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Seismic microzonation: A review of principles and practice

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The first part of this paper is an overview of various methodologies for seismic-geotechnical hazard zonation that conform to the recommendations of International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE, 1999). The purpose of this review is to illustrate the variety of methodologies currently in use for preparation of seismic hazard maps and to evaluate basic principles of zonation for different purposes and at different scales. In the second part of the paper, input data for seismic microzonation are discussed. Promulgated seismic regulations are a prerequisite for delineation of seismic hazard zones. Guidelines and recommendations for seismic microzonation should be incorporated into seismic regulations. There are two principal approaches to earthquake loss mitigation; one relates to land use management, and the other deals with the design and construction of individual buildings. Both approaches must be considered as components of urban planning and building design, and the application and use of these approaches should be required and enforced by municipal authorities.

Keywords: seismic hazard, seismic microzonation, landslide, liquefaction, land use management

1. Introduction

A natural hazard is defined as the probability of a potentially damaging phenomenon occurring within a specified period of time and within a given area (Varnes, 1984). In this context, seismic hazards represent the probable occurrence of earthquakes and seismically induced processes, which include ground motions, liquefaction and landsliding. Geotechnical hazards are described as the influence of natural hazards on engineering objects. Earthquake hazard maps may include one or more of the aforementioned seismic hazards (Levson et al., 2003).

Seismic macrozonation includes delineation of the zones that are homogenous in seismological and geological characteristics and a description of zone characteristics by associating dynamic parameters (peak ground acceleration – PGA, peak ground velocity- PGV, or spectral acceleration- SA) with the specified probability of occurrence. As such, seismic zonation is the first step for all further assessments of seismic hazards (Markušić and Herak, 1999). These parameters are mapped at a national scale for a standard ground condition, which are usually rock or stiff soil. Mapping at this scale is called macrozonation (Finn et al., 2004). Building code utilizes national seismic macrozonation maps in specifying the minimum design requirements (DRM, 2004c).

Mapping of seismic hazards at local scales to incorporate the effects of local soil conditions is called seismic microzonation (Finn et al., 2004). The term microzonation does not necessarily imply a scale of mapping, although the requirement for defining local site conditions tends to dictate the more detailed scale maps (Klohn-Crippen, 1994; Roca et al., 2008).

There are two aspects of earthquake hazard safety: i) structural safety against potentially destructive dynamic forces, and ii) safety of a site related to geotechnical phenomena, such as amplification, landslides, and liquefaction. Dynamic effects have been considered in building codes worldwide to ensure the safety of structures under earthquake loading. However, little attention has been paid to the safety assessment of individual sites in the form of land use regulation (ISSMGE, 1999).

The first part of this paper provides an overview of the definitions and general methodologies of seismic-geotechnical hazard zonation according to recommendations issued by International Society for Soil Mechanics and Geotechnical Engineering – ISSMGE (ISSMGE, 1999). The purpose of this review is to demonstrate the variety of methodologies used for preparation of seismic hazard maps and the basic principles of zonation for different purposes and in different scales. In the second part of this paper, input data for seismic microzonation are given. The definition of input data is very important because the application of specific methodology directly depends on the quality and quantity of input data.

Delineation of seismic hazard zones requires establishing a framework at the national or regional level with the following aspects clearly defined: (i) position of seismic microzonation in the construction practice and urban planning; (ii) methodologies for data collection, evaluation and zonation; and (iii) seismic regulation that includes codes, laws and documentation, such as guidelines, recommendations, and manuals. The main assessment and management of earthquake risk concepts are from the Guidelines for Evaluating and Mitigating Seismic Hazards in California (DOC, 2000) and the Turkish Manual for Seismic Microzonation for Municipalities (DRM, 2004b).

Although a major purpose of seismic microzonation could be to replace the national macrozonation map, seismic microzonation will primarily serve for land use management and city planning, as defined in this paper.

2. Methods for zonation of seismic geotechnical hazards

Site safety during earthquakes is related to geotechnical phenomena, such as amplification, landslides, mudflow, and liquefaction. Assessments of these phenomena are executed in different ways, but there have been few attempts to formalize a standard approach. In this context, essential progress is presented in the Manual for Zonation on Seismic Geotechnical Hazards, which is prepared by the Technical Committee on Earthquake Geotechnical Engineering of the International Society on Soil Mechanics and Geotechnical Engineering (ISSMGE, 1999).

This chapter reviews methods for hazard assessment of three types of geotechnical phenomena: ground motions, slope instability and liquefaction. For each type of phenomenon, three grades of zonation are described (Table 1). The quality of the resulting zonation maps depends on the quality and/or quantity of the input data.

Table 1. Use of input data depending on the scale of mapping, i.e., the level of zonation (ISSRM, 1999).

	Grade I	Grade II	Grade III
Ground motions	• historical earthquakes and existing information • geological maps • interviews with local residents	• microtremor • simplified geotechnical studies	• geotechnical investigations • ground response analysis
Slope instability	• historical earthquakes and existing information • geological and geomorphologic maps	• air photos and remote sensing • field studies • vegetation and precipitation data	• geotechnical investigations • analysis
Liquefaction	• historical earthquakes and existing information • geological and geomorphologic maps	• air photos and remote sensing • field studies • interviews with local residents	• geotechnical investigations • analysis
Scale of mapping	1:1000000–1:50000	1:100000–1:10000	1:25000–1:5000

2.1. Zoning for ground motions

Assessment of ground motions depends on the following: regional seismicity, attenuation of ground motion intensity and local site effects (as illustrated by Figure 1). The most important factor in defining surface ground motions is the local site effects. Therefore, assessment of site effects depends on the level of zonation, i.e., on the mapping scale.

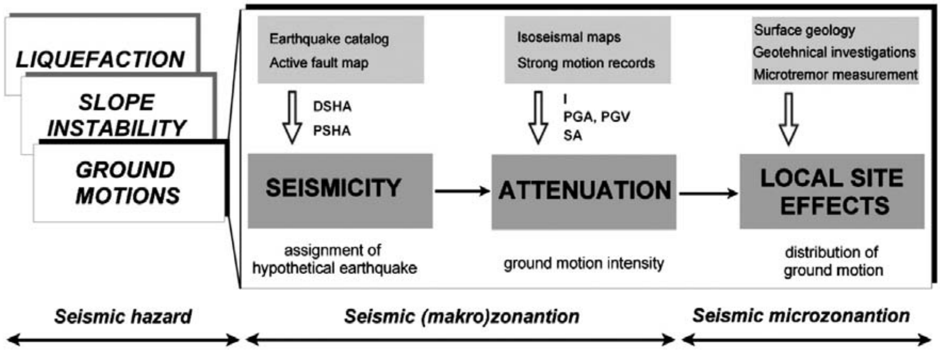

Figure 1. Flowchart for seismic zoning of ground motions (modified according to ISSMGE, 1999).

2.1.1. Seismicity

Regional and local seismicity can be investigated using seismological and geological data. Seismological data are collected from catalogs of historical and instrumentally located earthquakes, as divided in the Croatian Earthquake Catalogue into historical (occurring prior to 1908) and instrumentally (recorded from 1908 to today) (Herak et al., 1996). Geological data are collected from active fault maps, which are available for most areas.

There are two approaches to the evaluation of seismicity: deterministic (DSHA- Deterministic Seismic Hazard Analysis) and probabilistic (PSHA – Probabilistic Seismic Hazard Analysis). The deterministic approach is based on selected scenario earthquakes and specified ground motion probability level. The probabilistic approach encompasses all possible earthquake scenarios and all ground motion probabilities, then computes the probability of earthquake occurrence during a certain time period (DRM, 2004d). Probabilistic methods can be viewed as inclusive for all deterministic events with a finite probability of occurrence. In this context, proper deterministic methods that focus on a single earthquake ensure that each event is realistic, i.e., has a finite probability of occurrence (Mc Guire, 2001).

2.1.2. Attenuation

The attenuation of ground motion intensity, which is the severity at which the earthquake is felt locally that becomes less intense in relation to the source, plays an important role in assessing the potential for strong ground shaking (ISSMGE, 1999). Empirical attenuation relationships are generally employed in the quantification of seismic hazards in either deterministic or probabilistic approaches. These attenuation relationships could be based on the Intensity, PGA, PGV, SA or other factors.

Attenuation relations based on seismic intensity are developed using isoseismals of historic earthquakes. Instrumentally measured intensities, such as peak acceleration and velocity, are more reliable measures of the severity of strong shaking than seismic intensity scales. Modern attenuation relations typically yield the natural logarithm of a ground shaking parameter, such as acceleration or spectral acceleration (PGA or SA), as a function of magnitude and distance (Finn et al., 2004). The reliability of the derived relationships depends on the quality and quantity of data and on distance and magnitude ranges used in the analysis (Mualchin, 1996).

Attenuation relations used in Croatia include the PGA expression of Prelogović (Prelogović et al., 1985) and Herak (Herak et al., 2001) and the I_{max} expression of Herak (Herak et al., 1989).

2.1.3. Local site effects

Once the probable earthquake characteristics are determined, the second step is evaluating the ground motion characteristics on the surface while accounting for local geological and geotechnical site conditions. Local site effects are considered the most significant factors in the zonation of ground motions. Approaches to the evaluation of local site effects depend on the level of zonation, i.e., mapping scale.

Grade I method of zonation involves evaluating the local site effects using existing information that is readily available from published reports and other sources.

The easiest approach is to compile data on the distribution of damage induced during past destructive earthquakes. Using this approach, the isoseismal maps of past destructive earthquakes can be prepared. The intensity increment map is then established based on the seismic intensity distribution.

Site surface geology has often been used to interpret the observed intensity increment at each site. Many investigators have established empirical correlations between surface geology and seismic intensity increment. Therefore, the values of intensity increment for particular geological units can be determined from the empirical expression.

Grade II methods of zonation require additional investigations. These investigations include geotechnical investigations, geophysical testing and soil sampling from boreholes for laboratory tests.

Geotechnical investigations should preferably be performed to the depth of bedrock. Strata with shear-wave velocities greater than 750 m/s are commonly defined as "bedrock" in many cases. There are several ways to define subsurface soil profiles using penetration tests (Standard Penetration Test – SPT for cohesionless soils or relatively stiff soils; Cone Penetration Test – CPT for soft soil deposits) or geophysical methods (mostly "down-hole" and "cross-hole" methods) (ISSMGE, 1999).

Ground classification based on soil boring or geological data may be a more direct indicator of local site effects than surface geology data, as used under the Grade-1 method. In the Japanese Building Code, soil conditions were classified into four types. This type of classification is a practical way to evaluate site effects because borehole tests data are readily available in most city areas and has been adopted in the Seismic Codes of many countries. In Eurocode 8, the soil is classified into five major categories and two specific sub-categories that correspond to very loose or liquefiable material, respectively. The advantage of such a classification is that the three parameters used for soil identification (shear wave velocity, N SPT values, and undrained strength) are relatively easy to measure. The classification according to the International Building Code (IBC 2000; latest edition 2009) distinguishes soil profiles into five major categories based upon site shear wave velocity, with a special site conditions such as liquefiable soils, soft clays and peat also recognized.

If site investigation data is not available, indirect information on the site period may be obtained by means of microtremor measurements. Microtremors are ambient vibrations of the ground caused by natural or artificial disturbances, such as wind, sea waves, traffic and industrial machinery. Seismometers of high sensitivity are used for microtremor measurements (ISSMGE, 1999).

Numerous investigations have found that the amplification factor is the ratio of surface layer shear-wave velocity to bedrock.

Grade III methods of zonation require the conducting of ground response analyses (including the one-dimensional equivalent-linear and nonlinear analyses, and 2D and 3D analyses). Additional laboratory tests are necessary if equivalent-linear and/or nonlinear analyses are performed. SHAKE2000 (Schnabel et al., 1972; Ordonez, 2005) is the most-widely used computer program based on equivalent linear analysis. D-MOD2000 (Matasovic and Ordonez, 2007) is widely used for nonlinear and effective-stress site response analyses.

2.2. Zoning for slope instability

Slope failures and rock falls during earthquakes have resulted in a great number of casualties and have been a major cause of damage to structures and facilities constructed on or near the slopes. The failures can range in volume from a fraction of a cubic meter to some hundred thousand cubic meters. The displacements can range from a few meters to a hundred meters or more. Landslides are one of the most damaging collateral hazards associated with earthquakes. In fact, damage from triggered landslides and other ground failures has even exceeded damage directly related to strong shaking and fault rupture (Jibson et al., 1998).

Slope stability depends on both external driving force and resistance of the material to movement. The external driving force includes gravitational and seismic forces, while the material resistance is governed by geological and geotechnical conditions (ISSMGE, 1999). The chosen zonation level for slope instability depends on the availability of field data, i.e., both in terms of quality and quantity.

Grade I zonation screens the potential areas of slope instability using the relationship between magnitude and maximum distance from a fault or an epicenter. On the basis of analyzing the sliding distribution triggered by past earthquakes, ISSMGE (1999) have proposed empirical criteria for slope instability zonation. However, these criteria only indicate the outer boundary of area influenced by landslides. Moreover, these zonation methods do not incorporate the effects of local geology and soils or groundwater conditions, which have an important influence on slope stability.

Grade II zonation incorporates additional seismological, morphological, and geological data for evaluation of landslide susceptibility. ISSMGE (1999) presents the only examples of heuristic approaches in which instability factors are ranked and weighted according to the assumed or expected importance in causing mass movement. Susceptibility zonation maps aim to predict the most likely location of slope failures. The resulting maps exhibit zones of relative susceptibility (e.g., low, high) to landslides.

Grade III zonation requires additional geotechnical investigations for gathering data suitable for performing slope stability analyses in static and dynamic conditions. These models require input data on soil layer thickness, soil strength, depth below the potential sliding surface terrain, slope angle, and pore pressure conditions. Deterministic analyses are usually applied to grid-cells (e.g. 500 x 500 m) with different pseudo-static and permanent displacement approaches used. The aim of the analysis under pseudo-static conditions is the evaluation of the factor of safety (Fs) and the coefficient of critical acceleration because both are representative of the available strength. The critical acceleration relates to the load factor while Fs relates to the strength factor. The permanent displacement approach is founded on Newmark's displacement method for a sliding block (Newmark, 1965). When the applied ground acceleration is larger than the critical acceleration, Fs becomes temporarily less than one and the mass slides downhill. The safety of the slope is then assessed in terms of this displacement.

2.3. Zoning for soil liquefaction

Liquefaction is a phenomenon of partial or total loss of strength in saturated, cohesionless soils as a consequence of increased pore water pressure and reduced effective stress. Source mechanisms can vary, but typically are consequences of the dynamic cyclic loadings that are primarily caused by earthquakes. The horizontal ground motions caused by liquefaction can vary from smaller oscillations during trembling and without permanent displacements to smaller permanent displacements to lateral spreading and liquid-like flows.

Grade I zoning is based on the existing data for geological and geomorphologic properties. Maximum extent of the liquefaction susceptible area can be estimated directly from the magnitude of the predicted earthquake or on the basis of seismic intensity.

Grade II zoning uses existing data from various sources and additional data, such as analyses of aerial photographs and interviews with local residents.

Grade III zoning requires new specialized subsurface investigations, field and laboratory testing, and analyses.

Many methods for mapping liquefaction hazard have been proposed. Youd and Perkins (1978) demonstrated the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduced the mapping technique of combining a liquefaction susceptibility map with a liquefaction opportunity map to produce a liquefaction potential map.

Liquefaction susceptibility is a function of the capacity for sediment to resist liquefaction when subjected to ground shaking. The physical properties of soil, such as sediment grain size distribution, compaction, cementation, saturation, and depth, govern the degree of resistance to liquefaction. Liquefaction resistance can be estimated by in situ or laboratory tests. Standard penetration and cone penetration tests are mostly used to estimate liquefaction susceptibility (DRM, 2004d). SPT-based methods were previously developed by Seed and Idriss (1971), Seed et al. (1985), and other references listed herein.

Liquefaction opportunity is a function of the potential seismic ground shaking intensity. *Liquefaction potential* depends not only on soil liquefaction susceptibility, but also the level of seismic activity in the region, i.e., the liquefaction opportunity.

The most frequently used quantitative analysis for evaluation of liquefaction potential is the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed et al., 1983; Seed et al., 1985; Seed & Harder, 1990; Youd & Idriss, 1997; Youd et al., 2001; Idriss and Boulanger, 2008), with FS as a quantitative measure of soil liquefaction potential. Liquefaction potential can also be evaluated using computer programs such as PROLIQ (Atkinson et al., 1986), which is composed of Seed's method for liquefaction evaluation and the probabilistic method of seismic risk evaluation (Cornell's method) (Levson, 2003), and D-MOD2000 (Matasovic and Ordonez, 2007) which is a fully nonlinear effective-stress computer program.

For engineering purposes, the evaluation of soil liquefaction impacts such as liquefaction-induced settlement and lateral spreading is more important than assessing the actual soil liquefaction potential.

3. Input data for microzonation

Earthquake hazards can be mapped using a number of different methods (overview of methods is given in section 2), which usually reflect different levels of certainty or degrees of quantification. The amount, quality, and cost of information required for mapping generally increases with greater levels of certainty. Collected data can then be processed into a series of GIS layers followed by quantitative evaluation of the hazard potential.

Application of each methodology will dictate use of the specific input parameters. Basic input data with the corresponding recommended evaluation

Table 2. Basic input data that are essential for microzonation with the corresponding recommended evaluation methods (DRM, 2004b).

Essential input data	Recommended methods
Topography	Digital topographic map (scale 1:5000) DEM, DTM
Groundwater table	Boreholes and/ or geoelectric soundings CPTU[1] (including information on seasonal influences)
Geotechnical units	• Detailed surface geology maps • Geological/geotechnical in-situ data (Borings, SPT[2], CPT[3], CPTU) • Geophysical methods (SASW[4], Cross-hole, In-hole seismic wave velocity measurements, Micro-tremors, CPT Seismic cone, etc.)
Bedrock or Competent site conditions ($v_s \geq 750$ m/s)	Borings & Geophysical methods
Delineation of Basin structures	Deep seismic surveys or microtremor array measurements
Basic geotechnical and geophysical properties of the different geotechnical units: • Strength parameters (shear strength parameters in areas with potential stability problems) • Shear wave velocity	• Laboratory tests • Correlations with SPT or CPT/CPTU tests • Geophysical methods (SASW, Cross-hole, In-hole, Micro-tremors, Seismic Cone, etc.)

[1] CPT with pore water pressure measurement; [2]Standard Penetration Test; [3]Cone Penetration Test; [4]Spectral Analysis of Surface Waves

methods are given in Table 2. Municipalities are recommended to collect all geotechnical, geophysical, and geological data from the ongoing building activities in each respective territory. These data can be used to enhance and update microzonation maps.

3.1. Input data for ground motions

Appropriate maps of expected ground shaking hazards are a prerequisite for further mapping of different seismic hazard zones – amplified ground shaking, liquefaction and earthquake-induced landslides (DOC, 2000).

Seismic macrozonation maps are based on regional characterization of earthquake hazards at smaller scales. Therefore, the accuracy of the national seismic macrozonation map is too low for microzonation studies, and conducting a regional seismic hazard study based on detailed regional geological and seismological studies is essential. These earthquake hazard maps should be defined in respect to PGA or SA for competent site condition with an accuracy of 1:25000 map scale. The assessment of regional hazard for microzonation purposes should be based on a Probabilistic Seismic Hazard Assessment (PSHA). The other necessary output from the earthquake hazard study should be acceleration time history records for site response analysis.

Such assessments require the following input data:

– Earthquake hazard (over several time histories) at competent site conditions calculated for a specified return period (the return period is 100 years in the Turkish manual)

– Shear wave velocity

– Material behavior under cyclic loading.

Several techniques are available to calculate surface shaking. For microzonation purposes, one-dimensional analysis is generally acceptable.

3.2. Input data for earthquake-induced landslides

Slope stability depends on the associated geometry, soil environment, and hydrostatic conditions. Therefore, information on the soil environment and hydrologic conditions is a prerequisite for predicting the slope behavior (DRM, 2004b).

Assessment of the earthquake-induced landslides hazard requires the following input data:

– Local hazard at soil surface (result of the ground shaking map)

– Topography

– Material strength

Additionally, all identified existing unstable areas should also be mapped (landslide map or inventory). Various zonation methods have been developed in the literature to estimate susceptible zones of slope failures during earthquakes (ISSMGE, 1999).

3.3. Input data for liquefaction

The principal conditions for liquefaction or excessive settlements are that the soil is composed of a loose granular material and high water table near the surface, which results in saturated soil conditions. Therefore, knowledge of the detailed soil conditions at a specific site is essential to predict the liquefaction susceptibility.

Defining liquefaction susceptibility requires the following input data:

– Local hazard at soil surface (result of the ground shaking map)

– Depth of groundwater table

– Material strength behavior under cyclic loading

– Soil stratification.

Additionally, all previously identified areas with known liquefaction susceptibility should be mapped. Several techniques are available to assess the liquefaction susceptibility. For microzonation purposes, correlations with in-situ tests (SPT, CPT) are generally acceptable. SPT tests are preferred over CPT tests because better correlations with the liquefaction susceptibility exist (DRM, 2004b).

4. Framework for seismic microzonation

Earthquake casualties and losses are primarily the result of building and infrastructure failure induced by earthquake effects. The two principal approaches to reducing these losses are to avoid high hazard areas for the building and infrastructure sites and to ensure that buildings and infrastructure are designed and constructed to resist expected earthquake loads. The first approach relates to land use management and the second approach deals with the design and construction of individual buildings (DRM, 2004a).

Both the seismic microzonation and the building codes must be considered in urban planning and building design. Although the scientific and engineering basis for these tools is widely available, application and use must be required and enforced by municipal authorities. The effectiveness of seismic microzonation and land use management planning is dependent on the effectiveness of implementation policy and enforcement of zone defined development controls.

Guidelines and recommendations for seismic microzoning have been produced in many countries (ISSMGE, 1999; DRM, 2004b; DOC, 1997; DOC, 2000). The purpose of such documentation is to advise responsible agencies on reviewing and evaluating microzonation studies performed by companies. Furthermore, such guidelines should inform agencies of the required inputs and outputs for a microzonation project and should define methodology, technical recommendations and the minimum requirements for companies to perform this task.

An appropriate technical unit at the regional or local level must manage the process of seismic microzonation. This unit should be responsible for planning, supervising, implementing and maintaining the microzonation project. The results obtained from microzonation studies must be updated at regular intervals. The reliability of the microzonation maps will increase as more data becomes available.

Final seismic microzonation maps should be incorporated into urban development plans. Zone-specific building recommendations provide guidelines for additional investigations to define the design input appropriately.

As previously described, the main concepts related to the assessment and management of earthquake risk is from the Guidelines for Evaluating and Mitigating Seismic Hazards in California (DOC, 2000) and Turkish Manual for Seismic Microzonation for Municipalities (DRM, 2004b). Therefore, the framework for seismic regulations using the examples of California and Turkey are described herein.

Municipalities in Turkey are primarily responsible for the application and enforcement of land use and building regulations. In the case of building regulations for earthquake safety, the reference standard is the "Specification for Structures to Be Built in Disaster Areas" that was updated in 1997. In the case of land use management for earthquake safety, the reference document is the Manual for Seismic Microzonation for Municipalities (DRM, 2004b). This

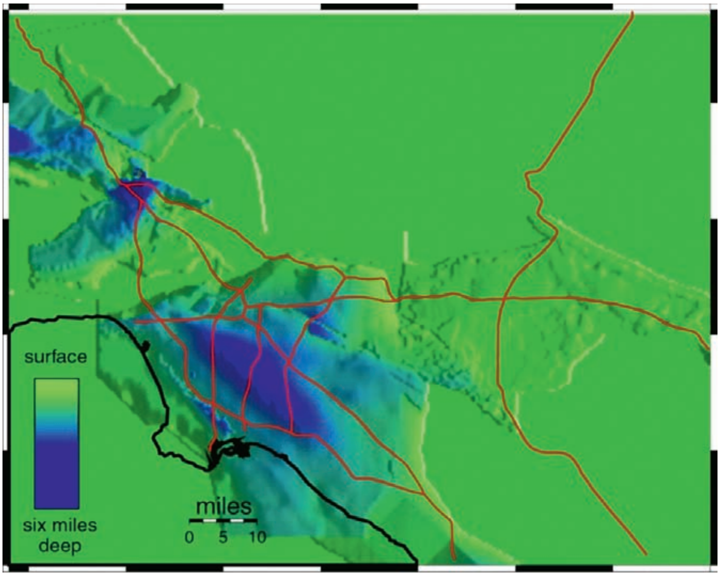

Figure 2. Depth to "Competent Bedrock" in Greater Los Angeles Area.

manual provides guidance on the required procedures for development of seismic microzonation maps at the municipal level. The microzonation projects should produce the following results: regional earthquake hazard map at a scale of 1:25000, ground shaking map, liquefaction susceptibility map, and landslide susceptibility map at a scale of 1:5000. Microzonation of a municipality must be reviewed and appropriately revised after an earthquake affecting the municipality and/or every 15 years accounting for new data and technology.

Presently, seismic microzonation is, arguably, the most advanced in California. The Seismic Hazards Mapping Act of 1991 mandated the California Geological Survey (CGS; formerly California Division of Mines and Geology) to delineate seismic hazard zones within and around the major cities in the state. General guidelines for evaluating and mitigating seismic hazards (SP 117) within these zones were published in 1997 (California Department of Conservation, Division of Mines and Geology, 1997). These guidelines were subsequently expanded and updated in 1999 and 2002 (California Department of Conservation, Division of Mines and Geology, 2008) to include both potentially liquefiable zones and zones of slope instability. The criteria for delineating seismic hazard zones (SP 118) were updated in 2000 (California Department of Conservation, Division of Mines and Geology, 2000). Most of the cities and counties adopted SP117 as a guide for land-use planning and permitting processes. In accordance with SP117 requirements, these cities and counties require that the site-specific geotechnical investigations be performed in support of design of urban and other development projects within seismic hazard zones. Deeper (i.e., 15 m as opposed to standard 10 m) boreholes are required in the areas identified on the seismic hazard maps as "potentially liquefiable." Additional information, required for site specific site response analyses, soil liquefaction analyses, or to evaluate design acceleration response spectra in accordance with the building code requirements, is available for major urban areas in digital form over the internet. An example for information on depth to "competent bedrock" is presented for Los Angeles in Figure 2. An example of site classification for evaluation of acceleration response spectra is presented for the San Francisco Bay area in Figure 3.

The above presented examples demonstrate how the results of seismic microzonation can be incorporated in seismic regulations at both land-use and structural engineering levels, particularly in urban areas. This includes the local level, such as EC8.

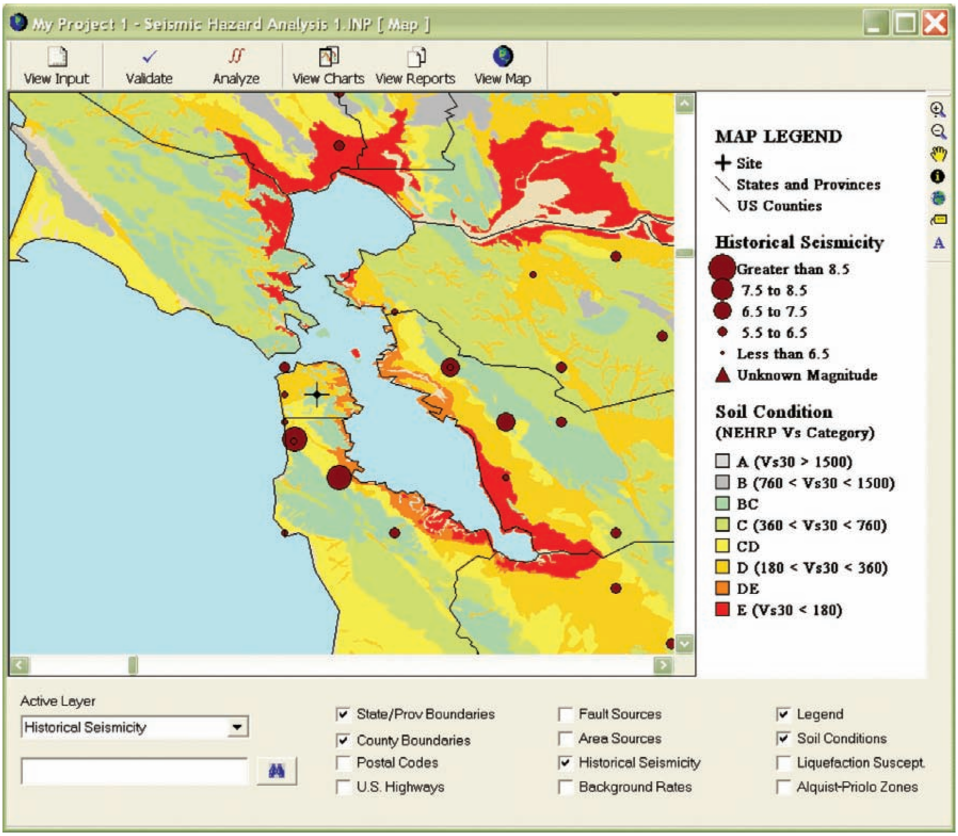

Figure 3. Site classification in accordance with the NEHRP Site categorization, as adopted in the International Building Code.

5. Conclusion

Microzonation is an efficient tool to mitigate earthquake risk by hazard-related land use management. However, microzonation does not replace the existing building and construction codes. Seismic microzonation maps do not provide detailed hazard parameters at the level of the specific building site, but they do provide guidance on required site-specific investigations.

The national seismic zonation maps are mostly at small scales, while seismic microzonation for a town requires larger scale studies. There are incompatibilities regarding differences among map scales adopted for estimating earthquake hazards and site characterization. Therefore, a major purpose of the seismic microzonation is to supply structural design input by replacing national macrozonation maps. However, the applicability of this approach is uncertain because there is no assurance of the reliability and uniformity of these microzonation studies.

A reason for this weakness is the necessity for interdisciplinary interpretation. Unlike seismic macrozonation, seismic microzonation requires input from civil engineering and engineering geology, especially in the field of geotechnical engineering.

There is demand from international, national, regional and municipal administrations for seismic microzonation maps to be included in urban planning, seismic codes and civil protection procedures.

Guidelines and recommendations for seismic microzonation have been produced in many countries, and including these documents in the framework of seismic regulations is highly desirable.

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SAŽETAK

Seizmičko mikrozoniranje: pregled načela i prakse

Snježana Mihalić, Maja Oštrić i Martin Krkač

U prvom dijelu rada dan je pregled definicija i metoda zoniranja seizmičko geotehničkog hazarda prema preporukama izdanim od Međunarodnog društva za mehaniku tla i geotehničko inženjerstvo (1999). Svrha ovog pregleda je ukazati na raznolikost metoda korištenih u izradi karata seizmičkog hazarda, kao i na osnovne principe zoniranja ovisno o namjeni i mjerilu karte. U drugom dijelu rada dani su osnovni ulazni podatci za seizmičko mikrozoniranje. Delineacija zona seizmičkog hazarda zahtjeva uspostavu okvira potresne regulative. Vodiči i preporuke za seizmičko mikrozoniranje trebale bi biti dio tog okvira. Postoje dva osnovna pristupa u reduciranju šteta izazvanih potresom: prvi se pristup odnosi na prostorno planiranje, a drugi se odnosi na projektiranje i izgradnju pojedinih građevina. Oba pristupa potrebno je uvažavati u prostornom planiranju i projektiranju, a lokalne vlasti trebale bi zahtijevati njihovu primjenu i provedbu.

Ključne riječi: seizmički hazard, seizmičko mikrozoniranje, klizišta, likvefakcija, prostorno uređenje

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