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General Report — Session 3: Case Histories and Failures in Geotechnical Earthquake Engineering

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CASE HISTORIES AND FAILURES IN GEOTECHNICAL EARTHQUAKE ENGINEERING: GENERAL REPORT ON SESSION 3

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INTRODUCTION

This General Report presents a summary of the 31 papers accepted for the session 3 focused on Geotechnical Earthquake Engineering: Case Histories and Failures of the Ground. The session includes discussion of land slides, as well as lessons learned from recent earthquakes including the Kobe 1995, Turkey 1999, Chi-Chi 1999, Greece 1999, Bhuj India 2001, Alaska and Italy 2002, Mexico, China and Algeria 2003, 2004 M-9 SE Indonesia and Japan Earthquake, Chile 2005, Japan and other 2006 – 2008 events.

The papers originate from twelve countries and cover a suite of important topics in the area of earthquake geo-engineering. These include dams and dam safety; damage to tanks, piers and port structures; observations of performance and damage to Geotechnical Engineering structures; Earthquake-Induced landslides; fault studies; lifeline fragility; liquefaction, site response and amplification; Laboratory based testing, Constitutive and Numerical Modelling; and Structural Isolation and Damping. A list of the papers is found in table 1 ordered by topic. The summaries below will give the reader a general overview of the focus of the paper and is intended to direct the reader to areas of interest. The activities of Session 3 also host a Discussion panel and two special presentations on recent earthquakes in Chile and Japan. The Session 3 organizers greatly appreciate the efforts of the authors and commend the quality of the accepted papers.

Paper	Origin	Authors	Topic
3.03	India	Bapat	Damage to Tanks, Piers, Piles, and Ports
3.22	UK,Japan	Madabhushi, et al.	Damage to Tanks, Piers, Piles, and Ports
3.29	India	Datye and Khare	Damage to Tanks, Piers, Piles, and Ports
3.48	USA	Puri and Prakash	Damage to Tanks, Piers, Piles, and Ports
3.25	India	Ayothiraman, Maity, and Khasung	Dams and Dam Safety
3.43	Iran	Salemi, Baziar, Merrifield, and Heidari	Dams and Dam Safety
3.08	Indonesia	Atmaja, et al.	Geoengineering Earthquake Damage
3.09	India	Prakash and Pancholi	Geoengineering Earthquake Damage
3.55	USA	Kayen, Steele, Collins, and Walker	Geoengineering Earthquake Damage
3.01	Japan	Okamura and Shigematsu	Earthquake-Induced Landslides
3.02	Canada	Seid-Karbasi, et al.	Earthquake-Induced Landslides
3.24	USA	Malhotra and Lee	Earthquake-Induced Landslides

3.34	Taiwan	Cheng , et al.	Earthquake-Induced Landslides
3.11	USA	Lindberg, et al.	Fault Studies
3.16	Iran	Jafari and Moosavi	Fault Studies
3.44	Pakistan	Mahdi	Fault Studies
3.17	Turkey	Ansal, Kurtulus, Tönük	Lifeline Fragility
3.04	China	Kayen, Tao, Shi, and Shi.	Liquefaction
3.37	Turkey	Akin and Topal	Liquefaction
3.05	Taiwan	Kuo et al.	Liquefaction mapping
3.12	Italy	Russo, Vessia, and Cherubini	Site Amp.
3.13	Italy	Rainone, Torrese, and Signanini	Site Amp.
3.33	Iran	Davoodi, Jafari, and Sakhi	Site Amp.
3.36	USA	Tezcan	Site Amp.
3.49	Italy	Grasso, Spina, and Maugeri	Site Amp.
3.51	India	Satyam and Rao	Site Amp.
3.53	Chile	Verdugo and Pastén	Site Amp.
3.35	Italy	Abate, Massimino, and Maugeri	Soil Lab, Constitutive, and Numerical Modeling
3.41	Iran	Nabili, Jafarian, and Baziar	Soil Lab, Constitutive, and Numerical Modeling
3.50	Iran	Halabian, Hashemolhosseini, and Saldourgar	Soil Lab, Constitutive, and Numerical Modeling
3.52	India	Babu and Arunvivek	Structural Isolation and Damping
3.54	USA	Kayen	Recent Damaging Earthquakes in Japan, 2003-2008

Table 1. Session 3 papers presented in order of topic, noting the authors and country of origin of the study.

SUMMARY OF RESEARCH PAPERS

Paper No. 3.01, DAMAGE TO MASONRY RETAINING WALLS DURING NIIGATAKEN-CHUETSU EARTHQUAKE, by Okamura and Shigematsu: This paper describes an investigation of the Niigata Chuetsu Prefecture, Japan earthquake of 2004. In the 2004 Earthquake, large numbers of retaining walls that had supported road embankments in the mountainous area collapsed, effecting emergency response, and severing vehicle transportation that had the effect of isolating people in the mountain areas for days. This investigation looked at a number of damaged and undamaged road embankments in the mountains and revealed that failure was commonly triggered by the bearing capacity failure of the foundation soil. Laboratory tests including triaxial compression tests were used to determine the strength of foundation soils. A simple, pseudo static method, was then used to examine the seismic stability of existing retaining walls and evaluate a factor of safety against the bearing capacity failure under combined static and seismic loading. Also, an attempt was made to use the portable dynamic cone penetration test for estimating in situ strength parameters.

Paper No. 3.02, PREDICTION OF POST-EARTHQUAKE FAILURE FOR A NEAR-SHORE SLOPE IN A LOW SEISMIC REGION, by Seid-Karbasi, Ji, Atukorala, and Byrne: This paper describes an investigation of large earthquake driven lateral spreads and flow slides in sand deposits have taken place in coastal and river areas, often after earthquake shaking ceases. The ground slopes in these slides were often gentler than a few percent. Low permeability silt or a clay layer may be responsible for some of these historical landslides. This paper describes the results of a coupled stress-flow analysis carried out for a near-shore LNG import terminal planned for a site on a moderate submarine slope comprising a liquefiable sand layer overlain by a clay layer located in a region with moderate seismic risk (PGA< 0.15g). Artesian water conditions are present at the site due to the presence of the hydraulic barrier layer and the mountain slopes near the shoreline. The hydraulic barrier also blocks or retards the upward flow arising from excess pore pressures generated by earthquake shaking and causes the pore pressures to remain high for some time after strong shaking. Under such conditions, thin water films may form below the low permeability soil layers, further promulgating the lateral spreading. An effective-stress based approach was employed to analyze the excess pore pressure generation in the sand layer associated with earthquake loading. The analyses showed that pore pressure redistribution during and after earthquake shaking may result in continued displacements after shaking has ceased, although displacements at the end of shaking are not very large. Under seismic loading conditions, large lateral deformations (or strains) are likely to occur within a thin layer of liquefied sand located immediately underneath the clay layer. This thin layer is likely to suffer significantly more strength and stiffness loss than the soils further below due to the presence of the hydraulic barrier. A failure plane (localization) may develop within this thin and weakened layer.

Paper No. 3.03, DAMAGE TO TALL STRUCTURES SITUATED AT LONG DISTANCE FROM EPICENTER DUE TO LONG PERIOD SEISMIC WAVES AND EFFECT ON STRUCTURES ON FILLED LANDS, by Bapat: It has been observed that the Long Period Surface Waves (LPSW) can cause heavy damage to tall structures (height > 17 m) far from the epicentral region. For example, damage was observed during Mexican Earthquake of 1985 some 520 km distance from the epicenter; during the Bhuj Earthquake (India) of 2001 damage was observed in Ahmedabad, some 310 km away from the epicentre in Bhuj; and during the Pakistan Earthquake of 2005 some 150 km away near the Kashmir border. The damage is accentuated if the structures are sited on filled land.

Paper No. 3.04, SHEAR WAVE-VELOCITY INVESTIGATION OF SOIL LIQUEFACTION SITES FROM THE TANGSHAN, CHINA M7.8 EARTHQUAKE OF 1976 USING ACTIVE AND PASSIVE SURFACE WAVE METHODS, by Kayen, TAO, SHI L., and SHI H.: This paper describes an investigation of soil liquefaction sites from the July, 28 1976 Tangshan M7.8 earthquake. The researchers revisited 26 sites identified in the maps and published in the1978 report of the Ministry of Railways and conducted a suite of active- and passive-array surface wave tests. They gathered and evaluated the Rayleigh wave dispersion characteristics of the ground collected by both the harmonic wave-spectral analysis of surface waves (SASW) and passive array Spatial Auto-Correlation method (SPAC). These sites are clustered along the north coast of the Bo Hai Sea in three areas: Lutai, Tianjin; Tangshan City and outlying village, Hebei; and Luannan county, Hebei. The dispersion curves for the two methods were quite similar where they overlapped in frequency space, typically between 3 Hz and 20 Hz. Hybridizing the SASW and SPAC tests can produce a continuous dispersion curve that covers the entire frequency range of interest for liquefaction or site amplification studies. The 26 test sites in Tangshan are segregated into liquefaction and non-liquefaction points based on observations after the earthquake. The data from high-values of seismic intensity near Tangshan city to low-intensities distant of the event in Luannan County segregate out into clusters of liquefied and non liquefied points clearly separated by probabilistic liquefaction boundary curves developed using system reliability methods and Bayesian updating approach from a large global data set of several hundred sites.

Paper No. 3.05, EVALUATION OF LIQUEFACTION POTENTIAL AND POST-LIQUEFACTION SETTLEMENT OF TZUOSWEI RIVER ALLUVIAL PLAIN IN WESTERN TAIWAN, Kuo Chang, Hsu, Shau, and Lin: This paper describes an investigation of liquefaction of the alluvial deposits of Tzuoswei River, the largest river system on Taiwan, during the September 21, 1999, (*ML* = 7.3) Chi-Chi Earthquake. The study re-assessed the potential for liquefaction and associated post-liquefaction settlements based on the liquefaction analysis procedures of Seed; Tokimatsu & Yoshimi; and the new Japanese Roadway Authority method. Based on about 1200 boreholes these methods were evaluated using the weighing technique suggested by Iwasaki. Post-liquefaction settlements were estimated based on the procedures proposed by Ishihara. Contours of liquefaction potential and post-liquefaction settlements were produced for the entire study area. These type of studies help evaluate the efficacy of current design methods such as the JRA method and the authors are to be commended for their effort.

Paper No. 3.08, SOME LESSONS FROM YOGYAKARTA EARTHQUAKE OF MAY 27, 2006 by Atmaja, Rosyidi, Taha, Lesmana, Wintolo, and Adi: This paper describes an investigation of the Mw 6.3 Yogyakarta earthquake of May 27, 2006 and presents some geological and geotechnical aspects of the earthquake. The Yogyakarta region is located on soft sediment deposits, and low frequency seismic waves appear to have been amplified. The vertical and horizontal PGA at a seismograph station YOGI was 0.183 to 0.303 g and 0.197 to 0.336 g, respectively. Field observations included major landslides, liquefaction, ground settlements, and fluctuations in the water levels and water-quality of wells.

Paper No. 3.09, GEOTECHNICAL ASSESSMENT AND EVALUATION OF THE IMPACT OF KACHCHH (BHUJ) INDIA 2001 EARTHQUAKE, by Prakash and Pancholi: This paper describes an investigation of the devastating Bhuj (Kachchh) Earthquake of MS 7.6 of the January 26, 2001. The geotechnical manifestations of deformation of this earthquake include fractures/ fissures, lateral spread, slump, subsidence, upheaval, sand blows and craters. Bhuj Earthquake resulted in considerable damage to earthen dams lying in isoseismal VIII and above in Kachchh. Damage to dams is in the form of longitudinal and transverse cracks, differential settlement, slumps or slides, lateral displacements and in some cases leakage of reservoir water. A general review of the geological, seismological and geotechnical data indicate that the main cause of the ground deformation and damage was liquefaction of the soil, although tectonic displacements may have also influenced the development of widespread fissures. This paper is on an important topic of performance of earth dams during Bhuj earthquake particularly as these dams are used to provide potable water supply to the Kachchh region which receives scant rainfall year on year. The paper would have been even more interesting if the authors included some of the retrofit measures adopted during the repair phase of these dams.

Paper No. 3.11 PROBABILISTIC ESTIMATION OF SITE SPECIFIC FAULT DISPLACEMENTS by Lindberg, Buck, Manhart, Chaney, Bickner, and Vadurro: This paper describes an investigation of The College of the Redwoods (CR) located near Eureka, California that was located on secondary faults of the active Little Salmon Fault (LSF) zone. In the early 1990's a deterministic estimate of the maximum past dip-slip displacement was measured at 1.7 feet. This displacement was resolved into approximately 1.5 feet horizontal offset and 0.8 feet of vertical offset, based on the secondary fault plane dip. Geologically, it has not been possible to establish the actual dates of the maximum displacements on the observed faults, though it was assumed that they had occurred within the last 11,000 years. This study evaluates the validity of using deterministic maximum values of displacement for designing mitigation for structural response, or whether a probabilistic approach could be utilized. The only data available was a series of trench logs as deep as 14' made in the early 1990's. Here, the frequency distributions of both horizontal and vertical displacements were examined, and Probability Density Functions (PDF) versus displacements were developed. The area under the PDF curves between given displacement intervals represents the probability of occurrence (POC) of that interval. A cumulative probability of occurrence for a displacement interval can be determined by adding the individual POC's. Based on this it was estimated that a horizontal displacement of $\leq$ 1.0 foot has a probability of 89% of occurring in the next 11,000 years at the site. A vertical displacement of $\leq$ 1.0 foot has a probability of 88% probability of occurrence.

Paper No. 3.12, CONSIDERATIONS ON DIFFERENT FEATURES OF LOCAL SEISMIC EFFECT NUMERICAL SIMULATIONS: THE CASE STUDIED OF CASTELNUOVO, by Russo, Vessia, and Cherubini : This paper describes a numerical study of local seismic effects in Castelnuovo, carried out by means of 1D and 2D simulations in order to evaluate amplification effects in terms of acceleration response spectra and amplification factors, and compared with prescriptions from technical provisions as Eurocode 8 that direct design activity. High soil heterogeneity, the interaction of input motion and geometrical irregularities of the soil layers affect seismic soil response and can cause differential damage in urban areas. Spatial variation of amplification effects are investigated to understand how numerical simulation results compare with amplification provisions of the simplified technical codes. In this study Castelnuovo di Garfagnana town near Pisa, Italy was modeled by numerical simulation and studied to understand the geological and geotechnical conditions that control local seismic amplification effects.

Paper No. 3.13, SEISMIC SITE EFFECTS IN THE FAULTED PIANCASTAGNAIO AREA (ITALY): AN EXPLANATION ATTEMPT, by Rainone, Torrese, and Signanini: This paper describes an analysis of the seismic site effects estimated in the absence of strong motion surface and borehole array measurements, using surface geological, geomorphological, geotechnical, and geophysical multidisciplinary surveys and numerical modeling. In densely populated urban areas, it has been possible to verify if numerical simulations can be, at least qualitatively, correlated with levels of building damage. However, frequently there are cases of inconsistencies between modelling results and macro-seismic effects. This was the case for Piancastagnaio, a small town in Tuscany, Italy, in which an ML = 3.6 earthquake in 2000 damaged some building constructed in the 1920's. The damage level is consistent with much higher expected amplitudes of intensity of VIII-IX of the EMS scale. The authors analysis, carried out in compliance of the new Italian seismic code (D.M., dated 14.09.05; O.P.C.M. 3274, dated 20.03.03) and European (Eurocode8) classify the subsoil on the basis of the Vs30 values that do not justify the apparent strong anomalous amplifications, nor the structural damage. The authors identify the failure mechanisms as the cause of the local site amplification effects.

Paper No. 3.16, LESSONS TO BE LEARNED FROM SURFACE FAULT RUPTURES IN IRAN EARTHQUAKES by Jafari and Moosavi: This paper describes an investigation of surface ruptures from recent Iran earthquakes, and the development of case histories In this paper, the importance of earthquake fault rupture hazards are presented, and examples are used to demonstrate how the hazards associated with surface fault rupture can be used to develop and implement effective engineering designs to mitigate this hazards. From the recent events, it was observed that in the Dasht-e-Bayaz earthquake, relative displacements in bedrock were found to be far smaller than in alluvium. Although a majority of the differential movement across a fault zone is localized in limited area, secondary fractures such as down warping of the up thrown block may be triggered by nearby earthquake faults. A displaced fault can cause landslides when found beneath a weathered slope. Shaking on the hanging wall side is more intense than that on the footwall side of reverse faults.

Paper No. 3.17, DAMAGE TO WATER AND SEWAGE PIPELINES IN ADAPAZARI DURING 1999 KOCAELI, TURKEY EARTHQUAKE by Ansal, Kurtulus, Tönük: This paper describes an investigation of the vulnerability of pipeline systems in the city of Adapazari based on available information on the performance of the water and sewage pipeline systems during 1999 Kocaeli, Turkey Earthquake. The water supply pipeline system in Adapazari experienced extensive damage. The main damage was observed in transmission and distribution systems primarily due to brittle asbestos cement (AC) pipes used in the system combined with the fracturing effect of ground deformations associated with liquefaction and softening of alluvial sediments. Recently, a pipeline damage inventory was compiled based on repair reports and interviews with water works technicians. Since the entire system was replaced after the earthquake only a limited number of repair reports were available. The geotechnical and geological site conditions were evaluated based on available borings, and in-situ tests. Vulnerability of water pipelines due to ground shaking and liquefaction was evaluated separately. Variation of earthquake characteristics on the ground surface was estimated based on 1D site response analyses using the outcrop motion recorded in Adapazari during the 1999 Earthquake. Liquefaction susceptibility was estimated based on a simplified liquefaction analysis and SPT blow counts obtained during the site investigations. Distribution of damage predicted by means of empirical vulnerability functions proposed in literature was compared to the observed pipeline damage. This is an interesting paper on the vulnerability of pipe lines crossing liquefiable sites. Differential settlements can often cause damage to pipe lines at joints/interfaces or other stiffeners. Similar damage was observed during the Kobe earthquake to gas pipe lines. There is a need to understand the failure mechanisms of pipe lines that cross liquefiable deposits and future research should address this issue.

Paper No. 3.22, SEISMIC BEHAVIOUR OF WATER FRONT STRUCTURES WITH TIRE CHIP BACKFILL by Madabhushi, Cilingir, Haigh, and Hazarika: This paper describes an investigation of Japanese water front structures that suffered significant damage in recent earthquakes. One of the primary causes for the poor performance of these structures is the liquefaction of foundation soil and, in some instances, liquefaction of the backfill soil. The liquefaction of the soil in-front of the quay wall tends to cause large lateral displacements and rotation of the wall. Full or partial liquefaction of the backfill can result in the increase of lateral earth pressure exerted on the wall and can cause additional lateral displacements. In this paper numerical analyses of a gravity wall type water front structure was considered. Often, gravity walls are placed on a rubble mound deposited onto the sea bed. The paper presents finite element analyses of a generic gravity wall problem in which strength degradation of the foundation soil and the backfill material are modeled constitutive soil relationships. At the Port and Airport Research Institute (PARI) in Japan, research is now being done to investigate the use of old car tire chips as a backfill material using a 1G underwater shaking table and dynamic centrifuge modeling. The finite element analysis was repeated to include a zone of backfill consisting of the tire chips. The results from the analyses of the gravity wall on rubble mound with liquefiable foundation and backfill soil are compared to those with tire chip backfill.

Paper No. 3.24, REINFORCEMENT OF SLOPES FOR SEISMIC STABILITY by Malhotra and Lee: During the Kobe earthquake and other recent events there is some evidence that reinforced slopes perform better when subjected to earthquake loading, Tatsuoka (2003). Hasuler and Sitar (2004) investigated performance of reinforced slopes using dynamic centrifuge facility at UC Davis. This paper compares the practice for analyzing the stability of an earthen slope under a pseudo-static seismic load and conventional limit equilibrium analysis and Newmark type displacement analysis based on rigid block on an inclined plane. The paper reviews the development of these approaches and examines the issues of shear strength degradation, strain incompatibility. Three case histories are presented of projects located in areas of high seismicity where some form of reinforcement was used to improve the overall seismic slope stability. Although several methods of seismic slope stability assessment are available, each has some limitations. Soil slopes are compliant, not rigid bodies. Soil strength is strain dependent and so is yield acceleration. The selection of an appropriate input motion is critical to a realistic prediction. Moreover, selection of the allowable permanent displacement is subjective and should be dependant either on the serviceability requirements of the structure supported by the slope, or on the level of damage acceptable to the owner. The selection of available mitigation measures depends on the site conditions, the driving forces and the failure modes. Different mitigation measures require analyses of different modes of failure. For example, piles used to stabilize slopes offer resistance through bending, while jet grout columns act in shear. In addition, consideration of strain incompatibility between soil and reinforcement, and the selection of allowable tolerable displacements are important issues.

Paper No. 3.25, EFFECT OF FOUNDATION-RESERVOIR INTERACTION ON SEISMIC BEHAVIOUR OF GRAVITY DAMS, by Ayothiraman, Maity, and Khasung: This paper discusses the combined effect of foundation-reservoir interaction on the seismic response of concrete gravity dam by considering a case study: Bichom Concrete Gravity Dam located in Arunachal Pradesh, India. The dam is comprised of overflow and non-overflow monoliths and seismic analysis was carried out for both structures separately for Design Basis Earthquake excitation (DBE) assuming linear behaviour. The significance of foundation flexibility on the seismic response of dam was investigated by comparing the response of the dam with rigid and flexible foundations. The hydrodynamic effect of impounded water is modeled as an added mass by Chopra's Method. The effect of foundation-reservoir interaction on the response of both monoliths, such as time period responses, crest displacements, base reactions and stress distributions are discussed in this paper. It is predicted from the analysis that the dam a with rigid foundation is relatively safe except for minor cracks at the heel of non-overflow monolith, but the dam with a flexible foundation will suffer moderate damage regardless of whether the reservoir is empty or full. This is an interesting paper on behaviour of dams founded on different types foundations (stiff rock or more flexible soil layers). The paper also highlights the need for more research on the changes in the seismic response of the dam based on reservoir level and the foundation flexibility.

Paper No. 3.29, PERFORMANCE OF LARGE STORAGE TANK IN BHUJ EARTHQUAKE, by Datye and Khare: This paper describes an investigation of The 2001 Bhuj M7.7earthquake and a case study of a phosphoric acid storage tanks weighing 100,000 kN and measuring 30 m in diameter built for a fertilizer plant in Kandla, Gujarat. The post earthquake performance assessment was carried out by exhuming the nearby piles and non-destructive testing of piles in-situ. The storage tanks are supported on piles and installed on a ground treated with stone columns. During the earthquake, the tanks showed no failure and have performed well. In particular, long flexible piles driven in hard clay performed well.

Paper No. 3.33, USING NEW SIGNAL PROCESSING TECHNIQUES IN ANALYZING MASJED SOLEYMAN EMBANKMENT DAM'S EXPLOSION RECORDS, by Davoodi, Jafari, and Sakhi: This paper describes an investigation of the use of blasting tests for earthquake studies with regards to their smaller amplitude vibrations relative to those normally encountered in earthquakes. Blasting studies, clearly, can be used to calibrate dam behaviour in a linear elastic range. Accuracy of numerical models should be improved by full scale tests and in situ earthquake records or alternatively using high quality dynamic centrifuge tests ala VELACS project. One potential problem is that blasting records are known to have non – stationary signals in frequency and intensity, and that classical signal processing methods, such as FFT and PSD, have many limitations in non-stationary random vibration analysis. Blasting tests records on the Masjed Soleyman dam, the highest embankment dam in Iran, are processed in the time – frequency domain by classical and the time–frequency distribution (TFD)method. The TFD method leads to better and more accurate system identification based on real records in earth dam. Using this powerful and modern signal processing technique, the frequency content of blasting spectra can be processed in both time and frequency domain. Using the classical TFD signal processing methods, the modal frequencies of dam body in upstream – down stream direction were obtained. Comparing the results obtained by the methods shows that the TFD method illuminated more modal frequencies (such as 2.9-3.2, 3.8-4.0, 5.3-5.5 and 6.8-7.1) than were extracted using classical signal processing methods. The scalogram presented in this article show that high frequency contents are dominant mostly in the strong motion of the explosion signals and as the time passes, and as the amplitude of the signal intensity decreases, lower frequencies are excited in comparison with high frequencies. Similar methods to the TFD method reported in this paper have been used by earlier researchers. For example, Haigh et al (2002) have used modified WAVELET analyses to investigate the earthquake motions in time-frequency domain.

Paper No. 3.34, INVESTIGATION OF LANDSLIDES AND DEBRIS FLOWS IN TACHIA WATERSHED BETWEEN MAAN DAM AND TECHI DAM, by Cheng, Chern, Chiou, and Lin: This paper describes an investigation of landslides and debris flows triggered during the Chi-Chi earthquake and subsequent typhoons in the watershed of Tachia river. The earthquake and landslides inflicted damage to the power generation facilities and highway network. In order to coordinate reconstruction planning, a quantitative assessment of landslides, debris flows, and river deposit characteristics was conducted using aerial photos and satellite images obtained at after the earthquake and following a number of typhoon events. The future trends of landslide and debris flow initiation are also investigated by using empirical models. The analysis shows that over 50,000,000m^3 to 70,000,000m^3 of slide debris was triggered in the Chi-Chi earthquake and subsequent typhoon events between the years 1999 to 2005. By conservative estimation, 60% of the debris from these down slope events still remains within the watershed, which is causing the silting of the main river channel. The deposition in the main river channel is the current trend, and aggregated average river channel scouring is not expected to occur until 20 to 30 years in the future.

Paper No. 3.35, SIMULATION OF SHAKING TABLE TESTS TO STUDY SOIL-STRUCTURE INTERACTION BY MEANS OF TWO DIFFERENT CONSTITUTIVE MODELS, by Abate, Massimino, and Maugeri: This paper presents the results of a FEM 3-D model that reproduces results of a physical model subjected to shaking table tests. The tests, performed at the BLADE/EERC laboratory of Bristol University, have been simulated by means of a new numerical model based on a recent constitutive model characterized of isotropic and kinematic hardening of granular soil. The shaking table tests were performed using a six-degree of freedom shear-stack shaking table with a scaled one-storey steel frame. The stacked shear box was filled with Leighton Buzzard Sand. The sand was characterized by 11 shaking tests. For the 3-D numerical modeling, the soil is modeled with a cap-hardening Drucker-Prager model, and the above new constitutive model utilized in the FEM code of the Research Group of Catania University. Experimental data was gathered during the shake table tests that allowed for the verification of the proposed numerical model in simulating the of dynamic soil-structure interaction. The proposed model is compared with the other numerical models based on simpler constitutive formulations.

Paper No. 3.36, GENERATING REALISTIC GROUND MOTIONS FOR NONLINEAR SEISMIC HAZARD ANALYSIS- AN APPLICATION TO HARD ROCK SITES IN EASTERN NORTH AMERICA, by Tezcan: This paper describes an investigation of the dependence of seismic response analyses on the shape of the time-domain filter used in the stochastic method of ground motion prediction. Brune's single-corner point source model was used in conjunction with the current attenuation relationships developed for hard rock sites in the Eastern North America (ENA) to obtain the target ground motion spectrum. A total of three hundred synthetic accelerograms were generated by filtering the Gaussian white noise with exponential, triangular and trapezoidal windows. For each accelerogram, displacement response of the Duffing's oscillator was calculated, and its average amplitude spectrum was constructed in the joint time-frequency domain using Mexican hat wavelets. This procedure was repeated for three levels of nonlinearity. Among the three shapes examined, the trapezoidal window was associated with longer durations of sustained energy, thereby increasing the level of the expected damage. The dependence of the seismic response to the particular filter shape became more pronounced with increased levels of nonlinearity. This study concludes that ground motions with the same Fourier Amplitude Spectrum can cause substantially different levels of seismic damage on the same structure, depending on the time-frequency localization of the energy imparted to the structure. This paper raises an important issue on the filtering of earthquake ground motions. Brennan et al (2005) also identified the significance of over-filtering the ground motions.

Paper No. 3.37, ASSESSMENT OF SPT-BASED LIQUEFACTION POTENTIAL OF ERBAA (TOKAT), TURKEY, by Akin and Topal: This paper describes an investigation of liquefaction-related damages of the buildings in the Erbaa (Tokat) settlement area of Turkey. The seismicity of the northern part of Turkey is mainly controlled by active North Anatolian Fault Zone. Several earthquakes and earthquake triggered hazards occurred by the tectonic activity of this fault zone. In recent past, 1999 Adapazari earthquake (Mw=7.4), in the western part of this fault zone resulted in liquefaction-related damages of the buildings of Erbaa (Tokat) located partly on an alluvial plain of Kelkit river. Several boreholes were drilled and laboratory tests were performed on soil samples. Liquefaction analysis was performed by using SPT-based methods suggested by Youd et al. (2001), Cetin et al. (2004), and Idriss and Boulanger (2006). For the analysis, an earthquake magnitude of Mw=7.4 and the different peak ground acceleration (PGA) values were considered. The distribution of the liquefaction potential areas was presented on the maps. Based on the analysis, the loose granular materials of alluvium are likely to liquefy in the event of a nearby large magnitude earthquake and high PGA value. The effort of the authors in revisiting the Adapazari sites that liquefied during the Turkey earthquake must be commended.

Paper No. 3.41, EVALUATION OF THE MARTIN ET AL. (1975) PORE PRESSURE BUILD UP MODEL USING LABORATORY TEST DATA, by Nabili, Jafarian, and Baziar: This paper describes an investigation of the phenomenon of excess pore pressure development in loose saturated granular soils during earthquakes. Researchers have attempted to predict these phenomena (excess pore water pressure and liquefaction) using constitutive modeling and numerical approaches. In this paper, a numerical modeling procedure is presented to predict the seismic excess pore water pressure using a fully coupled effective stress analysis. Several cyclic and monotonic soil shear tests and a level ground centrifuge test conducted during the VELACS project were utilized in order to calibrate the numerical models. The Mohr-Coulomb elastic-perfectly plastic model and the Martin et. al. (1975) excess pore water pressure build up model were concurrently incorporated in the analysis. This study focuses on a reasonable step-by-step procedure in order to adjust and obtain the calibration parameters of these models. Comparing the excess pore pressure buildup time histories of the numerical and experimental models (both element and centrifuge tests) showed that the Martin et al. (1975) models can be used in the numerical assessment of excess pore water pressure with an acceptable degree of preciseness. This is an interesting paper on evaluation of excess pore water pressures and the effort of the authors in calibrating the constitutive parameters must be commended.

Paper No. 3.43, INVESTIGATION OF DYNAMIC BEHAVIOR OF ASPHALT CORE DAMS, by Salemi, Baziar, Merrifield, and Heidari: This paper describes an investigation of the dynamic behavior of a rockfill dam with asphalt-concrete core utilizing numerical models and centrifuge model tests. The dam material parameters are determined by laboratory tests including static and cyclic triaxial tests and wave velocity measurements. The case study selected is the Meyjaran asphalt core dam, recently constructed in Northern Iran, with a 60 m height and 180 m crest length. The seismic response analyses are performed using a non-linear three dimensional finite difference software under various hazard levels of earthquake loadings. Their results showed that the induced shear strains in the asphalt core are less than 1% during an earthquake with a_{max}=0.25g and the asphalt core remains watertight. Also, small scale physical models of the asphalt core dam have been tested on centrifuge, under impact loading and response accelerations and induced deformations were recorded by instruments installed within and on the models. The recorded data and observations of the centrifuge model tested at 80g acceleration showed that the induced deformations in the asphalt core under an impact load with a large acceleration of 7.6 m/s^2 were very small. Comparing the results of centrifuge tests with the results of numerical dynamic analyses of a prototype dam indicates that the numerical results corresponded well with the data recorded during centrifuge tests. This is an interesting paper that utilises both dynamic centrifuge modelling and numerical analyses.

Paper No. 3.44 PAKISTAN'S KASHMIR-HAZARA ZONE AND THE OCTOBER 08, 2005 EARTHQUAKE, by Mahdi: This paper describes an investigation of the Kashmir Hazara Zone (KHZ) in Pakistan that was the source of the disastrous M7.7 October 8, 2005 shallow depth earthquake. The KHZ structure is a major fault/fold zone that has been geologically mapped and monitored with seismometers. The Kashmir-Hazara Syntaxis (KHS) is a folded structure which emanates from the Pir Panjal Range in Kashmir and extends northwards to Balakot, where its western limb takes a loop to the southwest and extends with this trend towards the city of Muzaffarabad. The Jhelum Thrust (JT) is a terminal branch of Main Boundary Thrust (MBT) and the source of the recent Mw = 7.7 earthquake of October 08, 2005. The earthquake had a depth 16 km, and seismic moment between 2 - 3 x 1027 dyne•cm and the rupture duration was about 30 seconds. The patch of the fault that slipped during the earthquake is approximated by an ellipse of 50-to-70 km length in the NW-SE direction, and 20-30 km width in the transverse direction. The length of this patch is in fair agreement with the length of the fault along which surface deformation is observed in the field from Balakot to the mountains south of Hattian.

Paper No. 3.48 DESIGN PREDICTION AND PERFORMANCE OF PILES FOR SEISMIC LOADS by Puri and Prakash: This paper presents state of the art on analysis and design of piles subjected to seismic loading. Generally, pile foundations are regarded as a safe alternative to mat foundations for supporting structures in seismic areas. The performance of piles depends on soil profile, pile and earthquake parameters. In non-liquefying soils the shear modulus degrades with increasing strain or displacements whereas, material damping increases. Single piles and pile groups require stiffness in different modes of vibration. Group action of piles is generally accounted for by including interaction factors. In liquefiable soils, the liquefaction may lead to increased pile cap displacement, down-drag as well as damaging lateral pressure against the piles. Japanese and North American design practices are not entirely consistent and typically result different design solutions to problems. In this area of research, considerably more work is needed to refine design methods and best model potential seismic load scenarios.

Paper No. 3.49, SEISMIC MICROZONATION STUDIES IN THE CITY OF RAGUSA (ITALY), by Grasso, Spina, and Maugeri: This paper describes an investigation of the geotechnical zonation of subsoil of the city of Ragusa that suggests a high vulnerability to site amplification of the ground motion. This geotechnical hazard is mapped in a seismic microzonation model of the city. Based on the seismic history of Ragusa, the authors modeled site amplifaction scenarios for (1) the "Val di Noto" earthquake of January 11, 1693 (M=7.3); (2) the "Etna" earthquake of March 1, 1818 (M=5.9); (3) the 1895 earthquake (IMAX= 7 EMS); (4) the Modica earthquake of January 23, 1980 (MW = 4.63); and (5) the "Sicilian Earthquake" of December 13, 1990 (ML=5.6). Despite the lower magnitude, a medium size local earthquake such as the 1990 "Sicilian" event, accounts for the principal seismic hazard of Ragusa, since it may cause the heaviest damage to the urbanized area of the city. According to historical data, the epicenter of this earthquake was located at sea. This earthquake is associated to the strike-slip segment of the Ibleo-Maltese fault system. This fault system is the major seismogenic structure of Eastern Sicily, and is responsible for numerous major historical earthquakes. Based on the response spectra obtained from1-D non-linear modeling, the city of Ragusa is been divided into zones with different peak ground acceleration (response spectral motions at zero-period) at the surface. Shaking maps for the central area of the city of Ragusa were generated via GIS for the scenario earthquakes.

Paper No. 3.50, SEISMIC RESPONSE OF STRUCTURES WITH UNDERGROUND STORIES CONSIDERING NON-LINEAR SOIL-STRUCTURE INTERACTION, by Halabian, Hashemolhosseini, and Saldourgar: This paper describes an investigation of soil-structure interaction analysis of structures using non-linear soil models. Soil nonlinearity affects soil-structure interaction in a complex way and is difficult to model due to the inadequacy in the modeling of the unbounded soil medium. In the case where anelastic soil behaviour is assumed, the surface motion tends to be amplified proportionally to the input motion. However, in reality the amplitude and frequency content of the response are modified due to the stiffness degradation and higher energy dissipation of the soil. This work deals with the influence of soil non-linearity, by introducing models for hysteretic behaviour of soil on the soil-foundation-structure interaction phenomena. The objective is to study the beneficial or detrimental effects of the non-linear SSI concerning both the drift and settlement of structures with underground stories. To examine the effect of non-linear soil-structure interaction a non-linear soil model is incorporated into finite difference FLAC software, and interface elements are used between the near-field soil and basement walls. For the modeled structure, a parametric study was performed to demonstrate the effect of the soil parameters on the response of the structure. The results show significant changes in the seismic response of the structure (e.g., drift, settlement and developing pressure around the basement walls) when the non-linear soil-structure interaction is considered.

Paper No. 3.51, SEISMIC SITE CHARACTERIZATION OF DELHI REGION USING MICROTREMOR METHOD: A CASE STUDY, by Satyam and Rao: This paper describes an application of the H/V microtremor method for dynamic site characterization of the sedimentary basins in Delhi NCR at 144 different stations. Field measurements were taken using velocity sensors for a period of 1 hr at each station point. The data were analyzed using VIEW 2002 software for the estimation of the fundamental resonance frequency. The results of the all 144 stations were divided into four categories (T1 throughT4) based on the shape of the H/V spectra, resonance frequency, and soil type. Since the detailed (bore hole data) soil profile at all these locations is available, the resonance frequency is compared with sedimentary thickness. It is observed that the resonance frequency is high at stiffer ridge areas and very low in places with low velocity soils with significant sedimentary thickness.

Paper No. 3.52, SOME EXPERIMENTAL INVESTIGATIONS FOR THE DEVELOPMENT OF INTEGRATED MODEL OF A STRUCTURE WITH THE CONTROLLABLE FLUID DAMPER, by Babu and Arunvivek: This paper describes the development of an integrated model of a structure with a controllable fluid damper. The damper is used to reducing the dynamic wave propagation potential within the structure. Before its employability, system identification and model validation are pre-requisites for the optimal functioning of the fluid damper. A model of the controllable fluid-magneto-rheological damper is used with smart materials in controlled experiments. The experimental results are used to verify the integrated system model. The experimental results indicate that wave amplitude potential can be significantly reduced using the controllable fluid damper to meet the requirements associated with seismic response reduction in civil engineering structures.

Paper No. 3.53, SEISMIC SOURCE AND ITS EFFECT ON SITE RESPONSE OBSERVED IN CHILEAN SUBDUCTIVE ENVIRONMENT Verdugo and Pastén: This paper describes an investigation of the influence the seismic source on the frequency content of seismic motions at the ground surface. In this context, Chilean subduction zone setting provides a variety of seismogenic sources that allow for the study of this factor. The analysis of spectrograms of recorded earthquakes of different seismogenic sources at sites with differing near surface site conditions is presented. In the case of shallow thrust earthquakes a predominant frequency can be observed, that agrees with the predominant frequency obtained by the H/V spectral ratio measurement (e.g., Nakamura´s procedure). For shallow thrust events the applicability of the H/V spectral ratio to estimate the predominant frequency of a site is good, and indicates that soil deposits are excited at modes associated with vertical shear wave propagation. On the other hand, the spectrograms for intraplate earthquakes show predominant frequencies covering a wide range, which often different and higher than the predominant frequency obtained by H/V spectral ratios.

Paper No. 3.54, RECENT DAMAGING EARTHQUAKES IN JAPAN, 2003-2008, by Robert Kayen: During the past six years Japan has been struck by three significant and damaging earthquakes: The most recent M6.6 Niigata Chuetsu Oki (offshore) earthquake of July 16, 2007 off the coast of Kashiwazaki City, Japan; The M6.6 Niigata Chuetsu earthquake of October 23, 2004, located in Niigata Prefecture in the central Uonuma Hills; and the M8.0 Tokachi Oki (offshore) Earthquake of September 26, 2003 effecting southeastern Hokkaido Prefecture. These earthquakes stand out among a many in a very active period of seismicity in Japan. In the upper 100 km of the crust during this period, Japan experienced 472 earthquakes of magnitude 6 or greater. During the Niigata Chuetsu Oki event of 2007, damage to the Kashiwazaki-Kariwa nuclear power plant, structures, infrastructure, and ground were primarily the product of two factors: (1) high intensity motions from this moderate-sized shallow event, and (2) soft, poor performing, or liquefiable soils in the coastal region of southwestern Niigata Prefecture. Structural and geotechnical damage along the slopes of dunes was ubiquitous in the Kashiwazaki-Kariwa region. The 2004 Niigata Chuetsu Earthquake was the most significant to affect Japan since the 1995 Kobe earthquake. Forty people were killed, almost 3,000 were injured, and many hundreds of landslides destroyed entire upland villages. Landslides were of all types; some dammed streams, temporarily creating lakes threatening to overtop their new embankments and cause flash floods and mudslides. The 2003 Tokachi-Oki earthquake was the third event of magnitude 8.0+ to strike the southeastern portion of Hokkaido in the last 50 years. The event produced tsunami run-ups along the shoreline of southern Hokkaido that reached maximum heights of 4 meters. Despite high acceleration levels, the observed ground failure, liquefaction, structural, port, and lifeline damages were remarkably light.

Paper No. 3.55, GOOGLE EARTH MAPPING OF DAMAGE FROM THE NIIGATA-KEN-CHUETSU M6.6 EARTHQUAKE OF 16 JULY 2007, by Kayen, Steele, Collins, and Walker: The use of Google Earth significantly advanced the capabilities of the recent post-disaster investigation of the Niigata Chuetsu Oki earthquake, as compared with previous mapping software typically used by disaster reconnaissance team members. The easy data merging and sharing capabilities of Google Earth translated into a more thorough scientific investigation in addition to significant cost reductions of the field effort by (1) more efficiently guiding the reconnaissance in the field; (2) identifying redundant data sets gathered by different teams; (3) allowing researchers outside of the investigation area to see the data and imagery in a spatial context so that they could virtually participate in the study; and (4) expanding the free data set available to researchers in paperless format who download a .kml with links to larger data sets (imagery, animations, data tables) on servers. Additionally, there were likely some gains in safety. By creating a format that allows researchers to virtually visit the damage area, fewer investigators are exposed to disaster area hazards (e.g. strong aftershocks, further collapse of structures, post-disaster related-diseases associated with decay, and loss of clean water and sanitation services). Google Earth will also enable links between experts and students within a scientific community of practice, in which students can participate in and learn expert practices, and experts learn from technical experiments carried out by students. To view the report and Google Earth map file of the earthquake investigation discussed in this paper, go to. http://pubs.usgs.gov/of/2007/1365/
As well as: http://walrus.wr.usgs.gov/infobank/n/nii07jp/html/n-ii-07-jp.sites.kmz

FINAL REMARKS AND TOPICS FOR DISCUSSION

The papers presented in this session cover a wide range of important topics in the area of Geotechnical earthquake engineering. Including the year is of damn safety geoengineering earth-quake reconnaissance; earthquake induced landslides; investigations of earthquake faults; lifeline fragility; liquefaction up soil; site amplification; structural design; and theoretical and laboratory studies of soil behavior and models. The papers indicate a high level of technical expertise among the international geo-engineering community. Some investigations originating in less developed countries, where resources are sometimes limited, demonstrate the highly creative and resourceful nature of our engineering colleagues. Several papers described initial/incomplete stages of ongoing case histories that will result in very useful data, which should then be disseminated. The purpose of the discussion topics below, is to establish a communication venue between the authors and the delegates of this Conference to foster what we expect to be a lively and vigorous dialogue.

SUGGESTED LIST OF SESSION 3 DISCUSSION TOPICS

1) Damage to tanks, tears, files, and ports.
2) Advances in dam safety and dam design.
3) Geotechnical earthquake engineering damage.
4) Earthquake induced landslides.
5) Surface characteristics of fault rupture.
6) Lifeline fragility in poor performing soils.
7) Damage associated with Liquefaction.
8) Amplification of ground motions in soil during earthquakes.
9) Constitutive and numerical modelling of soil behavior.

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