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General Report — Session 11: Seismic Zonation and Microzonation, Earthquake Risk Assessment, and Earthquake Risk Management

M. S. Power

G. Estrada

S. Zlatovic

L. Matesic

F. R. Bickner

See next page for additional authors

General Report – Session 11

Seismic Zonation and Microzonation, Earthquake Risk Assessment, and Earthquake Risk Management

M.S. Power	G. Estrada	S. Zlatovic	L. Matesic	F.R. Bickner	C. Cardona	F.H. Swan
U.S.A.	Colombia	Croatia	Croatia	U.S.A.	U.S.A.	U.S.A.

Ten papers were received for this session. Summaries of these papers are provided below

11.01 Use of Microzonation to Site Facility on Low-Angle Thrust and Associated Fault-Bend Folding by F.R. Bickner, G.A. Vadurro, G.L. Manhart, D.N. Lindberg, C.J. Watt, and R.C. Chaney

Typically, hazards associated with surface faulting are mitigated by avoiding active fault traces. However, where buildings have been constructed before the existence of an active fault is known, it becomes necessary to evaluate the nature of the hazard in order to determine the appropriate course of action. The hazard should be characterized in terms of the amount and type of deformation, the width of the deformed zone, and the likelihood of displacement.

The College of the Redwoods campus is located within a broad zone of faulting and folding associated with an active low-angle thrust fault, the Little Salmon fault zone, in northern California. Studies of the fault zone near the campus have shown that the fault is active and indicate a recurrence interval 300 to 560 years for surface faulting events. Consequently, during about the past twenty years, there have been several studies to assess the geologic hazards related to faulting and folding at existing and proposed new buildings on the college campus. The investigations included compilation and review of the existing geologic information, interpretation of aerial photographs, geologic mapping, geotechnical borings and trenching. As part of an investigation to locate a new learning resource center on the campus, these data were compiled to prepare a microzonation map delineating faults, fold axial surfaces, and exclusionary hazard zones.

The campus lies between two primary fault traces that trend northwest and dip towards the northeast. The main part of the campus is on the hanging wall of the western trace, which dips beneath the campus and, presumably merges with the eastern trace at depth to the east of the campus. Dip-slip displacement per event on the western trace is 3.6 to 4.5 m. Deformation in the hanging wall consists of 25- to 50-m-wide zones of distributed faults and fractures. The maximum observed secondary fault offset (cumulative displacement) was 1.8 m. Discrete axial surfaces associated with folds occur throughout the hanging wall. The variability in the faulting is pronounced along the trend of the fault. Therefore, site specific knowledge of the subsurface conditions is essential to reliably assess the displacement hazard at individual building sites.

Fifty-foot setbacks from the faults were used to define the exclusionary zones. The deformation associated with folding across axial surfaces also is considered potentially damaging to structures located across these features, but the displacement is expected to be significantly less than the displacements on the main fault traces. Such sites are considered to be buildable provided that the structural engineer implements appropriate design measures to mitigate the expected ground deformation.

11.02 Study on Seismic Retrofit Planning Method for Sewage Treatment Plants on the Basis of Seismic Risk Management by A. Yuasa, T. Ohsumi, K. Yamamoto, and T. Kawakami

A seismic risk management methodology is described for determining an optimum degree of seismic retrofit for sewage treatment plants that are seismically vulnerable. The methodology is motivated by the substantial age of many sewage treatment plants in Japan and the heavy damage to sewage facilities during the 1995 Hyogoken-Nanbu (Kobe) earthquake.

The methodology involves the application of seismic risk analysis. First, the seismic hazard at a sewage treatment plant site is evaluated in terms of defining different earthquake ground motion levels and their probability of occurrence. Second, a nonlinear response seismic intensity method developed by the authors to used to calculate the level of damage for the unretrofitted plant and for the plant when retrofitted by different methods to different degrees of seismic resistance. Repair costs are estimated for the unretrofitted and retroftitted plant for each retrofit scheme for each earthquake ground motion level. The annual risk to the unretrofitted plant and to the plant for each retrofit scheme is expressed as the sum of the damage (repair) costs for each earthquake ground motion level times the annual probability of that ground motion level. From these analyses, the annual repair cost savings due to seismic retrofit may be determined for each seismic retrofit scheme. These cost savings may then be compared with the annual cost of the seismic retrofit scheme to select the scheme that provides the greatest net annual cost reduction (i.e., annual damage cost savings minus annual costs of implementing a seismic retrofit scheme).

The seismic risk management methodology is illustrated by an example. Furthermore, the damage assessment methodology was found to give estimated damage costs in close agreement with actual damage experienced during the 1995 Hyogoken-Nanbu (Kobe) earthquake.

11.07 Development of Supreme Super High-Density Realtime Disaster Mitigation System for Gas Supply System by Y. Shimizu, K. Koganemaru, W. Nakayama, and F. Yamazaki

Tokyo Gas is developing a real-time system for damage assessment of its gas supply system. The 1995 Great Hanshin (Kobe) earthquake showed how difficult it is to gather information on damage in the post-earthquake environment. As a result, the real-time damage assessment system termed SUPREME is being developed.

SUPREME utilizes data from 3700 SI sensors installed in district regulators throughout the gas service area of 3,100 square kilometers. This system will replace an earlier system, termed SIGNAL, for gathering seismic information and providing network alert based on information from 332 SI sensors. The SI devices record three-component acceleration time histories. In addition to the data from the SI sensors to determine ground motion amplitudes, improved estimates of ground motions are interpolated between sensors using amplification functions that are a function of the estimated local soil shear wave velocity. This information is available on a GIS system using boring data from 50,000 points around the service area. Data from the SI sensors are also utilized to assess whether or not liquefaction has occurred at a location (see below for methodology). Immediately after an earthquake, SUPREME combines SI values, maximum acceleration values, and liquefaction assessments, plus topographical data and pipe network data such as types of pipes, to make estimates of the damage incurred by the system. Additional data for damage assessments include pressure gauge data from district regulators. The new SI sensors close shutoff valves on the basis of combined SI and maximum acceleration values.

Data on ground liquefaction are a very important part of the damage assessment. The new SI sensors judge that liquefaction has occurred when several conditions are satisfied. These conditions relate to the values of SI, peak acceleration, estimated displacement, and estimated period of the acceleration wave forms (as defined by zero crossings of the time histories). The authors have tested the liquefaction prediction methodology using ground motion time histories recorded during earthquakes in Japan and in the U.S. and believe that the determination of liquefaction in real time will have a very high accuracy.

11.08 Methodology and Final Results of the Medellin Seismic Instrumentation and Microzonation Project by G. Estrada

Medellin is an important industrial city of Colombia, which is the capital of Antioquia province (department) and it is located in the northwest of this country. It has a very high population density, about 2,000,000 people in an area of just 100 km^2. Even though Medellin has never been destroyed by an earthquake, there were several important reasons to undertake studies which supply criteria about seismic response, potential damage and seismic protection programs. Its location makes it very susceptible to suffer earthquakes and its great topographical and geological diversity make clear the importance of earthquake ground response. In addition, a big part of Medellin city was developed using old seismic codes and other zones without fulfilling seismic norms, this condition is especialty critical in poor neighborhoods. These characteristics imply a very variable construction quality, which leads to a relatively high structural vulnerability in Medellin.

The main objective of the Medellin seismic instrumentation and microzonation study was to carry out and propose new provisions for new buildings in Medellin, in order to apply these criteria in its development programs, and determine the potential for damage to existing constructions during earthquake motions. By this project it was possible to install and operate an accelerograph network, implement a seismological information analysis center, carry out the seismic hazard study, and develop the geotechnical and seismic microzonation of Medellin.

This project considered the evaluation of earthquake ground response, landslides and liquefaction. The seismic microzonation study covered compilation of existing information in a geotechnical database, geological and geomorphological studies, geotechnical exploration (constituted by drillings, geophysical tests, static and dynamic laboratory tests), analyses of seismic response in accelerograph sites using recorded accelerograms, definition of dynamic behavior of representative soils of the city by relationships of shear modulus and damping ratio, calibration of one-dimensional analyses models of local soil conditions using the SHAKE program (in base to real registers on rock and soils), development of a 3D model of geological and geotechnical conditions of Medellin in a geographical information system (the final result of which was a grid of 50 m-square cells, so that every cell has associated data of soil profiles), definition of homogeneous zones according to geological, topographical, geotechnical and seismic response conditions, and design spectra for rock accelerations of 0.03 g and 0.15 g, which reflects suitably the seismic hazard of the city and represent the particular seismic response of each zone. On the other hand, this study included analysis of landslides induced by earthquakes in Medellin.

The results of the Medellin seismic microzonation allowed concluding that the principal seismic geotechnical hazard in this city is the amplification phenomenon, since soils of Medellin have low susceptibility to liquefaction, and occurrence of landslides may be associated with earthquakes, but these events are not their main cause. The Medellin seismic microzonation guided dividing the city in 14 homogeneous zones with their respective design spectra. Finally, it is important to indicate that the maximum spectral acceleration obtained in Medellin for the design earthquake (rock acceleration of 0.15 g) varies from 0.50 g to 0.80 g, and the amplification of peak acceleration ranges from 0.18 g to 0.38 g.

11.09 A Project to Understand Urban Earthquake Risk Worldwide by C. Cardona, R. Davidson, and C. Villacis

The Understanding Urban Seismic Risk Around the World (UUSRAW) project was launched in 1998 by the Secretariat of the International Decade for Natural Disaster Reduction (IDNDR) and GeoHazards International (GHI), a non-profit organization dedicated to reducing earthquake risk in the world's most vulnerable communities. The 18-month project was designed to help cities around the world recognize the ways in which they are similar (and different) with respect to the earthquake hazard and to share their experiences and resources in working to reduce the impact of future earthquakes. The study aimed to (1) provide a systematic comparative assessment of the magnitude, causes, and ways to manage earthquake risk in cities worldwide, (2) identify cities around the world that are facing similar earthquake risk challenges and foster partnerships among them, and (3) provide a forum in which cities could share their earthquake and earthquake risk management experiences using a consistent, systematic framework for discussion.

The project established an internet network of 74 seismically active cities worldwide, and in each one, identified a scientist or municipal officer to act as a local city representative. These city representatives gathered the information necessary to develop a systematic comparison of the earthquake risk and risk management practices of all participating cities. The Earthquake Disaster Risk Index (EDRI), a composite index that compares metropolitan areas according to the magnitude and nature of their earthquake disaster risk using five main factors: Hazard, Vulnerability, Exposure, External Context and Emergency Response and Recovery Capacity, provided the framework for the UUSRAW project.

While the experience has highlighted a few logistical difficulties associated with coordinating a large group of geographically dispersed participants (e.g., inter-regional differences in computer capabilities and language), the success of the project suggests that the internet is a valuable tool for enabling future global endeavors.

The UUSRAW project produced a final report -- currently being disseminated by the UN-ISDR and GHI -- including a comparative analysis of the earthquake risk and risk management practices in the participating cities, a compilation of two-page city profiles that describe the key elements of a city's earthquake risk and risk management practices in a systematic way, and a compilation of more than 60 risk management effort case studies from 27 cities. The project also established a worldwide network of earthquake professionals that can support continued work in comparative urban earthquake risk assessment.

11.10 RADIUS – Managing Urban Earthquake Risk in Developing Countries by C. Villacis and C. Cardona

As part of the International Decade for Natural Disaster Reduction, the United Nations launched the Risk Assessment Tools for the Diagnosis of Urban Areas against Seismic Disasters (RADIUS) initiative to reduce the effects of seismic disasters in urban areas, particularly in developing countries. This initiative had two concrete objectives: to 1) develop seismic damage scenarios and earthquake risk management plans for nine selected cities worldwide, and 2) develop practical tools for urban seismic risk management using the results of the case studies. In each city, the project also sought to raise awareness on the city's seismic risk, incorporate the different sectors of the community in risk management activities, and set up conditions for the institutionalization of risk management activities.

The nine cities that were selected were Addis Ababa (Ethiopia), Antofagasta (Chile), Bandung (Indonesia), Guayaquil, (Ecuador), Izmir (Turkey), Skopje (TFYR Macedonia), Tashkent (Uzbekistan), Tijuana (Mexico), and Zigong (China). The RADIUS case studies were designed with the specific objective of initiating long-term risk management processes in the cities where the project was implemented through the interaction and involvement of the community. The project has had immediate impact in the cities, and local actions are already being taken to reduce the seismic risk of these cities. Furthermore, the project has encouraged several other cities to express interest in carrying out similar efforts to reduce their earthquake risk.

Results of the RADIUS case study projects, as well as the tools that were developed as part of the RADIUS initiative, are included in the project's final report, which is currently being distributed by the UN Secretariat of the International Strategies for Disaster Reduction (ISDR) and GHI.

11.14 Seismic Microzonation of Central Khartoum, Sudan by Y.E-A. Mohamedzein, J.A. Abdalla, A.M. Elsharief, A.B. Abdelwahab, and E.O. Ahmed

The objective of this study is to quantify the effect of the local soil conditions in Central Khartoum, Sudan, on the seismic risk. From other macro seismic zonation studies by the authors (Abdalla et al, 1997), peak bedrock accelerations were evaluated. From those studies, the authors selected a peak bedrock acceleration of 0.045g for developing bedrock acceleration time histories that were subsequently used in site response analyses of representative soil profiles for Central Khartoum. Artificial time histories were developed for these analyses.

Data from more than 100 soil borings were examined to develop a characterization of the local soil conditions. Central Khartoum is generally characterized by alluvial deposits overlying bedrock at a depth of about 25 meters. The alluvial soils are clays and silts up to 8 meters thick overlying sands down to bedrock. Ground water depths range from about 4 meters depth near the Blue Nile river to about 10 meters depth farther away. Three different soils zones were evaluated for Central Khartoum, with differences between them characterized mainly by the denseness of the sandy soils as determined by SPT-N values.

Dynamic site response analyses of soil profiles for each zone were carried out using one-dimensional shear beam models. The analyses indicated little soil amplification, with peak ground accelerations at ground surface ranging from about 1.0 to 1.15 times peak bedrock acceleration.

Because the alluvial sands are loose to medium dense and below the ground water table, their liquefaction potential was evaluated using a probabilistic approach. From a probabilistic seismic hazard analysis, a relationship was developed between peak ground acceleration and annual frequency. The Seed-Idriss simplified procedure and the SPT-N values from soil borings provided a basis for characterizing the liquefaction resistance of the sands; the authors developed specific liquefaction resistance equations. By combining the seismic hazard analysis results with the liquefaction resistance characterizations, the probability of liquefaction was evaluated and found to be low. For example, for an exposure time of 50 years, the probability of liquefaction was found to range from about 1 to 3 percent for the three soil zones.

11.15 Geotechnical Data Base for the City of Zagreb and Its Application in Site Response Analyses by P. Kvasnička and L. Matešić

The paper describes the formation of a geotechnical data base and its use in estimating site response in the western part of Zagreb, Croatia. A data base of boring logs and soil properties measurements in a consistent format were established in a geographic information system (GIS). The data base included more than 150 boring logs, which generally did not extend to depths greater than 10 meters. This data base is useful for general site characterization and for planning site-specific investigations.

Information on the deeper stratigraphy not included in the GIS data base were obtained from various sources, including hydrothermal borings by an oil company and subsurface investigations for a nuclear power plant at a nearby site. Although a seismic model was established to a depth of 2.7 km, bedrock or rock-like material having a shear wave velocity greater than 700 m/sec was assessed to be present at a depth of 50 m. Accordingly, a profile for site response analysis using SHAKE was established to 50 m depth. Shear wave velocities for the layers in the profile to the depth of soil borings were estimated using a correlation between SPT blow count and shear wave velocity developed by Imai and Tonouchi (1982), and shear wave velocities below the boring depths to 50 m depth were estimated from the hydrothermal borings.

Peak bedrock accelerations were estimated by others to equal about 0.12g and 0.20g for return periods of 100 years and 1000 years, respectively. The SHAKE analyses indicated that these accelerations were amplified to peak ground surface accelerations of about 0.24g and 0.42g, respectively, and that most of the amplification occurred in the upper 8 m of the soil profile.

11.16 Development of a Shear-Wave Velocity Model of the Near-Surface Deposits of Southwestern British Columbia, Canada by P.A. Monahan and V.M. Levson

Southwestern British Columbia is one of the most seismically active areas in Canada that includes the urban areas of Vancouver and Victoria. The area contains a wide variety of geologic deposits ranging from bedrock to glacial deposits of Pleistocene age to latest Pleistocene and Holocene deposits. The various deposits differ greatly in their stiffness, density, and shear wave velocity depending on the age, environment of deposition, and soil classification.

Using a large data set of recorded shear wave velocity measurements and other subsurface data from borings and cone penetrometer tests, the authors developed a shear wave velocity characterization of the different stratigraphic units. This shear wave velocity characterization is in terms of (a) average velocities (and variations) for the units and (b) the average velocities to a depth below ground surface of 30 meters (and variations) for the units. The latter set of velocities are for use with the U.S. NEHRP site response classification system, wherein Site Classes A through F have progressively lower shear wave velocities in the upper 30 meters (average velocities in upper 30 meters designated v_{s30}) and, correspondingly, progressively higher capabilities for ground motion amplification.

The authors describe the various deposits in detail and characterize each by its average shear wave velocity, v_{sav}, and average velocity in the upper 30 meters, v_{s30}. In some cases, variations in v_{sav} for different depth ranges are also described. Thus, the results can be used throughout the study area to estimate soil amplification of ground motion using the NEHRP site factors, as well as providing a basic soil characterization useful for many purposes, including supplemental or comparative data for site-specific ground response analyses.

The authors note several environments in the study area where additional data are needed for an adequate characterization.

11.17 Seismic Risk and Site Response Analysis for City of Bandung-Indonesia by I.W. Sengara, Y. Munaf, Aswandi, and I.G.M. Susila

The authors have analyzed seismic hazard in the City of Bandung, Indonesia and, on the basis of these studies, developed recommendations for design response spectra for the predominant classes of subsurface conditions in the City. A peak ground acceleration contour map for the city for a 500-year return period was generated and provides input for damage estimates for buildings and lifelines as part of the RADIUS Project (see paper by Vallacis and Cardena, this session, for a description of RADIUS).

Significant seismic sources contributing to seismic hazard in Bandung include both subduction zones and shallow crustal sources. A probabilistic seismic hazard analysis (PSHA) using the EQRISK computer program was carried out for Bandung on the basis of characterizations of the earthquake recurrence on these sources and selected attenuation relationships for each source. From these analyses, peak ground acceleration on rock was evaluated as a function of return period. Then, a series of site response analyses at 20 locations in the city were carried out on the basis of characterization of the varying subsurface conditions in the City and using the SHAKE91 computer program. From these analyses, a contour map of PGA for a 500-year return period was developed that showed PGAs varying from about 0.27g to 0.33g with the higher values in parts of the City containing an upper layer of soft to stiff clay deposits and the lower values in areas with an upper layer of sandy deposits.

From the site characterization activities and site response analyses, two site classes were described, S_2 and S_3, which are similar in estimated shear wave velocity characteristics to U.S. NEHRP Site Classes C and D, respectively. Proposed design response spectra were developed for each class. The spectrum for Site Class S_3 is higher and contains more long-period content, again reflecting the presence of soft to stiff clay in the profile.

The authors note that the study could be refined on the basis of more complete seismic, geological, and geotechnical information.