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EARTHQUAKE ENGINEERING RESEARCH INSTITUTE
COMMITTEE ON CONTINUING EDUCATION

SLIDES ON EARTHQUAKE-RESISTANT DESIGN

SET II: SEISMIC MICROZONATION

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PREFACE

Background on Seismic Microzonation

Note: This preface is provided to give a broader understanding of the basic elements inherent in seismic microzonation.

1. What is to be done?

1.1 Design Goal

The goal is to devise a set of standard procedures that can be used throughout the world to produce seismic microzonation products. Products produced in a seismic microzoning study are applied in land-use, building codes, design and construction practices, repair and strengthening of existing buildings, and response and recovery planning. These applications can save lives and economic resources.

Although the pre-earthquake environment is more optimal, experience shows that seismic microzonation studies are accepted more readily as a strategy for reducing losses from earthquake hazards in the post-earthquake environment. Political considerations are usually less of an impediment in the post-earthquake environment.

1.2 Background

Seismic microzonation, the division of a region into smaller areas expected to experience the same relative severity of an earthquake hazard (for example, ground shaking, surface fault rupture, earthquake-induced ground failure, tectonic deformation, or tsunami runup) is an important part of the process of evaluating earthquake hazards and assessing the risk in an urban area. Seismic microzonation is the part of the process of evaluating earthquake hazards that provides the prospective user of an area with the design criteria that will permit him to select the most suitable part of the area for the proposed use.

2. How will it be done?

2.1 Compilation of Seismic Microzonation Experience

Seismic microzonation has been performed in many countries throughout the world. However, there is no standard procedure for seismic microzonation, and the results have varied widely from country to country (See proceedings of the three international conferences on seismic microzonation held in the United States and the proceedings of the microzonation conference held in Algeria).

2.2 Technical Procedure

The key to the creation of a standard procedure in seismic microzonation is to obtain explicit answers to the following questions:

-- Where are the earthquakes occurring now?
-- Where did they occur in the past?
-- Why are they occurring?
-- How often do earthquakes of a certain size (magnitude) occur?
-- How big (severe) have the physical effects been in the past?
-- How big can they be in the future (e.g., next 50 years)?
-- How do the physical effects vary spatially and temporally?
-- How have these physical effects impacted various types of buildings and lifeline systems?

Although these questions appear to be simple, the answers typically require detailed research and technical studies that integrate geologic, seismological, and engineering data on two scales:

1) Evaluation of seismic hazards on a regional scale: (a map scale of about 1:100,000 to 1:1,250,000). This part of a microzoning study establishes the physical parameters of the region needed to evaluate the earthquake hazards of ground shaking, surface fault rupture, tectonic deformation, and tsunami runup. Technical tasks such as the following are required:

    a. Compilation of a catalog and map of the prehistorical, historical, and current seismicity.
    b. Performance of neotectonic studies (mapping, age dating, and trenching) to acquire information on recurrence times in the past several thousand years not provided by historical seismicity.
    c. Preparation of a seismotectonic map showing the location of active faults and their correlation with seismicity.
    d. Preparation of a map showing seismogenic zones and giving the magnitude of a maximum earthquake and the frequency of occurrence for each zone.
    e. Specification of regional seismic wave attenuation laws and their uncertainty.
    f. Preparation of probabilistic ground-shaking hazard maps in terms of peak bedrock acceleration, peak bedrock velocity, exposure times, and probabilities of nonexceedance.

2) Evaluation of seismic hazards on an urban scale: (a map scale of about 1:5,000 to 1:25,000). This part of a microzonation study integrates the seismotectonic and other physical data acquired in the regional in the study (Part 1 above) with site-specific data acquired in the urban area to produce seismic microzonation maps. Technical tasks such as the following are required:

a. Acquisition, synthesis, and integration of existing and new geologic, geophysical, and geotechnical data to characterize the soil/rock columns in terms of their physical properties and their response to various levels of ground shaking.
b. Preparation of ground-shaking hazard maps showing the dynamic amplification factors for soil/rock columns in terms of amplitude and frequency composition of ground shaking and the level of dynamic shear strain for a range of seismic loads.
c. Preparation of a map showing the potential for surface fault rupture and tectonic deformation.
d. Preparation of a map showing the potential for liquefaction.
e. Preparation of a map showing the potential for landslides.
f. Analysis of the vulnerability of various types of buildings and lifeline systems under a range of seismic loads.

3. What leads us to believe it can be done?

3.1 Basic Data

The basic data required for seismic microzonation are available in many countries throughout the world; what is missing is a standard procedure. Microzonation on the regional and urban scales requires the best available information on: 1) seismicity, 2) the nature of the earthquake source zone, 3) seismic wave attenuation, 4) local ground response, and 5) building and lifeline response.

3.2 Scientific and Engineering Problems

A number of technical issues (i.e., questions for which expert judgment is divided between "yes" and "no") have been identified for the problem of microzoning the ground-shaking hazard. They are summarized below to provide examples of their range and complexity. Considerations of structural response and potential vulnerability will not be discussed here. Similar technical problems can be stated for the ground-failure hazard.

<u>Seismicity</u> - The record of historical seismicity in both the United States and other countries varies considerably in length and completeness. Lack of completeness can introduce biases in statistical analyses unless careful judgments are made. Incorporating geologic evidence of recent faulting as well as geodetic data improves the likelihood of establishing the best possible recurrence rates for earthquakes. If geologic and geophysical data are not available, it may be extremely difficult to estimate the maximum magnitude in an area, and indeed, it is possible that number of geographic areas may not have experienced their maximum magnitude earthquake. Use of the record of historical seismicity alone may cause underestimation of the maximum magnitude.

The issues include the following:

a. Will the uncertainty involved in using catalogs of instrumentally recorded and felt earthquakes representing a short time interval and a broad regional area permit a precise specification of the frequency of recurrence of major earthquakes on a local scale?

b. Can the seismic cycle of individual fault systems be determined accurately and, if so, can the point in the cycle be specified?
c. Can the location and magnitude of the largest earthquake that is physically possible on an individual fault system or in a seismotectonic province be specified accurately? Can the frequency of this event be specified?
d. Can seismic gaps be identified and their earthquake potential evaluated accurately?
e. Can discrepancies between the geologic evidence for the occurrence of major tectonic movements in the geologic past and the evidence provided by current and historical patterns of seismicity in a geographic region be reconciled?

Seismogenic Zones - No standard method has been adopted for delineating seismogenic zones. Usually, each cluster of earthquake foci on active faults is considered as a source zone; however, scientific judgment is involved in drawing the boundaries of source zones. For example, one danger is that two or more regions having different seismotectonic characteristics will be incorrectly combined and the resultant analysis will suggest some average but nonexistent physical condition. In defining seismogenic zones, all available information is used to establish the physical correlations between earthquake occurrences and geologic processes and tectonic structures, including: 1) location of the boundaries of crustal blocks which are undergoing contrasting displacements, 2) history of vertical and horizontal regional tectonic movements, 3) the seismic cycle and history of active faults, and 4) tectonic stress. Each seismic source zone is chosen so that it encloses an area of seismic activity and, to the extent possible, an area of related tectonic elements. Although time-dependent models are now available, earthquakes are commonly assumed to be equally likely anywhere in a source zone, to have an average rate of occurrence that is constant in time, and to follow a Poisson distribution of recurrences.

The technical issues include the following:

a. Can seismic source zones be defined accurately on the basis of the record of historical seismicity? On the basis of geology and tectonics? On the basis of the record of historical seismicity generalized by geologic and tectonic data? Which approach is most accurate?

b. In assessing the earthquake ground-shaking hazard for a region, can a magnitude be assigned accurately to the largest earthquake expected to occur in a given period of time on a particular fault system or in a particular seismic source zone?

c. Can the physical effects of earthquake source parameters such as stress drop and seismic moment be quantified and incorporated in zoning maps?

Seismic Wave Attenuation - Characterization of the ground motion close to an active fault is one of the most important yet most difficult parts of the problem of constructing a ground-shaking hazard map. The empirical strong ground motion data are currently too limited to resolve all of the technical issues concerning the attenuation characteristics of both near- and far-field ground motion, even though unique ground-motion data have been acquired in the near field in the 1979 Imperial Valley, California, earthquake and in other locations worldwide. These data have reinforced current thinking in some areas and revised it in others, but have not resolved all of the controversial issues concerning seismic wave attenuation. Frequency-dependent effects of the transmission path on earthquake ground motion have not been quantified fully because of limited data. Observational and instrumental data indicate that the regional seismic attenuation rates depend on the physical properties (i.e., Q structure) of the Earth's crust and upper mantle in a region, that the attenuation rates can vary considerably from region to region, and that Q is frequency dependent.

Attenuation curves are required to specify how values of peak ground motion (or spectral velocity ordinants) decrease as distance from the causative fault increases. Such curves are essential when constructing a zoning map of the peak-acceleration ground-shaking hazards. The problem is that many peak-amplitude attenuation curves having substantial differences exist in the literature. The question of magnitude dependence of attenuation is important in probabilistic ground-shaking hazard estimation because it sharply influences the estimated level of maximum ground motion in two cases: 1) areas having a high rate of seismicity, and 2) when long periods of time are considered.

The technical issues include:

a. Can the complex details of the earthquake fault rupture (e.g., rupture dimensions, fault type, fault offset, fault slip velocity) be modeled accurately enough to give precise estimates of the amplitude and frequency characteristics of ground motion close to the fault? Far from the fault?

b. Do values of peak ground-motion parameters or spectral velocity ordinants saturate at large magnitude?

<u>Local Ground Response</u> - Since the early 1900's, literature of earthquake engineering and engineering seismology has recognized and documented that structures founded upon unconsolidated material (soil) are damaged more frequently and usually more severely in earthquakes than structures founded on rock. The damage distribution on many occasions (for example, in the 1967 Caracas, Venezuela, and the 1985 Mexico earthquakes) has been recognized as being related to the specific properties of the site geology. Many past studies have used empirical ground-motion data and analytical models to define the frequency-dependent effect have been and still are controversial; only acquisition of ground-motion data recorded at sites underlain by rock and a variety of soil columns close to the fault from large- to great-magnitude earthquakes will resolve these arguments.

The technical issues include the following:

a. For various soil types, is there a discrete range of peak ground-motion values and levels of dynamic shear strain where the ground response is repeatable and essentially linear? Is there a range where nonlinear effects dominate?

b. Can the physical effects of selected physical properties of the soil and rock column (e.g., thickness, lithology, geometry, water content, shear-wave velocity, and density) be modeled accurately? Which of these physical properties control the spatial variation, duration, and amplitude and response characteristics of ground motions in a geographic region for the fault-site geometries?

c. Can the variation of ground motion with depth below the surface be modeled accurately in order to estimate the ground-shaking effects on underground lifeline systems?

3.3 Seismotectonic Analogs

The optimal approach is to select countries that have analogous seismotectonic settings. Most of the zones of seismic activity in the United States have counterparts and analogs in other areas of the world. Much more can be learned about the tectonic setting, earthquake mechanics, earthquake hazards, and risk for parts of the United States by studying tectonic analogs in other countries. Certain aspects of source zones in the U.S. that are not clearly understood (i.e., pronounced overburden masking basement feature, lack of long historic record of seismicity, etc.) become impediments or road-blocks to understanding, particularly if efforts are concentrated solely on specific features in the U.S. Critical keys to the understanding of major strike-slip faults like the San Andreas fault may come from research and field mapping of similar features in say Turkey, Guatemala, New Zealand, Venezuela, the Philippines, Japan, Alaska, Iran, Pakistan, western China, and the U.S.S.R. The similar statement can be made for normal and thrust faults. A comparison of some of these fault systems indicates that parts of them are in various stages of their earthquake cycle. By studying analogous critical earthquake-generating features in other countries, it may be possible to "catch" forerunning or precursory features of large shocks and to apply that experience prior to the occurrences of the next large earthquake on, say, the San Andreas fault or other fault systems in the U.S.

Intra-plate earthquakes and the state of stress in Australia, Canada, northern Europe, the U.K., parts of Africa, and peninsular India show many similarities to those associated with the central and eastern U.S. Many shocks in those areas seem to occur along old fault systems that have moved many times throughout geologic history in response to various plate-tectonics events. The configuration of major tectonic elements and the reactivation of fault systems in the southeastern U.S., the site of the Charleston earthquake in 1886, are similar to those of west Africa near Accura, Ghana, and the Benue trough of Nigeria. The tectonic setting of the New Madrid seismic zone in the Central U.S. is similar to that of the seismic zone that extends into the interior of Australia near Adelaide. Several zones of intra-plate shocks are similar to those of the eastern and central U.S. in that they are characterized by very large areas for a given level of energy release.

A great deal can be learned from studies in other countries about the repeat time of large earthquakes along given segments of strike-slip and convergent plate boundaries. The average repeat time is a function of the long-term rate of plate movement and the geometry of the rupture zone. Variations in repeat time at a given place appear to be associated with the length of the rupture zone and the amount of seismic slip associated with the last large shock in that zone.

Since the historic record of earthquakes along the Alaska-Aleutian arc is so short, information from convergent zones near Japan, New Zealand, India, Pakistan, the U.S.S.R., the Lesser Antilles, Mexico, Central and South America, and other similar areas can be applied to earthquake-related problems for Alaska and the Aleutians. Similarly, the unusual style of plate motion to the north of Puerto Rico and the Virgin Islands -- thrust faulting on nearly horizontal planes with the slip vector nearly parallel to the plate boundary -- is similar to that in the westernmost Aleutians and in the Andaman Islands.

4. What is the benefit?

4.1 Potential Applications of Seismic Microzonation Products

Applications of seismic microzonation products (maps, data, analyses) can be made in terms of land-use, building codes, construction practices, repair and strengthening of existing buildings, and response and recovery planning. The benefits in any given country where seismic microzonation has been performed include:

a. Improving the current building code, identifying options for modifications that incorporate the scientific and engineering lessons learned from past destructive earthquakes.

b. Improving of regional and urban land-use practices, identifying options for alternatives to current practices that might reduce potential losses.

c. Improving design and construction practices for new buildings, specifying options for alternatives to current practices that might be more effective in ensuring high quality.

d. Improving the current practices to repair and strengthen existing buildings, suggesting options for alternatives to current practices that might be more effective.

e. Evaluation of plans for emergency response and disaster recovery.

4.2 Implementation

Three groups of professionals will implement the new knowledge provided by seismic microzonation: the design professional, the urban and regional land use planner, and the emergency manager.

5. REFERENCES

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5.3 University of Washington, Proceedings of the Third International Earthquake Microzonation Conference, Seattle, Washington, June 28 - July 1, 1982, 3 volumes.

5.4 Ministry of Urban Development and Construction, Proceedings of the International Conference on Seismic Microzonation, Ech Cheliff, Algeria, October 11-12, 1984, 2 volumes.

5.5 Thiel, Charles C., 1988, Seismic Microzonation: An Approach to Seismic Land-Use Planning in Hays, W. W., (Editor), Proceedings of Conference 41 on "A Review of Earthquake Research Applications in the National Earthquake Hazards Reduction Program: 1977-1987, U.S. Geological Survey Open-File Report 88-13-A, pp. 320-342.

5.6 Woodward Clyde Consultants, 1984, Seismic Microzonation of Ech Cheliff Region, Algeria, Report prepared for Controle Technique de la Construction, Algiers, Algeria; 6 volumes.

5.7 Hays, W. W., 1985, The Realization of a Seismic Microzonation Study in the Chlef Region of Algeria Following the 1980 El Asnam Earthquake, in Kusler, Jon A. (Editor), Proceedings of International Symposium on Housing and Urban Development After Natural Disasters, pp. 51-57.

5.8 Panel on Seismic Macro- and Microzonation, 1981, in State-of-the-art in Earthquake Engineering: Proceedings of the Seventh World Conference on Earthquake Engineering, Special Volume, pp. 47-68.

COMMENTARY FOR SLIDES

SLIDE	TITLE/DESCRIPTION
MZ 1	MAP OF EFFECTIVE PEAK ACCELERATION FOR CONTERMINOUS UNITED STATES.

This zoning map depicts the ground-shaking hazard in terms of zones of effective peak acceleration (EPA). It was created by the Applied Technology Council. (Reference: National Bureau of Standards, and National Science Foundation, 1978, Tentative Provisions for the Development of Seismic Regulations for Buildings, Applied Technology Council Publication ATC 3-06, NBS Special Publication 78-8, Government Printing Office, Washington, D.C., 514 p.)

Note that Zone 4 correlates with 0.4 g. even though higher levels of acceleration are expected. Site specific studies are recommended within Zone 4, to define the relevant design parameters at a site.

The map is based on and corresponds roughly with a 50 year exposure time and a 90 percent probability of nonexceedance.

MZ 2 COMPARISON OF GROUND-SHAKING HAZARD

This map depicts the actual levels of peak horizontal ground acceleration expected at sites underlain by bedrock within a 50 year exposure time. The values are shown in terms of "zones" and have a 90 percent probability of nonexceedance. This map was created by Dr. Ted Algermissen and his colleagues (Reference: Algermissen S. T., and others, 1982, U.S. Geological Survey Open-File Report 82-1033.) and is essentially the same as the basic data used in the last 1970's to create the ATC map (see slide MZ 1).

Within each color band (zone), a range of values of ground shaking exists; hence, there is a need for microzonation.

MZ 3 DEFINITION OF SEISMIC MICROZONATION

Seismic microzonation is the sub-division of a region into areas expected to experience the same relative severity of an earthquake hazard (e.g., ground shaking, surface fault rupture, liquefaction, etc.).

MZ 4 EVALUATION OF EARTHQUAKE HAZARDS

Seismic microzonation studies fall within the framework of a regional evaluation of earthquake hazards. Microzonation studies are conducted on global, regional, and local scales to answer specific questions needed to define the earthquake loadings. in the design process.

MZ 5 KEY ELEMENTS IN EARTHQUAKE HAZARD EVALUATION

This slide shows schematically the most important physical parameters contributing to the ground-shaking hazard in an earthquake. Seismic microzonation studies must take each parameter of the source, path, and site into account during regional-scale studies.

MZ 6 REGIONAL SCALE STUDIES

This slides describes the objectives of regional scale microzonation studies.

MZ 7 URBAN SCALE STUDIES

This slide describes the objectives of urban scale microzonation studies.

MZ 8 TYPICAL PRODUCTS

This slide describes the typical products (maps, data, analyses) of a seismic microzonation study.

MZ 9 APPLICATIONS

The products of a seismic microzonation study can be applied in many ways, including improving: 1) the existing building code, 2) design and construction practices, 3) repair and strengthening practices, and 4) regional and urban land use practices. All of these applications are now being implemented in Algeria.
(See slide MZ 20).

MZ 10 SEISMICITY OF NORTHERN AFRICA

Algeria is part of the African tectonic plate which is colliding on its northern boundary with the Eurasian tectonic plate. As a result, earthquakes, a wide belt of folded mountains (the Atlas Mountains), and a zone of crustal shortening are being produced in Northern Algeria. Damaging earthquakes have impacted Northern Algeria at least a dozen times in the past 250 years. Northern Algiers is in a thrust fault environment.

MZ 11 10 OCTOBER 1980 EL ASNAM EARTHQUAKE

Alvaro F. Espinosa, U.S. Geological Survey, is the source of this slide which illustrates the rupture of the Oued Fodda thrust fault on 10 October 1980, producing a magnitude 7.3 earthquake. The epicenter was about 10 km (6 miles) east of the city of El Asnam (now named Ech Cheliff). The 47-km-long Oued Fodda fault ruptured over a distance of about 35 km (21 miles) in the earthquake. The earthquake severely damaged buildings and lifeline systems in the region, killed 2,700, and left 300,000 homeless. Economic losses reached $4 billion.

MZ 12 SEISMIC MICROZONATION STUDY IN THE ECH CHELIFF REGION

Following the 10 October 1980 earthquake, Algeria undertook a comprehensive seismic microzonation study. Microzonation maps were envisioned as a tool to plan for reconstruction and redevelopment in the Chlef region and to guide earthquake-resistant design of new buildings. The study was entrusted to L'Organisme de Controle Technique de la Construction (CTC) who contracted with Woodward Clyde Consultants in 1983 to perform the technical work and to transfer the technology to Algerian scientists and engineers.

MZ 13 SEISMOGENIC ZONES

One of the key steps in the seismic microzonation study was the delineation of seismogenic zones. Through photo interpretation, geologic mapping, and trenching, the primary active fault systems were identified. The historical seismicity was reevaluated and integrated with the geologic data to define three areal source zones. The large earthquakes (M 6 and greater) were constrained to the known or inferred active fault systems (e.g., Oued Fodda, Lower

Ech Cheliff, Offshore Zone, etc.). Smaller earthquakes were associated with the areal sources represented by Zone I, II, and III. These earthquakes are not expected to cause surface rupture.

MZ 14 GROUND-SHAKING HAZARD MAP, 200 YEAR RETURN PERIOD

Using standard techniques, (For example, see U.S. Geological Survey Open-File 82-1033) the seismic exposure in terms of peak horizontal ground acceleration was calculated. Because of the lack of strong ground motion data in Algeria, the attenuation function was defined on the basis of data for travel paths in California thought to have similar wave propagation characteristics

The calculated value of horizontal peak acceleration in Ech Cheliff is 0.25 g. There is a 90 percent probability of nonexceedance.

MZ 15 GROUND-SHAKING HAZARD MAP, 500 YEAR RETURN PERIOD

The same calculations were performed for a 500 year return period, the time interval used in many building codes. The level of peak horizontal acceleration in Ech Cheliff is 0.35g.

MZ 16 SEISMIC MICROZONATION MAP OF ECH CHELIFF: GREEN ZONE

The proceeding two ground shaking hazard maps were made at a regional scale. This one, and the two that follow it, are at an urban scale. The map corresponds with approximately one-fourth of Ech Cheliff.

Although the ground-shaking level for the 500 year return period can be considered to be the same throughout Ech Cheliff (i.e., 0.35 g), the facts indicate that some parts of Ech Cheliff will experience a greater hazard than others; therefore, there is a need for microzonation. Considering all of the earthquake hazards (e.g., ground shaking, liquefaction, landslides, subsidence, flooding, and surface fault rupture), the integration of their expected effects allows the delineation of a "green zone", the safest zone.

The hazards that are synthesized on the maps include liquefaction potential, landslide potential, surface fault rupture potential, and potential for compaction (settlement) of loose manmade fill or young sandy alluvium. Ground shaking levels are not shown on the synthesis and microzonation maps because they are relatively uniform within each urban area.

In synthesizing the hazards, the following codes were used for hazard identification.

l high potential for liquefaction
l' moderate potential for liquefaction
g potential for landslides
t' young, deep, loose, sandy alluvium that may have some potential for compaction
f potential for surface fault rupture

The areas having these hazards were delineated using the geotechnical maps (to delineate areas of fills and alluvium having potential for compaction) and using the ground failure maps (to delineate areas of potential for liquefaction, landsliding, and surface fault rupture).

MZ 17 SEISMIC MICROZONATION MAP OF ECH CHELIFF: YELLOW ZONE

Following the same principles as noted for slide MZ 16, a "yellow zone" can be delineated. Construction sited in this zone should exercise the appropriate level of caution for the higher relative level of hazard.

MZ 18 SEISMIC MICROZONATION MAP OF ECH CHELIFF: RED ZONE

In a similar manner, a "red zone" can be delineated, special engineering studies should be made when siting important buildings in this part of Ech Cheliff which is considered to have the highest relative level of hazard.

MZ 19 THE BOTTOM LINE ON SEISMIC MICROZONATION

Seismic microzonation maps provides a prospective user with information and design criteria that permit him to select the most suitable part of an urban area for the proposed use.

MZ 20 STEPS IN SEISMIC MICROZONATION

In reality, seismic microzonation in any urban area is a process that moves through three periods of time:

1) a period of intergration during which the problem solutions involving the technical disciplines of geology, seismology, architecture, engineering, and land-use planning are integrated with the policy and political considerations of the community. Sometimes, a long period of time (years) is required for intergration to be achieved.

2) a window of opportunity, which usually coincides with the occurrence of a damaging earthquake. During a fairly short period of time, many things that were considered to be impossible (e.g., instruments, institutes, building codes, ordinances, enforcement of inspection, improved seismic safety policies, etc.) before the earthquake become possible.

3) a period of implementation during which "change" is encouraged and accepted. During this period, significant changes in the practices of siting, design, land use, construction, and emergency response and recovery planning are implemented and institutionalized in an urban area. Sometimes the changes stimulate others and seismic microzonation studies are initiated in other regions and even other countries.