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General Report — Session 10: Case Histories of Geotechnical Earthquake Engineering, Failures, and Geotechnical Analysis of Recent Earthquakes

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INTRODUCTION

Well-documented case histories that describe how earth systems respond to earthquakes are invaluable contributions to the advancement of our profession. Observations from the field anchor our theories and test our understanding. Hence, earthquake reconnaissance efforts that produce case records of field performance are critically important. Moreover, once these field data are collected, careful and objective back-analyses of the resulting case histories are warranted.

The purpose of this session is to share these field data and back-analyses with the profession to ensure important lessons are learned from each earthquake event. Twenty-nine papers are presented in this session. They have been organized into these broad categories for the purpose of summarizing them in this general report:

a) Earthquake ground motions (7 papers)
b) Surface fault rupture (4 papers)
c) Liquefaction and site improvement (6 papers)
d) Foundation and structural performance (7 papers)
e) Earth structures (5 papers)

EARTHQUAKE GROUND MOTIONS

Matsui et al. utilize building and pipeline damage statistics from the 1995 Kobe earthquake to identify possible causative factors for the observed damage. Contributing factors identified in this study include distance from the ruptured fault, liquefaction, and site effects through the ground characteristic value $T_g = \frac{4H}{V_s}$, where H = thickness of the soil deposit and V_s is the thickness-weighted mean shear wave velocity of the deposit. It was found that in the near-fault region, wooden house damage primarily depended on distance, with significant damage located 3-4 km from the fault. At farther distances, (R > 5 km) the wooden house damage decreased slightly as the ground characteristic value T_g increased. In liquefied areas, the rate of wooden house collapses decreased 5 to 20% from the average value, most likely due to increased damping of ground motions. Conversely, water supply pipeline damage rates increased in liquefied areas. Pipeline damage depended on whether liquefaction occurred and on the ground characteristic value T_g. The rate of pipeline damage increased as the value of T_g increased, with higher T_g values indicating soft ground in coastal areas susceptible to ground motion amplification and liquefaction.

Zulfikar and Takemiya utilized a convolution scheme in time for the source function and in space along the rupture direction with a layered Green function method to simulate ground motions in the near-fault region for the 1999 Kocaeli earthquake. Good agreement between the model simulations and the recorded ground motions was achieved. They showed the value of employing wavelet transform analysis to characterize the variation in frequency content with time for the recorded and simulated motions. Capturing the important effects of fault asperities in the rupture process was shown to be important, and this was captured by utilizing an inhomogeneous rupture mechanism with multiple asperities.

Teymur et al. also used a form of wavelet theory to analyze ground motions recorded during the 1999 Kocaeli earthquake. Harmonic wavelet analysis of non-stationary signals allows one to plot the signal in a time-frequency space enabling the energy distribution in the signal to be observed. The wavelet transform allows one to discern discontinuities within the signal, where one can focus one's attention. Analysis of the Kocaeli ground motions indicated that accelerations with the same frequency occurred at different time instants in the records. This could not have been observed using traditional DFFT methods. Acceleration traces showed at least two distinct ruptures and other details including the changing of the waveform as the distance from the ruptured fault increased.

Two papers used observations of damage from the 1999 Athens earthquake to investigate topographic effects. **Kallou et al.** used observations of damage in the small town of Adames near the banks of the Kifisos river canyon and one-and-two dimensional analyses to study the relative importance of local soil conditions and site topography. They found that 2D topographic effects are substantial only within 50 m from the canyon ridge. Moreover, topographic effects were only important when relatively soft soil layers existed at the site. At a site close to the canyon ridge, amplified shaking and increased damage appeared to result due to the combined effects of topographic amplification and 1-D soil amplification. At the location of four collapsed buildings located 250 m from the canyon edge, topographic effects were negligible, and 1-D site amplification due to soft soils were largely responsible for higher spectral accelerations and increased damage. The authors defined topographic effects through the Topographic Aggravation Factor, which is defined as the 2-D/1-D Fourier spectral ratio, and they found that near the canyon ridge, this factor varied between 1.5 to 2.0 over a broad frequency band.

Athanasopoulos et al. investigated the influence of surface topography on the seismic site response at a partially collapsed hotel (Hotel Dekelia) located near the banks of the Kifisos River in the same general area discussed previously. 2-D finite element analyses are performed with the equivalent-linear program FLUSHPLUS, whereas the previous investigators used ABAQUS with special techniques to capture incident SV waves. Both equivalent-linear and fully nonlinear soil models were used by Athanasopoulos et al. in their 1-D seismic site response analyses. Both local soil conditions and surface topography contributed to amplified shaking and most likely contributed to the partial collapse of the 3-story hotel that also had a soft first story. FE analyses indicated local soil conditions could amplify peak ground accelerations (PGA) by 30% and maximum values of spectral acceleration by 200%. Surface topography may have amplified PGAs by 35% and maximum spectral accelerations by up to 100%.

Koliopoulos and Margaris assess empirical predictive relations proposed for Greece using accelerograms recorded during the 1999 Athens earthquake. The duration and energy characteristics of 42 horizontal components of ground motion are captured with these recently developed predictive relations. Then, the use of a new probabilistic version of the 3D response spectra technique is explored. They found that the 3D damage response spectra or energy-related indices helped identify the damage potential of destructive ground motions. This technique allows one to evaluate the role of local soil conditions and duration.

Sancio et al. presents some key geotechnical observations from the June 15 and 21, 1999 earthquakes in Central Mexico. A total of 29 strong motion recordings over a variety of geologic site conditions were compared to available attenuation relations for normal fault mechanisms for deep and intermediate earthquakes, which are less established than those for shallow crusted earthquakes. Whereas, PGA was found to be affected by site conditions for these events, peak ground velocity (PGV) did not differ significantly for these generally soft rock to stiff soil sites.

SURFACE FAULT RUPTURE

Four papers addressed the hazards associated with surface fault rupture, with emphasis given to the 1999 Chi-Chi earthquake in Taiwan. **Yang et al.** summarize the data of observed damage along both the up-lifted, hanging-wall (east) side and the footwall (west) side of the ruptured Chelungpu fault in the vicinity of Wu-Fong Township. Structures situated atop the primary surface rupture were heavily damaged. Interestingly, the damage statistics also indicated that damage in the up-lifted, hanging wall side of the shallow reverse fault was much more severe than that on the footwall side of the fault. It was also found that buildings on the up-lifted side that were located closer to the primary surface rupture were more heavily damaged than those located further from the fault trace.

Miyajima and Hashimoto investigated damage to water supply pipelines in the vicinity of the Chelungpu surface faulting. Thousands of pipelines were damaged with failure rates of 0.14 per km of transmission and distribution pipelines and 4.56 per km of service pipelines. The damage rate was greatest for galvanized iron pipe. Most damage occurred in the more abundant polyvinyl chloride pipelines (98% of total length of system pipelines) of relatively small diameter (i.e. 80-200 mm). They also noted that buildings on the up-lifted side of the reverse fault were damaged more than these on the footwall side.

Yang and Beeson evaluate the usefulness of setting back from a fault by studying building damage near the Chelungpu fault. According to the Taiwan National Center for Research on Earthquake Engineering, at least 30% of the building damages in the Chi-Chi earthquake resulted from surface faulting and ground movement. Studying ground movement and building damage in Wu-Fong Township, the authors found that the California setback of 15 m was generally adequate on the footwall side of the reverse fault. However, significant building damage was observed outside the 15 m-wide setback on the up-lifted (hanging-wall) side of the fault. Although setbacks are useful, they should be non-arbitrary and depend on fault type and local geology. Additionally, implementing setbacks in heavily populated areas is difficult.

Kumar Ramancharla and Meguro employ the Applied Element Method, which models media as an assembly of small elements that are made by dividing the media virtually. Pairs of normal and shear springs along the element edges model element interactions. A reverse dip-slip fault displacement is modeled with this technique to study the influence of dip angle, bedrock displacement, and thickness of the soil deposit on the width of the affected zone.

LIQUEFACTION AND SOIL IMPROVEMENT

Lee et al. present their analyses of six sites that liquefied during the 1999 Chi-Chi earthquake. The cone penetration test (CPT) was utilized to characterize subsurface conditions at these sites. Shear wave velocities were also measured, and liquefaction susceptibility was evaluated using cyclic stress ratios (CSR) calculated using the Seed and Idriss simplified method and cyclic resistance ratio (CRR) was calculated using CPT and V_s procedures developed by one of the authors. The probability of liquefaction is calculated using the CSR and CRR through Bayesian mapping factors. Good agreement between the predictions and field observations of liquefaction was found. In addition, liquefaction-induced ground settlement calculated by the Ishihara and Yoshimine method agreed well with the observed ground settlements.

Lin et al. completed 14 borings with Standard Penetration Tests (SPT) and 8 CPT soundings to assess liquefaction susceptibility in Nantou, Taiwan during the 1999 Chi-Chi earthquake. In situ tests revealed that fine to medium silty sands or sandy silt layers located at a depth of between 5-8 m below the ground surface most likely liquefied. These soil strata have the highest liquefaction potential based on accepted SPT and CPT simplified liquefaction evaluation procedures and have physical properties similar to the boiled sediments sampled immediately after the earthquake. Lateral spreading near the Maolau River in Nantou is also described.

Tavares explains the probably mechanism for a flow slide which occurred in Guaratuba, Brazil in 1968. His liquefaction assessment found that this slide could not have been produced by blasting in a nearby quarry. Instead, a quick sand condition developed due to excess hydrostatic pressure in the sand through the differential water levels on land and in the sea. The remaining sand strata are dense to very dense.

Meneses-Loja characterizes a number of recent ground motion records in terms of liquefaction triggering parameters such as number of cycles and average shear stress. Using laboratory test results from Toyoura and an ideal sandy soil profile in his analysis, the author estimates the reduction in residual strength of saturated sand. The number of cycles and the average cyclic shear stresses of the post-strong seismic shaking were found to play important roles in the reduction of residual strength estimated from monotonic tests. Steady-state concepts are shown to overestimate the residual strength of the saturated sands.

Hausler and Sitar have compiled over 90 case histories on the performance of improved sites from 14 earthquakes worldwide. The field case histories cover a wide range of improvement methods and enhance our understanding of the performance of improved soil sites during earthquakes. The collected data indicate that improved sites generally perform well. Only 10% of the surveyed sites required significant post-earthquake remediation, repair, or demolition. Unacceptable performance resulted due to excessive ground deformation in the presence of severe lateral spreading or because of an insufficient remediation zone depth. This paper presents an insightful summary of the statistics compiled by the authors as well as several illustrative case histories.

Sesov and Talaganov present a project that required soil improvement to mitigate a liquefaction hazard to explore issues related to the performance of gravel drains. The effectiveness of gravel drains is very sensitive to ground conditions and earthquake characteristics. Unfortunately, the engineer needs to be careful, because the gravel drain dissipation method does not improve the "ductility" of the improved sand deposit's performance. The authors point to the benefits of densifying the soil improved by gravel drain installation and of constructing a well-computed sub-base layer under the structure to increase bearing capacity and to decrease settlement.

FOUNDATION AND STRUCTURAL PERFOMRANCE

Düzceer et al. describe the performance of deep foundations at an automobile manufacturing plan in Gölcük, Turkey during the 1999 Kocaeli earthquake. The plant is located atop young soil deposits in a seismically active region. Hence, before the Kocaeli event, the original foundation systems were designed to have combinations of bored, cast-in-place piles, jet grout columns, and displacement stone columns. The primary surface rupture from the Kocaeli earthquake developed along the southern boundary of the plant with secondary ruptures moving through the southwest corner of the body shop facility. Offsets of 1.6 m vertically and 2.0 m horizontally were measured along the primary fault trace, with floor elevations displaced downward about 1.5 m. The body shop sustained structural damage due to differential vertical and horizontal ground movements of around 80 cm and 30 cm, respectively. Field tests indicated that building foundations were still satisfactory, except the body shop was reconstructed further away from the fault trace with a more conservative foundation design. Reinforcement was increased, concrete strength was increased, and additional jet grout columns were placed around the structures to mitigate the effects of liquefaction, which was observed in the unimproved areas.

Miyazaki et al. utilized 2-D effective-stress finite element analyses to evaluate six pile-supported buildings that underwent various levels of damage due to liquefaction during the 1995 Kobe earthquake. The FE results compared favorably with field observations. Details of the location and severity of pile damage were captured by the analysis. The study found that: (1) damage to pile heads is mainly due to the inertia force from the superstructure and damage at deeper elevations was mainly due to kinetic forces resulting from ground displacements; (2) ductile, steel reinforced concrete piles were not damaged extensively; and (3) exterior diaphragm walls can reduce pile damage, but they can increase the seismic demand on the superstructure.

Psarropoulos et al. investigate the seismic response of a 600 m-long bridge, which is supported by seventeen pile-supported pier bents. The piles extend through a 22-25 m-thick soft soil deposit into stiff clays and dense sands. The site is well instrumented with accelerometers installed in the free-field and on the bridge, and with strain gauges installed on several piles. Three significant earthquakes that triggered the instruments were analyzed using a 2-D finite element model with linear visco-elastic soil behavior, which is appropriate for the low PGA levels of the events (max. PGA = 0.11 g). 1-D analyses were deficient, but 2-D analysis of this bridge crossing a valley were judged to be reasonable. Bending strains were captured by both the 2-D FE analysis and a simpler analytical approach. The superstructure induced inertial bending strains in the piles close to the pile cap.

Olivares and Silvestri investigate subsidence in a town in Italy. 2-D FE analyses using the program QUAD4M combined with 1-D nonlinear analyses and laboratory tests showing the development of excess pore water pressure in the clay shale underlying the site as a function of induced shear strain were employed in this investigation. The analyses confirmed the hypothesis that the slow subsidence of the town following the 1980 Irpinia earthquake can be attributed to post-seismic soil re-compression as a result of the dissipation of excess pore pressures developed from the earthquake shaking. Calculation of shear strains in the clay shale in excess of its volumetric threshold strain is used as a basis for confirming this hypothesis.

Stamatopoulos et al. describe three structural failures caused by recent earthquakes in Greece. Two hotels that were built on level ground may have failed due to significant differential settlements caused by seismically-induced ground settlement. A new energy method and the Tokimatsu and Seed method calculated settlements on the order of 10 to 50 cm for these cases. A factory that was built on the edge of a clayey slope may have failed due to slope displacements if the medium to stiff clay's shear strength was less than 41kPa, which the authors feel is reasonable for this material.

Klyachko argues that differential settlement of the shallow building foundations of 17 five-story residential large-block houses contributed to their collapse during the 1995 North Sakhalin Earthquake. Whereas other investigators attributed the collapses to poor construction, the author suggests that liquefaction was a principal factor Additional investigations are underway, but evidence of liquefaction in the area, collapse of taller, heavier 5-story buildings that may have punched into liquefied ground, and some relative upward heaving of foundations are observations used by the author to emphasize the potential importance of geotechnical factors on building performance.

Vlad and Vlad assess the potential for damage in masonry buildings in Romania. Theoretical and experimental engineering analysis of these structures, of both monumental and usual constructions, were employed in post-seismic investigation. Older masonry construction, especially without collar beams, are vulnerable. Strengthening schemes including the installation of collar beams, adding reinforced concrete overlays, and building supplemental reinforced concrete walls are presented.

EARTH STRUCTURES

Allen et al. describe a recent state-of-the-art seismic evaluation of Success Dam, which is located in the western foothills of the southern Sierra Nevada mountains in California. A previous investigation in 1983 concluded that the 44 m-high dam would perform adequately. However, a comprehensive exploration program in 1992, which included 62 Becker Penetration soundings, 20 boreholes with SPTs, and 39 cross hole shear wave velocity holes, found a previously unsuspected zone of weak material deep in the foundation under the upstream shell of the dam. Due to the inherent strengths and limitations of each method (e.g. BPT data are very large strain and V_s measurements are small strain), the authors believe that attempts to characterize this site using any single exploratory method or correlation would have been inadequate. Instead, a combination of tools with the application of sound engineering judgment is recommended for seismic safety evaluations. Detail aspects of the site investigation and insight garnered from carefully examining the field data are presented in this paper.

Tani reviews the seismic performance of large (> 15 m high) modern (post 1953) earth-fill dams. In Japan, none of these dams that has been built based on modern design standards have been destroyed by an earthquake. Earthquakes, including the 1995 Kobe event, have produced PGAs from 260 to 600 gal. at the foundation level of fill dams, which when converted to seismic coefficients (0.15 to 0.37) exceed design values (0.12 to 0.20), yet no dam has been heavily damaged or destroyed. Fill dams built according to modern design standards are constructed on firm foundations (N value by SPT > 50), have core and rock zones with densities of at least 95% of the JIS maximum density, and are sloped so that its slip safety coefficient (F_s) always exceeds 1.2. The successful performance of these dams indicates that they are "highly earthquake resistant" and that this design procedure is appropriate.

Fang et al. report the failure of retaining walls during the 1999 Chi-Chi earthquake. Several failures of various types of walls are described. Gravity walls failed due to sliding at a construction joint, overturning, shear rupture along a weak mortar bond of cobbles, surface fault displacement, an overall slope stability failure. A geogrid-reinforcement retaining structure also failed when its reinforcing strips were pulled out and the backfill fell out. The significant ground shaking and ground movements resulting from fault rupture or slope instability were identified as primary contributing factors.

Carville identified several cases where the 1994 Northridge earthquake caused extensive damage to property improvements overlying retaining wall backfill. Shaking-induced settlement of the backfill materials produced surface settlements of up to 20 cm, which in turn damaged overlying improvements, such as walks, fences, patios, and foundation slabs. Several cases of PVC drain-pipe damage were also documented.

Kerimov and Alizada suggest that uncontrolled human activity has increased the intensity and rate of earthquakes. An approach to this problem is offered by the authors.

CONCLUSION

A diverse group of papers, many making significant contributions to the earthquake engineering profession, are contained in Session X: Case Histories of Geotechnical Earthquake Engineering, Failures, and Geotechnical Analysis of Recent Earthquakes. Most importantly, however, these papers highlight the value of data that can be obtained through earthquake reconnaissance and the insight that can be gained from back-analysis of well-documented case histories.

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.