International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

29 May 2010, 8:05 am - 8:25 am

General Report — Session 3

Dimitrios Zekkos
University of Michigan, Ann Arbor, MI

Adimoolam Boominathan
Indian Institute of Technology, India

Adda Athanasopoulos-Zekkos
University of Michigan, Ann Arbor, MI

Recommended Citation

Zekkos, Dimitrios; Boominathan, Adimoolam; and Athanasopoulos-Zekkos, Adda, "General Report — Session 3" (2010). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 3.
https://scholarsmine.mst.edu/icrageesd/05icrageesd/session00c/3

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

ENGINEERING SEISMOLOGY, GROUND MOTIONS, & LOCAL SITE EFFECTS GENERAL REPORT ON SESSION 3

Dimitrios Zekkos
Assistant Professor
University of Michigan
Ann Arbor, Michigan, USA, 48109

Adimoolam Boominathan
Professor
Indian Institute of Technology Madras
Chennai 600 036,INDIA

Adda Athanasopoulos-Zekkos
Assistant Professor
University of Michigan
Ann Arbor, Michigan, USA, 48109

INTRODUCTION

This General Report summarizes the papers submitted to Session 3a titled "*Engineering Seismology: Near Fault and Directivity Effects, Geologic Indicators of Rupture Direction, Geometric Effects on Ground Motions, Motion Parameters for Design, Borehole Arrays, Interpretation of Field Array Data, Site Amplification*" (18 papers) and Session 3b titled "*Local Site Effects: One Dimensional Wave Propagation Predictions and Measurements, Nonlinear versus Equivalent Linear Analysis, Effective Stress versus Total Stress Analysis*" (16 papers). A total of 34 papers from 13 countries were submitted to these two sessions. Table 1 shows the number of papers submitted from each country. Overall 15 papers were submitted from Asia, 10 papers from North America, and 9 papers from Europe.

Table 1: Geographic distribution of the authorship of the papers included in session 3.

Country	# of papers
United States of America	9
India	5
France	4
Iran	4
Greece	2
Korea	2
Italy	2
Japan	1
China	1
Canada	1
Turkey	1
Bulgaria	1
Hong Kong	1

A summary of the papers is provided below and some topics of discussion are presented.

SUMMARY OF PAPERS

Paper #3.01a by Kolev and Perikliyska titled "Example for risk estimation of fault appearance under the place of designed skyscraper in Sofia" emphasizes the need for the geophysical and geological profiling for important projects in earthquake prone regions. The proposed skyscraper is situated on the hanging wall of a fault. The skyscraper is located in an urbanized region and the absence of information on the fault's historical seismicity complicated the investigation and the definitive characterization of the fault as "active". A total of four electrical resistivity tests were performed: three across and one along the fault. A high resistance anomaly was encountered in one profile in contrast to the low resistance of clayey and sandy sediments. The anomaly was not identified in the remaining profiles. Geological investigation lacked evidence for the occurrence of an active fault. The presence of soft soils and the potential for ground motion amplification during an earthquake was considered in the design of the pile foundation. The authors emphasize the need for geophysical and geotechnical investigation for important projects and for properly designed pile foundations to support heavy structures in highly seismic regions.

Paper #3.02a by Andisheh and Ghodrati Amiri titled "Evaluation of Iranian code No.2800 for seismic resistant design of near source buildings based on real record of Iran" reviews aspects of the Iranian seismic building code for design of buildings subjected to near-field earthquakes. Iran is one of the most seismically active areas in the world. The presence of many active faults in Iran, and the high historical seismicity suggests that the occurrence of severe earthquakes is likely in the future. Six near field earthquakes were selected and smoothed Newmark-Hall type elastic response spectra for these earthquakes were plotted along with UBC97 and the Iranian Code. The authors found that the Iranian seismic code under predicts the acceleration-sensitive region by almost two folds. The authors also observed that the Iranian code falls short in predicting the PGA, PGV and PGD of near-field earthquakes and recommends using the UBC97 code for design of structures near source.

Paper #3.04a by Bapat titled "Development of seismic safety during pre- and co-seismic periods" discusses the various precursors to an earthquake, which, according to the author, can be effectively used to prevent severe life loss. Precursors like abnormal human and animal behaviour, atmospheric changes and aviation effects were reported before the actual occurrence of an earthquake. The author feels that these factors, although only have partial scientific support, can be effectively used as an early warning system.

Paper #3.05a by Kaklamanos and Baise titled "Model validation of recent ground motion prediction relations for shallow crustal earthquakes in active tectonic regions" compares the prediction accuracy of the prediction models using several testing subsets of the master database used to develop the Next Generation Attenuation (NGA) models. A blind comparison of the new models with previous simpler models was also performed using ground motion records from the two most recent earthquakes of magnitude 6.0 or greater to strike mainland California (2004 Parkfield earthquake and 2003 San Simeon earthquake). The parameters used for developing the subsets are mainshock vs. aftershock, small, medium and large distance and soil vs. rock motions. The primary statistic that was used for comparing the models is the Nash-Sutcliffe model efficiency coefficient (E), a commonly used statistic in hydrology. Based on the results the authors recommend that model developers utilize aftershock dummy variables when they choose to include aftershocks in their regression sets, however their results don't suggest that aftershocks should be included in model development. The authors also argue that to improve the prediction accuracy of models there must be greater emphasis on site-specific data collection. Finally they state that increasing the complexity of prediction models does not necessarily increase their prediction accuracy, and can lead to over-fitting.

Paper #3.06a by Lenti and Martino titled "The levelled-energy multi-frequencial analysis for deriving dynamic equivalent signals (LEMA_DES): application for an earthquake scenario" presents the application of LEMA_DES in obtaining equivalent synthetic acceleration signals. This approach involves obtaining the dynamic equivalent signal by selecting and processing a limited number of representative harmonic functions from the reference acceleration spectrum. The proposed multi-frequencial dynamic equivalent signals take into account seismically-induced effects arising from frequency combinations from dynamic loading. The signals derived from the LEMA_DES were compared with 48 selected records and a sinusoidal signal. It was found that the LEMA_DES approach produces realistic results in terms of displacements, in comparison to other methods. The authors claim that the proposed approach is a reliable alternative to the currently adopted methodologies for deriving equivalent signals in the field of geotechnical engineering and engineering geology.

Paper #3.07a by Bakavoli and Haghshenas titled "Experimental and numerical study of topographic site effect on a hill near Tehran" compares results from an experimental study of the seismic response of a fill site near Tehran with results from a numerical analysis of the same site using a hybrid finite-boundary element code (HYBRID). The selected site is homogeneous and has no soft soil layers, therefore changes in the seismic motions are, according to the authors, attributed to primarily topographic effects. The field experiment was conducted by recording microtremors due to the ambient noise. The results from the two approaches have no similarities, and the authors suggest that this may be related to the existence of industrial noise near the site, the inability of the H/V technique to distinguish the fundamental frequency of the topographic irregularity and/or the difference between wave-fields in numerical analysis vs. microtremors. The authors conclude that microtremor methods are not an efficient way for estimating topographic effects and may not be applied for microzonation studies of elevated areas.

Paper #3.10a by Yamasaki, Vessely and Carpenter titled "Selection of ground motion records for two dam sites in Oregon" presents a case history of ground motion selection for proposed dynamic analyses of dams at two sites in western Oregon. The seismic sources were determined based on USGS's interactive deaggregation of the probabilistic seismic hazard for a return period of 2,475 years, and were characterized with respect to magnitude (M), distance (R) and standard deviation (ε). Acceleration response spectra were developed by combining and weighting several ground motion prediction equations. The ground motions were then selected from three databases: PEER, NGA and COSMOS. For Site A two seismic sources are identified as principal: the CSZ interface earthquakes and shallow gridded earthquakes, whereas for Site B the predominant seismic source contributor to the hazard are the shallow gridded earthquakes. Emphasis is given on the selection of the standard deviation for both sites and the authors based their selection on the recurrence interval of earthquakes representing the principal seismic sources, the return period used in the PSHA and the seismicity of the project site.

Paper #3.11a by Chin, DuRee, Trent and Ordonez titled "Evaluation of seismic response of a site class F site using equivalent linear and nonlinear computer codes" present the analyses performed for a site located in Aberdeen, Washington. A Uniform Hazard spectrum was used in design and the design PGA was equal to 0.6g. The site conditions, as evaluated by CPT testing consisted of fill placed over native alluvium. Fill materials encountered included sand and gravel, as well as dredged spoils consisting of silt and wood waste. The shear wave velocity of the site was about ~400-650 ft/sec even though it was as low as ~200 ft/sec where the wood waste was encountered. One-dimensional equivalent linear and nonlinear site response analyses were performed using 7 two-component ground motions as input. Ground motions were divided in two categories: Weak to moderate ground shaking and strong ground shaking. It is not entirely clear what weak to moderate and strong ground shaking means in this case. Comparisons between the equivalent-linear and the nonlinear analyses were performed using these 2 sets of ground motions. The response spectrum at the surface and the cyclic stress ratio profiles were compared. The authors observed that the equivalent linear and nonlinear approaches yielded similar results in terms of the surface acceleration response spectrum for weak to moderate ground motions, but for strong ground motions the equivalent linear approach resulted in lower intensity ground motion (on average). The nonlinear approach also yielded higher shear stresses than equivalent linear analyses.

Paper #3.12a by Zaicenco, Huffman and Weir-Jones titled "Seismic p-wave polarization in the context of on-site early warning system" discusses an efficient and reliable methodology for P-wave detection and discrimination for use in a proposed earthquake early warning system (EEWS) which includes two borehole strings and four triaxial sensors. The algorithm for detection and discrimination of P-wave is based on the polarization analysis of band-passed triaxial records obtained in real-time by geophone sensors installed in two boreholes. The methodology was tested using available data of blast records and strong-motion free field records. The authors recommend using the proposed methodology in determining the hypocentral location more accurately by including the azimuth and emersion angle of the seismic ray coupled with ray-tracing technique.

Paper #3.13a by Sarica titled "Selection of an appropriate a_{max} for liquefaction analyses from one-dimensional site response analyses" discusses the appropriate maximum ground acceleration (a_{max}) that should be used as part of the performance of a site-specific liquefaction analysis. Usually, one-dimensional free-field site response analysis is performed to estimate a_{max} at the foundation elevation and the strain-compatible soil parameters within the soil profile. According to the author, there is uncertainty on which of the above a_{max} should be used for liquefaction analysis. The author performed a small scale parametric study to show that the average a_{max} from the one-dimensional response analyses with best estimate soil profile is appropriate to use in simplified liquefaction analyses.

Paper#3.14a by Khodadadi Tirkolaei and Jiryaei Sharahi titled "Effect of topographical irregularities on seismic earthquake response of construction site – 2d numerical analysis of trapezoidal valley under real motion" discusses the effect of topographical irregularities on the response of a site to strong motion shaking. Although, some empirical correlations are available, according to the authors, they tend to overestimate the actual response. Hence, in the present study, the authors investigate the seismic response of various 2D topographical features using the PLAXIS finite element code. Numerical analyses of trapezoidal non-alluvium valleys was performed and was found that the response intensity increasingly varies from minimum amplification value at the toe to maximum amplification value at the crest of slope. The authors present a nondimensional graph in terms of shape ratio, dimensionless distance and ratio of bottom length to crest length to determine the amplification factor. The authors also state that the shape of the valley further influences the seismic response of slopes.

Paper #3.16a by Ancheta and Stewart titled "A validation study of a seismically induced ground strain model using strong motion array data" investigates whether the sensitivity of peak ground strains to the separation distance of observation points is also observed in array data. Data from the Lotung Large Scale Seismic Test (LSST) array located in Taiwan were used for the analysis. It was observed that ground strains scale both with the amplitude of ground shaking, but also with the distance between measurements. The authors also concluded that the distance dependence is similar to that previously identified by the Ancheta et al. (2008) semi-empirical procedure and that there is significant variability in strains both within a given event and from one event to another.

Paper #3.18a by Abrahamson and Yunatci titled "Ground motion occurrence rates for scenario spectra" presents a new approach for producing scenario spectra by expanding on the concept of the conditional mean spectrum (CMS) to develop a set of realistic spectra and provide a method for estimating the rates of each scenario that are compatible with the original hazard curves. The paper includes a step by step procedure for applying this new approach together with a sample problem. The authors conclude that this new approach can be used in seismic risk calculations of structural performance, but recommend that it should be evaluated for a wide variety of cases to determine its robustness.

Paper #3.19a by Athanasopoulos-Zekkos titled "Variability in earthen levee seismic response due to time history selection" presents 2-D equivalent linear analyses of 3 different levee configurations. A total of 1000 ground motions were considered in an effort to account for ground motion variability, which has been shown to be the single most important input parameter in the performance of seismic slope stability analyses (Bray 2007). The author studied the variability in the calculated Cyclic Shear Stress Ratio (CSR) as well as the Newmark-type permanent displacements calculated for specific critical failure surfaces and for varying yield coefficients. The effect of key ground motion parameters on the seismic response of earthen levees was studied. The results suggest that the CSR is strongly correlated with the mean period of the ground motion and that the Peak Ground Velocity of the input ground motion is better correlated to the Newmark-type displacements. These lessons can be used to formulate time history selection criteria for the seismic response of levees.

Paper #3.20a by Kwak, Park, Shin and Kim titled "Uniform hazard spectra of Korea considering uncertainties in ground properties" presents a new method for resolving the incompatibility of using deterministic site coefficients with ground motion parameters determined by probabilistic seismic hazard analysis (PSHA). The authors used the PSHA-NL software, a PSHA with non-linear seismic site effects program originally developed by Park and Hashash (2005), which integrates the traditional PSHA and seismic site effect characterization function to develop uniform hazard response spectra (UHRS) for Korea. To develop "truly" probabilistic UHRS, the uncertainties and randomness of the ground properties were accounted for by using extensive databases of measured shear wave velocity profiles, stratigraphies and dynamic curves for site classes considered in this study. The calculated UHRS were compared to the design spectra, and the comparisons indicated that the design spectra presented in the current design guidelines that are NEHRP-based are not suitable for soil profiles in Korea. Specifically, the response spectra of site classes S_C and S_D highly underestimates the seismic hazard, while it is overestimated for S_E.

Paper #3.22a by Tobita, Iai and Iwata titled "Numerical analysis of trampoline effect in extreme ground motion" presents the formulation, mechanism and results of finite element analyses performed to investigate the "trampoline effect". The term was coined by Aoi et al. (2008) to describe the situation where the recorded vertical acceleration is significantly higher than the acceleration of gravity or the acceleration of the horizontal components of the ground motion. The authors describe the formulation and then develop a model to simulate the effect of site conditions in the case of the 2008 Iwate-Miyagi Inland in Japan where a station in Iwate Prefecture located just 3 km from the epicentre recorded a clearly asymmetric vertical acceleration time history that its peak was nearly four times the gravitational acceleration. Luckily, the station was equipped with a vertical array site (as deep as 260 m), allowing the validation of such analyses. Through finite element analyses, it was confirmed that large input vertical ground motions recorded at depth, resulted in amplified vertical ground motions at the surface and tension in the vertical direction for a significant duration of time. In the analyses, to satisfy continuity, a zero stress is assumed when the element was under tensile volumetric strain.

Paper #3.24a by Sun, Tao, Yin and Zhang titled "3-D modelling of shear-wave velocity for numerical Green's function in near-field ground motion simulation" describes a procedure for the development of a 3D shear wave velocity model. The Lanzhou basin in China is used as an example and the model is 53.2 km long by 32 km wide. The model was developed on the basis of 383 boreholes. The model also included the Maxianshan Northern fault at depth. At that scale, the vertical variability in shear wave velocity is comparable to the horizontal (or lateral) variability. Simulations resulted in analytically developed surface ground motions at 7 selected locations of the model.

Paper #3.26a by Papadimitriou and Chaloulos titled "Aggravation of the peak seismic acceleration in the vicinity of 2D hills, canyons and slopes" presents the results from studies on the topographic aggravation of the peak seismic acceleration in the horizontal and vertical directions for various cases of 2D uniform surface geometries (e.g. hills, canyons, and slopes). The study is based on a large number of 2D wave propagation analyses of uniform soil conditions performed with the finite-difference method. The analyses show that the crests of canyons suffer from increased parasitic vertical accelerations as compared to the respective slopes (with the same slope inclination and height to predominant shear wavelength ratio), while the aggravation of the horizontal acceleration is similar. For the cases of hills, the analyses show that the width B of the hill top, is a crucial parameter, since small values of B lead to very large aggravations of the peak horizontal acceleration at the hill crest as compared to the respective slopes.

Paper #3.01b by Zheng, Hashash, Petersen and Whittaker titled "Site-specific response analysis in the New Madrid seismic zone" presents a site-specific study for a coal-fired power plant in Arkansas. A probabilistic seismic hazard assessment was performed to determine the Maximum Considered Earthquake (MCE) spectrum at an equivalent rock outcrop and one-dimensional site response analyses using SHAKE, SUMDES and DEEPSOIL were performed to determine the ground surface response. The soil profile consists of 880 meters of unconsolidated sediments that lie above the Paleozoic bedrock. The 9 earthquake histories used for the site response were spectrally matched to the MCE for hard rock spectrum using EZ-FRISK 7.14 RSPMATCH. The results show great non-linearity (strains greater than 1%) in the upper 60 meters of soil, thus the equivalent-linear method may not capture the soil behavior efficiently. A comparison between DEEPSOIL and SUMDES indicated that DEEPSOIL is more appropriate for the analysis because of the more accurate response analysis at the shorter period due to the use of the full Rayleigh damping scheme. The site-specific analysis also showed that the spectrum ordinates for periods less than 1.3 seconds are less than those of 0.8 times the Site Class E spectrum. Finally, the authors conclude that the ASCE-7-05 site coefficients may not be appropriate because of the large thickness of the soil sediments.

Paper #3.02b by Hosseini, Pajouh and Hosseini titled "The limitations of equivalent linear site response analysis considering soil nonlinearity properties" reviews the fundamentals of equivalent linear analyses and fully nonlinear analyses and subsequently presents equivalent linear and nonlinear analyses at four different sites using 3 ground motions scaled at a PGA of 0.1g. The authors concluded that the equivalent linear analyses overestimated the site amplification.

Paper #3.03b by Iglesia and Stiady titled "Seismic site response analysis using spreadsheets" presents a spreadsheet-based framework called 1DRISS and implemented in

Microsoft Excel 2003/2007 for quantifying local site response due to seismic excitation. The authors argue that performing site response analysis using spreadsheet has certain benefits such as providing a cost-effective means for validating the output results from other ground response analysis programs, enabling the user to readily plot results using charting capabilities typically integrated with the spreadsheet software and allowing the analyst to better understand the underlying concepts involved in seismic site response analysis. The developed spreadsheet methodology uses the frequency domain approach implemented in the 1-dimensional, equivalent-linear site response program SHAKE. The authors compare results from analysis using both SHAKE91 and 1DRISS for strain computations, strain-compatible shear modulus, strain-compatible damping ratio, surface accelerations and response spectra and conclude that there is sufficient agreement to justify use in academic and practical applications.

Paper #3.05b by Tsang, Sheikh, Venkatesan and Lam titled "Displacement design spectrum model accounting for non-linear site effects" discusses the displacement design response spectrum as an essential component for developing displacement-based seismic design and assessment procedures. A simple model for predicting site effects is proposed considering the soil resonance behaviour. The method takes into account modifications of the seismic waves by the soil layers, considering factors such as the level of bedrock shaking, material non-linearity, seismic impedance contrast at the interface between soil and bedrock, as well as the plasticity of the soil layers. A new and simple method for developing displacement design response spectra on soft soil sites is proposed.

Paper #3.07b by Jeong, Kwak, Park, and Kim titled "Evaluation of frequency dependent equivalent linear analysis" presents analyses for 2 cases, the Turkey flat site in California and the Lotung site in Taiwan. Analyses performed included 1-D equivalent linear and 1-D nonlinear analyses, as well as frequency dependent equivalent linear analyses (FDEL). The authors discuss the importance of FDEL analyses and the need to recognize that both shear modulus and material damping are dependent on the loading frequency. To achieve that, values of shear modulus and damping that are representative of the maximum shear strain are used and these values are then corrected using the smoothed shear strain Fourier spectrum concept.. The authors used the Yoshida et al. (2002) formulation and the Kausel and Assimaki (2002) formulation for the smoother shear strain function, as well as additional functions also based on the Yoshida et al. (2002) formulation but with different input parameters. Both ground motion components were investigated for one earthquake at each site and the results were compared to the recorded ground motions at the surface. The authors, on the basis of their analyses, concluded that the FDEL approach does not always improve the prediction and one formulation is not systematically more advantageous to another. The authors also noted that the rate of decay of the shear strain amplitude with frequency had the most impact on the calculated response.

Paper #3.08b by Kumar and Boominathan titled "Site specific seismic analysis of a deep stiff soil site" evaluates the seismic response of a deep stiff soil site near Ahmedabad, Gujarat. Seismic hazard analysis was performed employing a deterministic approach and considering the historic seismicity and seismotectonics within 250 km radius from the site. The site is characterized by predominantly stiff soil layers with unusually high shear wave velocities of 600 to 1200 m/s without occurrence of rock even at 60 m depth. The normalized response spectra for deep stiff soil site obtained from ground response analysis by equivalent linear method were compared with several contemporary codes. It was found that the seismic design codes tend to under predict the spectral acceleration by about 30% at mid period range. The authors conclude that the deep stiff soil sites do amplify the ground motion and are capable of producing sustained higher levels of shaking, which emphasizes the need for performing site specific seismic analysis for deep stiff soil sites also.

Paper #3.09b by Bonilla, Bozzano, Gelis, Giacomi, Lenti, Martino, and Semblat titled "Multidisciplinary study of seismic wave amplification in the historical center of Rome, Italy" presents an investigation of the seismic amplification using 1D equivalent-linear and 2D equivalent-linear and nonlinear site response analyses. The numerical model was derived from a 3-D engineering geology model of the Tiber river alluvium valley that essentially suggested significant spatial variability of the deposits in both vertical and lateral directions and identified 6 distinct soil units with a thickness of about 60 m overlying the ancient Pliocene high plasticity clays that reportedly have a thickness of 5-10 m. No information is provided for the units below that layer, but based on the description it is likely that the valley is deeper than that. The 6 distinct soil units varied from gravels to soft clays, had shear wave velocities that ranged from 210 m/s to 1000 m/s and in many cases significant impedance contrasts. The dynamic properties of soils were derived on the basis of laboratory and in-situ testing. The model was 90 m deep and almost 4 km in length. One synthetic rock outcrop ground motion was used in the analyses with a PGA of 0.06g. The accelerogram was scaled by a factor of 0.5 to simplistically account for ground motion outcropping. On the basis of these ground motions, the authors observed that 1D analyses result in higher ground motion intensities than 2D analyses at all frequencies. Both 1D and 2D analyses had similar site resonance frequencies, even though 2D analyses suggested some lateral variation of the resonance frequency. The authors discussed that this may be attributed to laterally propagating waves or other refracted waves along the sides of the soil units. The authors also commented that a softer layer was also identified to play a critical role in the response of the valley. The authors commented that a 3D model of the Rome basin may allow to better study the effects of lateral variability as well as other basin effects, and their impact on analyses.

Paper #3.12b by d'Avila, Gandomzadeh, Lenti, Semblat, Bonilla and Martino titled "Nonlinear site effects: Interest of one directional – three component (1D-3C) formulation" presents a finite element model to analyze the one-dimensional seismic wave propagation accounting for the 3-dimensional nonlinear behaviour of a soil. An example of analyses for one ground motion with a PGA of 0.3g is presented for a site in Rome. These preliminary results suggest that the octahedral shear stress and shear strain profiles are similar for the three component formulation when compared to the conventional one-dimensional formulation. The results also suggest similar results for the amplification ratios.

Paper #3.15b by Kockar and Akgun titled "Evaluation of local site conditions using ambient seismic noise recordings: a case study from Ankara, Turkey" presents an investigation at 352 site locations in the Ankara basin in order to characterize the site conditions for seismic purposes. The investigation involved the collection of microtremor measurements at the ground surface using a 3-component accelerometer. Measurements involved the collection of 300 sec recordings at a sampling frequency of 100 Hz. The authors report that competent rock sites or stiff pleio-pleistocene sediments appear to have a relatively flat response curve, while alluvial soft soil sites generally exhibited a peak maximum amplitude at their fundamental period, allowing the identification of different site classes. The authors used the spectral ratio of the horizontal to vertical component (HVSR) as well as the spectral ratio relative to a firm site reference station (SSR) in order to estimate the fundamental periods and the amplification factors of the site. The authors discussed the advantages as well as the limitations of the procedure. The results were correlated to existing geologic and geotechnical data and seismic hazard maps were developed. On the basis of the comparisons, the authors suggested that, despite its limitations, the HVSR spectral ratio can be used to determine the fundamental frequency of a site. It was found that the main factors that affected the site response were the age of the deposits, the thickness of the deposits and soil non-linearity.

Paper#3.18b by Uma Maheshwari, Boominathan and Dodagoudar titled "Effective stress v/s total stress ground response analyses for a typical site in Chennai (India)" presents the ground response of a sandy soil site by equivalent linear and nonlinear total and effective stress approaches. The shear wave velocity of the soil obtained from a Multichannel Analysis of Surface Wave (MASW) test carried out at the site varies from 170 m/s to 400 m/s for a depth of 26 m. Seismic response analysis was carried for the sandy soil deposit with an input bedrock motion having a PGA of 0.16g by three methods: equivalent linear, nonlinear total stress and nonlinear effective stress analysis using SHAKE 2000 and D-MOD2000. The authors observed that all the methods yield practically the same ground surface PGA and peak spectral acceleration due to the low intensity of input motion and relatively higher shear wave velocity of the sandy strata. It was also observed that the maximum pore pressure occurs at the depth of maximum acceleration.

Paper #3.19b by Giulio di Prisco and Pisano titled "1D dynamic non-linear numerical analysis of earth slopes: the role of soil ductility and time-sensitiveness" presents the 1D finite element code that has been developed and employed to simulate the shear wave propagation within an infinitely long slope, caused by a prescribed ground motion of the underlying bedrock. The soil behavior is modelled using a 1D constitutive model that employs an elasto-viscoplastic model with a hardening and a softening rule to address the dynamic response of both ductile and brittle systems. The authors draw several conclusions from the numerical analyses results: (1) the slope deformation depends on the ratio of the maximum propagating wavelength to the stratum height, (2) the introduction of soil viscosity has an important quantitative effect, (3) when a purely hardening soil behavior is assumed the possibility of a shear band generation is prevented, whereas when a purely brittle/softening behavior is taken into account, strain localization can occur, and in this latter case it seems difficult to substitute the analysis with simplified approaches such as the rigid-block model. The authors also consider a practical application using a real seismic input ground motion.

Paper #3.20b by Badaoui, Berrah, and Mebarki titled "Layer heights randomness effect on seismic response of a site in Algiers (Algeria)" studies the impact of uncertainty in soil layering. The investigation was performed by varying the thickness of the soil layers above the elastic halfspace for a site in Algeria and evaluating the impact of this variation on the ground acceleration, response spectrum and transfer function. Monte-Carlo simulations were performed, but one only ground motion was used as input. The impact of soil layer variability was found to be only slight on the peak ground acceleration. Some variation was observed in the amplification factors and the transfer functions particularly at the resonant frequencies.

Paper#3.21b by Anbazhagan, Abhishek and Sitharam titled "Site response study of deep soil column in Lucknow, India" estimates the site effects of deep soil column in the Indo-Gangetic basin for scenario earthquakes at Himalayan plate boundary. A synthetic ground motion generated using a Stochastic Finite Fault model (FINSIM) for two scenario earthquakes at seismic gaps yields a peak ground acceleration of 0.11g and 0.218g at site. The site consists of silty sand and silty clays with SPT N value of 100 at a depth of 30 m and these values were extrapolated to 100 m depth assuming a linear increase in the N-value. The site response analysis was carried out using SHAKE 2000 and DEEPSOIL programs, with input accelerations assigned at different depths. This study showed that the ground motions are amplified for input accelerations applied up to a depth of 80 m indicating a deficiency in the current practice of performing ground response analysis for a 30 m soil profile or simply based on the available depth of information.

Paper #3.22b by Ferraro, Grasso and Maugeri titled "Topographic site effects evaluation for the Monte Po Hill in the City of Catania (Italy)" present 1-D and 2-D equivalent linear site response analyses that were performed to evaluate the seismic stability of an unstable slope (Monte Po Hill). The site conditions consisted of relatively stiff soils to rock with shear wave velocities ranging from about 150 m/sec to as high as 800 m/sec. Shear wave velocities were measured using the downhole method as well as the Marchetti seismic dilatometer. The motivation for this evaluation was the presence of a school on the slope. Two synthetic ground motions, each representative of different earthquake sources, were used in the analyses and the amplification from the site conditions and due to topography were calculated. It was observed that the amplification was dominated by topography near the crest of the slope, but was dominated by site conditions near the toe of the slope.

Paper #3.24b by Ktenidou, Raptakis and Pitilakis titled "Weak motion linear soil amplification at Aegion, Greece, and comparison with seismic design codes" presents a comparison between recorded Peak Ground Acceleration (PGA) site amplification factors for two locations (DIM and CORSA) at a site in Aegion and suggests PGA amplification factors according to design codes such as EC8 and FEMA450. The authors found that the code provisions appear to give a lower boundary prediction rather than an average prediction of site amplification. The effect of surface and subsurface topographic features is also investigated by comparing results from 2D dynamic analysis and no great effect is found for the horizontal component of the PGA. Finally, the results are compared in terms of acceleration response spectra. Spectral shapes do not infer strong site effects at DIM, but they do for CORSSA, where they indicate strong surface waves due to 2D effects, particularly noticeable around the site's fundamental period.

Paper#3.25b by Govindaraju, Madhusudhan and Quadri titled "A study on the seismic response of ground and reinforced concrete buildings in Belgaum region, India" focuses on the seismic response of the ground and reinforced concrete buildings in Belgaum region (located in zone III, as per IS 1893–Part1: 2002) in India. A wavelet-based spectrum compatibility approach was used to generate synthetic earthquake motions for the region as no strong motion records are available in this region. The effect of soil deposits on the propagation of seismic motion to the ground surface was investigated based on an equivalent linear approach. Subsequently, frequency response analysis of buildings with various configurations was carried out using three dimensional numerical modelling and the software ETABS and it was found that the building configuration can influence the resonance region.

DISCUSSION

The papers submitted in this session indicate that interesting developments in engineering seismology, ground motions and site response analyses are taking place in many places in the world.

With respect to site response analyses, it appears that, worldwide, similar software tools are used to perform equivalent linear analyses (e.g. SHAKE, DEEPSOIL, QUAD4M), and nonlinear analyses (e.g. DEEPSOIL, DMOD). These tools are used not only in research, but also in seismic geotechnical practice. However, there are many more, recent, less established software tools that are used by researchers to perform analyses.

In reviewing the papers, there are some interesting observations that can be made. The reporters, in an effort to facilitate the discussion of this session, would like to document some of these observations and pose some questions.

There is an increased tendency to use 2D and even 3D site response analyses tools. These software tools are not necessarily well calibrated, are typically more elaborate, require significant effort to develop the model and are computationally intensive. There are questions that arise regarding the use of these models in seismic geotechnical practice and research:

- Are site investigations and site characterization approaches adequate to provide the data necessary to develop 2D or even 3D representations of the subsurface? How reasonable is it to use 2D and 3D representations when no soil-specific testing has been performed.
- If simplifications or assumptions need to be made to develop such a 3D model, what is the impact of these assumptions to the results?
- Given the well known importance of the input ground motions to the results of the analyses, are advanced three dimensional numerical models currently justified, particularly when, due to the challenges and needed resources associated with running these models, one or two ground motions only are used? Is using an elaborate three dimensional model and only limited ground motions a justified/recommended approach? The reporters would suggest it is not, and that an equal level of effort at all stages of the work (site investigation, field and laboratory testing, model development, analyses) would be needed. Given the large number of publications with very limited ground motions, that may not be a universally agreed upon opinion.

For high intensity seismic scenarios, nonlinear models are used and equivalent linear models are typically discouraged. In many cases however, only a small number of ground motions (one, three or seven) are used as input to the nonlinear analyses. Is that approach recommended? Information in the literature suggests that using a very limited number of ground motions is unjustified to capture either the mean or the variability in the site response.

REFERENCES

Ancheta, T.D., J.P. Stewart, N.A. Abrahamson, and R.L. Nigbor, [2008]. "Preliminary estimation of seismically induced ground strains from spatially variable ground motions," in *Geotechnical Engineering and Soil Dynamics IV,*, May 18-22, 2008, Sacramento, CA, ASCE Geotechnical Special Publication No. 181, D. Zeng, M.T. Manzari, and D.R. Hiltunen (eds.), 10 pages (electronic file).

Aoi, S., T. Kunugi, and H. Fujiwara [2008]. "Trampoline effect in extreme ground motion", *Science* 322, 727–730.

Bray, J. D. (2007). "Simplified seismic slope displacement procedures", Theme paper – Seismic Slope Stability, 4th International Conference on Earthquake Geotechnical Engineering, Thessaloniki, Greece, June 25-28, 2007.

Kausel, E. and Assimaki, D. [2002] Seismic simulation of inelastic soils via frequency-dependent moduli and damping. *Journal of Engineering Mechanics,* 128**,** 34-47.

Park, D. and Hashash, Y. M. A. [2005]. "Evaluation of seismic site factors in the Mississippi Embayment. II. Probabilistic seismic hazard analysis with nonlinear site effects", Soil Dynamics and Earthquake Engineering. No. 25**,** pp. 145-156.

Yoshida, N., Kobayashi, S., Suetomi, I. and Miura, K. [2002] Equivalent linear method considering frequency dependent characteristics of stiffness and damping. *Soil Dynamics and Earthquake Engineering,* 22**,** 205-222.