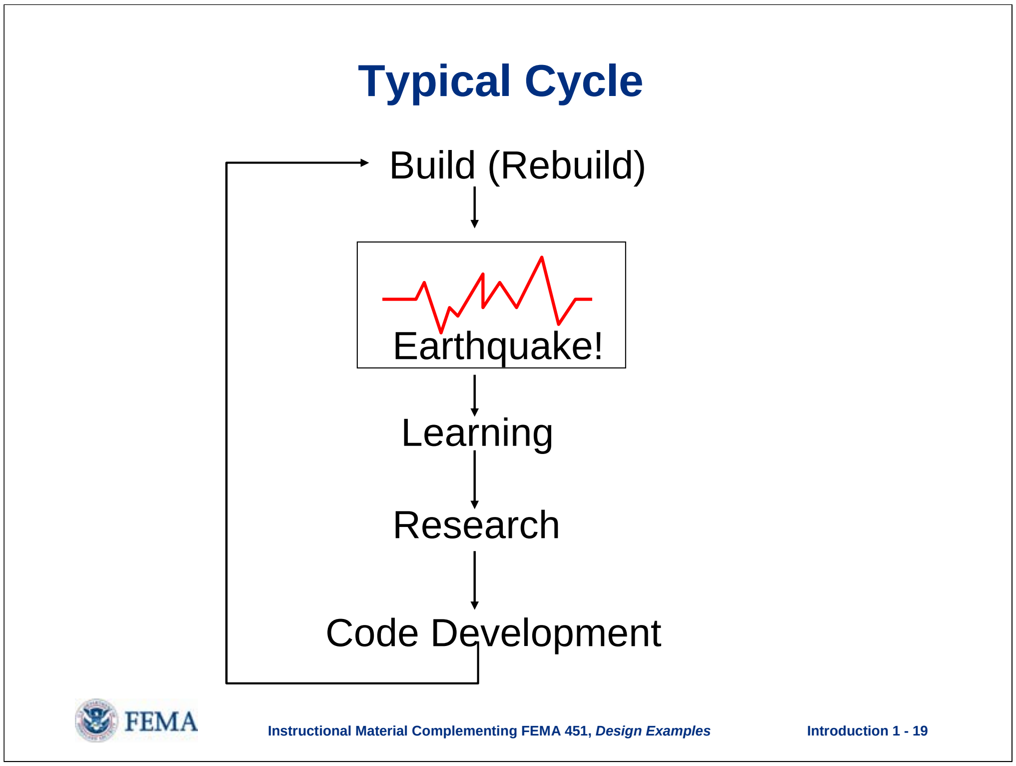
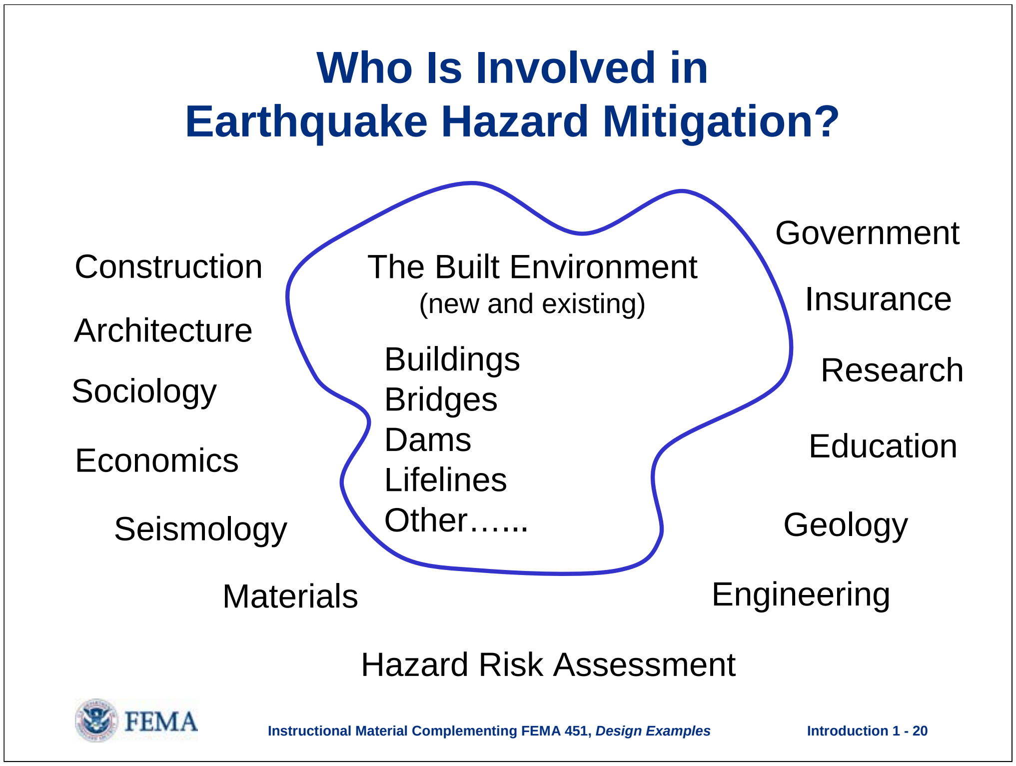
The Kobe earthquake killed more than 5,000 people and injured 26,000 others. More than 56,000 buildings were destroyed. Losses were estimated at more than $2 billion. This is more than 10 times the dollar loss for the Northridge earthquake which occurred exactly one year earlier in southern California. This slide was selected to emphasize the point that loss to nonbuilding structures and lifelines can have a significant effect on society. Further, it should be noted that a considerable amount of business and industrial activities that moved from the area after the earthquake never returned.



If there is any fortunate aspect of earthquakes, it is that the built environment is an excellent proving ground. Damage occurring during earthquakes is extensively studied and research is performed, ultimately leading to the development of improved building codes.

However, it seems that no matter how diligently we react to earthquakes, we are taught new and serious lessons when the next quake strikes. The damage occurring to welded frame structures during the Northridge earthquake is an excellent example.



Many disciplines are involved in earthquake hazard mitigation. All groups must work together to provide the level of protection needed by society.

These Instructional Materials FOCUS on STRUCTURAL ENGINEERING and

- New buildings
- Hazards associated with ground shaking
- "Force-Based" approach of 2003 *NEHRP Recommended Provisions* (FEMA 450)
- Examples presented in *NEHRP Recommended Provisions: Design Examples* (FEMA 451)
- Probabilistic and deterministic based ground motions
- New concepts of performance-based engineering

FEMA Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 21

These instructional materials focus almost entirely on new buildings. However, some information is provided for existing buildings, particularly as related to performance-based engineering, and on nonbuilding structures and nonstructural building components.

Further, these instructional materials concentrate on ground shaking, which is only one of the many hazards associated with earthquakes (e.g. fault rupture, liquefaction, landslides, flooding, and fire).

Published Design Documents for New Buildings

- NEHRP Recommended Provisions (FEMA 450)
- IBC and IRC
- ASCE 7

1906 San Francisco Earthquake

2003 *NEHRP Recommended Provisions for New Buildings and Other Structures*

- Uses seismic hazard map (2%-50years) for evaluation purposes
- Relies on “equal displacement” concept to establish design forces
- Utilizes *linear elastic* static or dynamic analysis
- Deformations checked globally

Intended result (obtained somewhat *implicitly*):

- Little or no damage for frequent earthquakes
- Minor nonstructural damage for common earthquakes
- Life-safety or collapse prevention for rare earthquakes

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This slide emphasizes the underlying principles of the *NEHRP Recommended Provisions*. Performance is evaluated somewhat implicitly, meaning that local deformations in members are not addressed. Before the Northridge earthquake, it was thought that this methodology was sufficient. Many engineers are now moving towards performance-based concepts, particularly in the rehabilitation of existing buildings.

Other Topics in this Series

FEMA Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 24

Topics 1 through 14 and 16 are the “basic” topics and include most of the concepts required to understand how earthquake analysis and design procedures are developed (Topics 1-7) and then how they are incorporated into the *NEHRP Recommended Provisions* and/or ASCE-7. These topics could generally be covered in a four- to five-day course with seven hours of instruction per day. If presented in such a classroom setting, instructors should consider developing a series of group exercises to help illustrate the concepts and to break up a long series of lectures. One of the exercises should use the computer program NONLIN that is included on the FEMA 451B CD.

The chapter numbers to the right of some of the topics refer to chapters in FEMA 451, *NEHRP Recommended Provisions: Design Examples*. In some cases, there is direct correlation between the examples in the slide sets and the FEMA 451 CD. For example, the topics in concrete and steel are related in this manner.

Other Topics in this Series
Part 2: Advanced Topics

Topic 15-1	**Introduction**
Topic 15-2	**Performance Based Engineering**
Topic 15-3	**Seismic Hazard Analysis**
Topic 15-4	**Geotechnical Earthquake Engineering**
Topic 15-5a	**Advanced Analysis, Part 1 of 3**
Topic 15-5b	**Advanced Analysis, Part 2 of 3**
Topic 15-5c	**Advanced Analysis, Part 3 of 3**
Topic 15-6	**Passive Energy Systems [FEMA 451, Ch. 6]**
Topic 15-7	**Seismic Isolation [FEMA 451, Ch. 11]**
Topic 15-8	**Nonbuilding Systems [FEMA 451, Ch. 12]**

FEMA Instructional Material Complementing FEMA 451, *Design Examples* Introduction 1 - 25

These topics are considered to be “advanced topics” and would be covered in a separate four-day course. Note that there is considerable overlap between the materials in Topics 5a and 15-3. As with the previous slide, the chapter numbers to the right of some of the topics refer to chapters in the FEMA 451 volume.

Chapters in the FEMA 451 Examples CD

Ch. 1	**Fundamentals**
Ch. 2	**Guide to the Use of the *NEHRP Recommended Provisions***
Ch. 3	**Structural Analysis (including nonlinear analysis)**
Ch. 4	**Foundation Design**
Ch. 5	**Steel Structures**
Ch. 6	**Reinforced Concrete Structures**
Ch. 7	**Precast Concrete Structures**
Ch. 8	**Composite Steel/Concrete Structures**
Ch. 9	**Masonry Structures**
Ch. 10	**Wood Structures**
Ch. 11	**Seismically Isolated Structures**
Ch. 12	**Nonbuilding Structures**
Ch. 13	**Nonstructural Components**

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Instructional Material Complementing FEMA 451, *Design Examples*   Introduction 1 - 26

The FEMA 451 CD contains 13 chapters as shown in this slide. The examples are extremely detailed and should be worked into the coursework where possible. Individuals pursuing earthquake engineering knowledge using these presentations for self-study also are strongly encouraged to work through these examples after working through with the presentation information.

Structural engineering:
The art of using materials that
have properties which can only be estimated
to build real structures that
can only be approximately analyzed
to withstand forces that
are not accurately known
so that our responsibility to the public safety is satisfied.