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General Report — Session 3: Engineering Seismology and Local Site Effects

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SESSION 3 – ENGINEERING SEISMOLOGY AND LOCAL SITE EFFECTS

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Classification of Papers

The twenty-six papers were submitted to this session, which can be classified under the following topics:

Estimation of Site Characteristics/Case Studies	9
Ground Motion Prediction	3
Spectral Analysis	2
Non-linear Dynamic Response Analysis	6
Estimation of Dynamic Soil Properties From Seismic Records	3
Fault Propagation	1
Occurrence of Liquefaction on Seismic Behavior	2

INTRODUCTION

The 26 papers of this session may be divided (somewhat artificially, of course) into 7 main subgroups as shown above: a significant number of papers (9) deal with estimation of site characteristics or case studies. These papers range from reporting on non-linear effects observed during specific earthquakes to probabilistic microzonation of sites. The second group of papers has been placed in a category entitled ground motion prediction. This group of papers (2) focuses on topics ranging from evaluation of a site using combination of source scaling models and ground motion records to looking at uncertainties and residuals. A small third group of papers (2) deal with spectral analysis including energy spectra. A fourth group of papers (6) deal with addressing the issues surrounding non-linear dynamic response analysis. These papers deal with approaches ranging from dealing with behavior of deep deposits of sediments to cyclic degradation due to pore water. These analyses are handled using approaches in both frequency, and time domains. A fifth group of papers (3) deal with the estimation of dynamic soil properties by back calculating from seismic records. These approaches range from using a parameter identification method to a "Complex Envelope". A sixth subgroup of papers is very small (1) but discusses the important topic of fault propagation. The seventh and final subgroup of (2) papers looks into the effect of liquefaction on seismic behavior.

These 26 papers are briefly summarized, and their conclusions discussed, in the following seven sections. An eighth section, as a conclusion, attempts to list the main outcomes and issues raised by this series of papers.

ESTIMATION OF SITE CHARACTERISTICS/CASE STUDIES

Paper 3.36 (P. Dimitriu, A. Anastasiadia, N Theodulidis, and N. Klimis) Nonlinear Site Response During the 7 September 1999 Athens, Greece, Earthquake (Mw 5.9)

In this paper the authors demonstrate that a site in Athens exhibited a non-linear response due to degradation of shear modulus during the 1999 earthquake. The approach taken was to take one recording and divide it up into a series of overlapping time windows. Horizontal to vertical spectral ratios (HSVR) of acceleration were calculated for subsequent overlapping windows. In addition for each horizontal component, the mean horizontal ground acceleration (MGA) was calculated in each window. The resulting HVSR's were grouped for MGA> 10.1 cm/s/s into weak earthquakes and MGA > 20.5 cm/s/s in strong earthquakes. The two curves were shown to be visually distinct with the strong motion curve shifted toward lower frequencies relative to the weak motion one. The analysis revealed a statistically significant dependence between the site resonance frequencies and the window mean horizontal acceleration. A simple calculation was shown to yield a realistic value for the relative reduction in shear modulus form weak to strong motion.

Paper 3.23 (Ronald C. Chaney, David N. Lindberg, Jim Cooksley Jr., Frank Bickner, Gary Manhart, and David Gervan) Compress ional and Shear Wave Tests Through Upper Sheet of Low Angle Thrust Fault

Results from compress ional and shear wave tests conducted on the upper thrust sheet of the low angle Little Salmon thrust fault by Eureka, California are presented. The Little Salmon fault zone is a low angle thrust fault that daylights on the south side of the College of the Redwoods and then projects underneath striking northwest and dipping northeast. A boring was drilled down to the fault plane located at a depth of 200 ft. in the upper thrust block to develop a model of the stratification as well as the material properties. The boring revealed the trunk of a redwood tree located at a depth of 180 feet. Compress ional and shear wave velocities as a function of depth were determined using a downhole geophysical technique. Results indicated two shear wave velocity units. The upper unit from 0 to 120 ft exhibited a shear wave velocity ranging from 950 to 1400 fps. The second unit ranged from a depth of 120 to 190 ft. with a shear wave velocity ranging from 2300 to 2600 fps. Compression wave velocity measurements also depict a change in velocity in the 100 to 120 foot range. Response spectra were generated using both results from SHAKE91 runs and the Boore, Joyner and Fumal empirical model. Results indicated that based on a limited study SHAKE91 estimated response spectra that were greater than the Boore et al. Model for frequencies less than 0.4 Hz. For frequencies greater than 0.4 Hz Boore et al predicts a response spectra greater than that from SHAKE91.

Paper 3.25 (C. Cramer, R. Williams and K. Tucker) A Seismic Site –Amplification Map for Memphis, Shelby County, Tennessee from Geophysical, Geotechnical, and Geological Measurements

The paper describes the approach that is being used in developing a seismic site amplification map for Memphis, Shelby County, Tennessee. The authors describe some of the work that has been initiated for collecting database concerning geophysical, geological and geotechnical conditions of the object area. The paper seems a bit incomplete without the results of the proposed investigations, but the authors have indicated that the results would be available at the time of the conference and that there will be a presentation on this project.

Paper 3.06 (Franco Pettenati and Livio Sirovich) New-Generation Objective and Reproducible Isoseismals, and Tests of Source Inversion of the USGS "Felt Reports"

The authors present a technique for treating earthquake intensity data objectively and reproducibly. This is accomplished by using a program ConVor to draw n-n natural-neighbor isoseismals. The program ConVor uses the n-n coordinates to weight and interpolate the intensity observations. Thus the weights of the experimental sites are natural neighbors to a new point, which is proportional to the areas of the intersections of their Voronoi polygons. In addition, the approximate source geometry and kinematics of the earthquake can be predicted by automatically inverting its intensity data. Both of these techniques are demonstrated by using intensity data from the 1987 Whittier Narrows Earthquake. Results are shown to agree closing with hand drawn isoseismal profiles. In addition, predicted source geometry and kinematics are in close agreement with results from instrumental data.

Paper 3.15 (Yufeng Gao, Hanlong Liu, Wei Shu, and Tugen Feng) Influences of S-Wave Velocity to the Seismic Response of Silt Ground

This paper presents a numerical study on the effect of variation in shear wave velocity estimates for various layers in a soil column have on the estimation of peak acceleration, duration and response spectra. This study uses three different acceleration time histories that are inputted into the SHAKE program. The soil columns used are silt at one density with depths ranging from 10 to 70 m in depth.

- The relationship between the difference of seismic acceleration peak and difference of s-wave velocity is approximately linear.
- The decrease in the s-wave velocity has considerable influence on the long-period region of the response spectrum
- An increase in the s-wave velocity influences the short and moderate period regions of the response spectrum.

Paper 3.02 (Vladimir Sokolov, C.-H. Loh, K.-L Wen) Probabilistic Microzonation of Urban Territories: A Case of the Taipei City

The paper is on a useful and important topic – the development of uniform hazard spectra for soil site conditions. At present we can do site-specific ground response analysis fairly well, and we can do probabilistic seismic hazard analyses for sites fairly well. The problem we face is that we cannot combine these analyses effectively to obtain site-specific hazard analyses. The article attempts to develop a formulation by which this could be accomplished.

The idea is to calculate hazard with a series of simulations that represent the possible range of source locations and magnitudes. For each simulation, a site amplification function (Ψ) is applied to the motion for a reference site (a) to obtain the soil motion. All of the calculations are done in the frequency domain using Fourier spectra. Conceptually, the approach makes sense and is promising. There are, however, some problems. First, attenuation relations for Fourier amplitudes are not as maturely developed as those for response spectra, accordingly there are considerable uncertainty, especially for large magnitude earthquakes. Second, the adjustment of reference site ground motion for site effects should include an adjustment to the error term, not just an adjustment of the median.

Paper 3.42 (Lindita Kellezi and Neils Foged) 3D FEM Analysis of Ground Vibration Measures for Moving and Stationary Transient Source

The paper concerns the use of in situ vibration barriers to reduce ground vibrations from transient sources such as trains. Three dimensional finite element analyses are performed of open trenches, buried concrete walls, and driven row of pile or driven sheet piles. The relative effectiveness of these barriers is discussed.

Paper 3.24 (Juan Carlos Tokeshi Nagamine, Yoshihiro Sugimura and Madan B. Karkee) Characterization of Micro tremor Records Using Simulated Micro tremors

The authors compare results of micro tremor studies using empirical and modeled data and the data from a small earthquake. The goal of the paper is to analyze the possibilities of simulation techniques for interpretation of micro tremors. A test site with well-known parameters of soil profile is used for the simulation. The comparison allows the author to study the nature of micro tremors (combination of wave components). It has been also shown that the simulation makes it possible to estimate the natural frequency of the ground.

Bearing in mind, that one of the goal of micro tremors study is the evaluation of soil profile parameters at a site, the use of numerical simulation technique and comparison with actual records should allow to construct, even if roughly, a soil model. However, based on the study, it is possible to say only about the very simple case – the test site has deep base layer with weak impedance contrast.

As far as the author used a ground motion record in the study, a few comments need to be made.

First, the parameters of the earthquake (magnitude, depth, and distance) are not given, and there is no information what part of the accelerogram had been processed for spectral analysis and studied.

Second, for the purpose of comparison with the micro tremor and simulated data it is advisable to use a set of earthquake records varied by magnitude, distance and azimuth of incidence, otherwise there is a high probability that comparison leads to erroneous conclusions.

Third, if the authors have a well-established soil model, why they do not compare the SH-wave spectral ratios and micro tremors H/V ratios? Actually, they noted that there is an amplification peak at frequency 0.89 Hz due to SH-wave propagation (Table 2), and the H/V ratios show the same predominant frequency for the fundamental Rayleigh wave (Fig. 8).

Paper 3.31 (Kohji Tokimatsu, and T. Sekiguchi) Site Effects Estimated from Microtremor Measurements at Selected Strong Motion Stations in Taiwan

The paper is concerned with the use of shear wave velocity (V_S) profiles, estimated by inverting the micro tremor data measured by an array of sensors on the ground surface, to assess the extent of local site effects at selected recording stations during the 1999 Chi-Chi earthquake in Taiwan. The inversion method that considers the dispersion curve as well as the horizontal-to-vertical spectral ratio (H/V) is utilized to estimate V_S profiles at six recording stations where the micro tremor measurements were conducted. Attempt is made to compare the local amplification characteristics based on the recorded motions with the theoretical amplification characteristics of the ground based on the estimated V_S profiles estimated from micro tremor measurements. It is concluded that the site periods estimated from the theoretical amplification considering equivalent linear behavior of ground are consistent with the spectral characteristics of recorded motions. This is significant in that the theoretical amplification is simply based on the micro tremor measurement on the ground surface without any knowledge about soil types and their layering.

Theoretical amplification spectra indicate that the fundamental natural ground period for the equivalent linear behavior case seem to be of the order of two times that for the linear behavior case for all the recording sites, irrespective of the apparent site stiffness. This may be due to the nature of equivalent linear model adopted and some additional clarification would have been helpful. In addition, it would be most helpful to the readers if some additional discussions about the uncertainties involved in this method and the extent of reliability to be expected are discussed during presentation.

GROUND MOTION PREDICTION

Paper 3.08 (Hiroyuki Kimura and HirokazuTakemiya) Seismic Analysis Using Synthetic Wave Based on the Dislocation Model to Simulate Ground Motions in the Hyogoken-Nanbu Earthquake 1995

The authors describes a process by which simulations are performed to generate motions on rock from the 1995 Kobe earthquake, and linear site response analyses are performed to obtain motions on soil. These motions are compared to recordings from two sites.

Paper 3.01 (Sokolov Vladimir, L. Chin-Hsuing and W. Kuo-Liang) Site Effect Evaluation Using Combination of Source Scaling Models and Ground Motion Records.

The paper is concerned with the estimation of spectral amplification of shear waves relative to a hypothetical 'very hard rock' based on the earthquake records of 35-station array system in the Taipei basin. The records include 66 earthquakes with M=2.6-6.5 and hypocentral distance of up to 150km, but the 1999 Chi-Chi earthquake is not included. Regarded to be useful indicator of local seismic effect, the amplification ratios obtained as the ensemble average for different earthquakes are compared with the theoretical amplification characteristics of the ground at recording stations based on the 1-D model. The possibility of nonlinearity of soft surface layers during earthquakes is disregarded in the comparison.
The authors have interpreted the results as indicating the dependence of spectral characteristics on the properties of multi-layered and complex structure of the basin deposits as well as on whether the earthquakes are deep or shallow. However, the reason for the difference in spectral characteristics between deep and shallow earthquakes at a recording site is not clarified. Since the parameters indicative of the extent of shaking or movement of the ground during the different earthquake events utilized in the study are not considered, the difference in spectral characteristics between small and large events, if any, is not clear. Differentiation between large and small events may be particularly important if the Chi-Chi earthquake records are to be included in the next phase of the study, as mentioned by the authors in conclusion.

Estimation of local site dependent spectral amplification constitutes valuable information for seismic microzonation and seismic hazard assessment. The approach utilized by the authors makes use of a large number of recorded motions. The results can be expected to have greater practical significance if attempt is made to investigate the reliability of estimated spectral ratios in consideration of the different uncertainties involved.

Paper 3.14 (Jonathan P.Stewart and Mehmet B. Baturay) Uncertainties and Residuals in Ground Motion Estimates at Soil Sites

The goal of the paper is evaluation of accuracy of ground motion prediction for various soil conditions using two approaches – ground motion attenuation relationship and ground response analysis. The numerical 1-D modeling of layered soil deposits was used for the purpose. The parameters (response spectra) of recordings from actual earthquakes were compared with the spectra predicted by empirical attenuation relationships and numerical modeling, and the statistical characteristics of the difference (standard error and residuals) were estimated. The results of the study allows the authors to conclude that, in short-period domain the site-specific ground response analyses improve the accuracy of ground motion prediction relative to attenuation models, especially for soft soil category. At the same time, the authors noted that a comprehensive additional study should be performed, and many more sites should be added to enable more stable and robust estimates.

Bearing in mind that the ground motion prediction based on empirical relationships is widely used in practice, it important to identify the geologic conditions where the use of generalized attenuation models may lead to significant errors. In this connection the results described in the paper may be considered as an important, although quite preliminary, contribution that need to be further investigated. Another notable point is a recommendation, that median plus one standard error ground motion parameters should be used.

However the reviewer would like to make a few comments.

1. The authors do not provide the information about the rock site input motion - how many time histories were used, from what seismic regions, what is the range of magnitudes and distances, etc. Obviously, when comparing the results obtained using regional attenuation relationships, the records from earthquakes occurred in the same region should be used.

2. It will be useful also to provide information about the levels of peak ground acceleration (PGA) and to perform such analysis in terms of PGA

SPECTRAL ANALYSIS

Paper 3.03 (Paolo Carrubba, Michele Maugeri) Site Dependent Spectra for the Umbro-Marchigano Earthquake (Italy) of September-October 1997

The authors used the records, which were obtained during a moderate earthquake sequence – the Umbro-Machigiano earthquake (Italy, September-October 1997, M = 5.4-5.8), to evaluate characteristic response spectra for four generalized site conditions. The response spectra calculated from the records have been normalized with respect to the maximum amplitude of the records, and the average spectral amplitudes of the group were compared with the building code EC8 design spectra. One of the major goals of the paper is a discussion of a difference between obtained region- and site-dependent empirical spectra and the building code spectra.

The comments may be summarized as follows:

1. First of all it is necessary to point out the possible misprint in Tables I-IV – I suppose that there should be "distance" (epicentral or hypocentral ?), not "depth" in the fifth column.

2. The approach, which was used by the authors to obtain the characteristic site-dependent spectra, has several shortcomings. As it follows from the tables (if "depth" is replaced by "distance"), then most of the soft-soil records (70

%) were obtained at distances more than 45-50 km (up to 97 km). At the same time, the almost all weathered-rock records (85 %) were registered at distances less than 40 km. Thus, the transformation of the spectral shape due to more rapid attenuation of the high-frequency radiation, should be taken into account, for example by recalculation of the empirical spectra to a certain "reference distance". Otherwise, it is not possible to conclude that the differences in the spectral shapes for the considered site conditions are caused by the influence of soil. Most probably, the high amplitudes of low-frequency part of the normalized "soft-soil" spectra (Fig. 2) are the consequences of rapid attenuation of the high-frequency components with distance. It is necessary also to show the characteristics of the data scatter (standard deviation).

3. The building code design spectra are (or should be) constructed on the base of Uniform Hazard Spectra (UHS), which reflect the influence of different magnitude events occurred at different distances that may occur with a certain probability during the lifetime of the construction. At the same time, the code-consistent response spectra are calculated by multiplication of the design spectra by a certain value of ground-motion peak amplitude that depends on the return period (probability of exceedence). The considered case is one possible actually happened event. Therefore, for the purpose of comparison of the empirical data and the building code requirements the empirical spectra should be normalized by means of so-called "design acceleration" – the site-dependent peak amplitude assigned to a certain return period.

4. There is confusion between the conclusion and the presented results. In the abstract and conclusion sections it has been stated, "… for vibrational period greater than 1 second the Umbro-Marchigiano earthquake gives an elastic acceleration spectrum for soft soil that is *less conservative than that of EC8…*" At the same time, in page 4 there is a statement "…for soft soil *the EC8 becomes less conservative* than the Umbro-Marchigiano earthquake, especially when vibration periods greater than 1.0 s are involved." Where is the truth? The statements in the abstract and conclusion sections are erroneous if the term "less conservative" in the abstract means, "has the smaller amplitudes".

Paper 3.18 (Luis D.Decanini, Guiseppe Lanzo and Fabrizio Mollaioli) Characterization of Site Effects By Means of Energy Spectra

The paper describes the influence of local site conditions on the energy-based characteristic of earthquake ground motion – input-energy spectra. On the basis of the data from the recent strong earthquakes it has been shown that input-energy spectra strictly depend on the local site characteristics and the long-period soil amplification is strongly pronounced as compare with response spectra.

Undoubtedly, the paper should be considered as a certain contribution to the development of the energy-based design procedures. However, in this connection, it is necessary to note the following. The energy-based approach elaboration was initiated to find a parameter that characterizes adequately the ground motion intensity or damage potential. Yes, the energy spectra incorporate the effects of the duration, and may be very useful in seismic design. However, the usefulness of any design input ground motion parameter is determined also by the possibility to evaluate the parameter during a future earthquake or to consider it as an output of probabilistic seismic hazard analysis. The possibility depends on the presence of well-developed relationships between the parameter and earthquake characteristics. Unfortunately, at present there is a lack of correspondent elaborations, and the wide application of the approach is restricted. This should be a goal of future research. The importance of the energy-based approach is extremely high for evaluation of design parameters in the case of near-field zone (close-to-source areas), as it has been revealed, for example, in the case of recent Chi-Chi (Taiwan) earthquake.

NON-LINEAR DYNAMIC RESPONSE ANALYSIS

Paper 3.07 (Youssef M. A. Hashash, and Duhee Park) Non-Linear Site Response Analysis for Deep Deposits in the New Madrid Seismic Zone

A new non-linear one-dimensional site response analysis model is presented for deep deposits. The model accounts for the effect of large confining pressures on the strain dependent modulus degradation and damping of the soil. The soil model employed was an extended version of a reference strain model by Matasovic. The authors show that this model can capture the variation in shear modulus increase with increasing pressure from lab experiments. The model by Matasovic was also shown to predict damping as a function of confining pressure. This model was used to evaluate deep (up to 1000 m) unconsolidated deposits in the Mississippi Embayment. The results show that high frequency components usually filtered using conventional wave propaganda methods are preserved. The results also show that the spectral amplification factors for the deep deposits range between 2 to 6 in the frequency range of 0.6-5 sec., and at longer periods can be as high as 8. Unfortunately the authors presented no recorded data from deep deposits where rock outcropping data is also present to calibrate the model. They did show that

Paper 3.13 (Ralph J. Archuleta, Daniel Lavallee, and Luis Fabian Bonilla) New Observations and Methods for Modeling Nonlinear Site Response

The authors present a model of non-linear soil dynamics that includes effects of anelasticity, hysteretic behavior and cyclic degradation due to pore water. This model is implemented in a nonlinear one-dimensional finite difference method. The hysteresis behavior is given by the generalized Masing rules. This formulation has a functional representation that includes the Cundall-Pyke hypothesis and Masing original formulation as special cases. This model allows anelastic damping as a function of the stress-strain loop. These new generalized

Masing rules are coupled to pore pressure effects by a constitutive equation in the strain space based on the multishear mechanism concept. A case study is presented using in situ observations from the Garner Valley down-hole seismographic array. Results from the case study show amplitude reduction as well as the shift of the fundamental frequency to lower frequencies. In addition, synthetic accelerograms show the development of intermittent high frequency peaks riding on a low frequency carrier wave and increasing duration. This behavior was shown to be in agreement with records from Garner Valley. Unfortunately the authors did not present any response spectra of their results.

Paper 3.05 (Susumu Nakamura and Nozomu Yoshida) Proposal of Non-Linear Response Analysis Method in frequency

The authors propose a non-linear response analysis method in the frequency domain. This method is based on defining a stress and strain relationship of soil in the frequency domain. The assumption is made that the stress – strain relationship is similar in both the frequency and time domains. Based on this assumption the authors express the shear strain at an arbitrary frequency as equal to the shear strain in the time domain times a multiplying coefficient. This model of the stress-strain relationship is incorporated into a commonly used non-linear response analysis method in the frequency domain. The analytical results for the Chiba Experimental Station from this method are compared against YUSAYUSA2 (time domain) and SHAKE (frequency domain). The authors consider the results from the non-linear dynamic response analysis program YUSAYUSA2 as the target values. The maximum shear stress predicted by the model agreed with the target at the surface but became less at depth. Shear stress was less than that predicted by SHAKE except in upper 10 m. Prediction of acceleration was similar to that of target and SHAKE except at surface. At the surface the models acceleration was less than the target. Unfortunately the authors did not compare the model against an actual case history.

Paper 3.30 (Lynn A. Salvati, Thomas M-H. Lok, and Juan M. Pestana) Seismic Response of Deep Stiff Granular Soil Deposits

The authors present the results from a new non-linear FEM program AMPLE2000 utilizing a hysteretic constitutive model to evaluate the dynamic site response of deep granular soil deposits. Results from laboratory tests using bender elements are presented to show effect of variation of mean effective stress and void ratio on Gmax. The formulation of Gmax is based on the concept of the generalized stiffness with separable functions for the void ratio and confining pressure. The effect of confining pressure up to 588 kPa on Gmax was shown to be a power law of the normalized effective stress raised to 0.5. This result is in agreement with earlier tests by Hardin and Drnevich. The effect of void ratio on Gmax was modeled using a relation proposed by Jamiolkowski et al. Where a material constant is divided by void ratio raised to the one-third power. The degradation of the modulus was accomplished using a two different model s: one for low strains and one for large strains. Unfortunately the authors do not indicate the formulation for damping. To demonstrate the model the authors used the example of the Caracas Valley. Two idealized soil profiles consisting of uniform, medium dense sand to depths of 30.5 m and 183 m were analyzed. The water table was placed at a depth of 20 m. Input rock motions from the Loma Prieta Earthquake were scaled to PGA of 0.092g and 0.473g. The model was shown to give results similar to SHAKE for a shallow profile and for a lower level of excitation. In contrast, for a deeper profile with higher levels of shaking the model gives significantly higher acceleration response spectra than the equivalent linear spectra. Unfortunately the authors did not present their results against known surface spectra.

Paper 3.39 (Xian Tao, Takaaki Kagawa and Akio Abe) Numerical and Experimental Simulation of Seismic Site Responses

Paper describes a new site response program. Features of the program include: (1) horizontal layering, (2) 3-D input motions, (3) multiple possible constitutive model, although the focus of the paper is on discrete element methods (DEM), and (4) pore pressure development and dissipation can be handled with a consolidation model. The paper describes the capabilities of the program and the DEM model, and illustrates its application.

As noted by the authors, the program is still under development. To be useful, the process by which parameter selection is done would need to be much better documented. Further, the sensitivity of the results to various input parameters should be investigated, and the model calibrated against available data from vertical arrays. Because this has not yet been completed, the paper essentially reports a promising work in progress, but is not particularly useful at present.

Paper 3.11 (Takashi Akiyoshi, K. Fuchida and S. Shirinashihama) Local Site Effects of Transient Dynamic Characteristics of Irregularly Layered

The authors have utilized the effective stress analysis based on the Biot's two-phase mixture theory in a 2-D FEM program to model the irregularly layered section of the ground in Kobe bay area including the belt incurring heavy damage during the 1995 Kobe earthquake. It is concluded that the introduction of a simple irregularity in soil layering in the FE representation together with the two-phase model to represent ground behavior can adequately explain the concentration of the damage in the belt area representing geological transition. Basically, the conclusions are based on the variation of 3 parameters: ground period, acceleration and shear stain. Qualitatively, all of these parameters seem to show larger values at the geological transition. However, it is not clear as to what is actually regarded in a quantitative sense as resulting in the heavily damage belt zone.

Soil liquefaction including its affect on adjacent firm ground has been discussed, but it is not clear what criteria if followed to distinguish liquefaction from no liquefaction. Variation in the natural period of the ground is considered to be an important parameter indicating nonlinear ground response. However, while the response of firm ground behaving linearly is believed to be affected by the excessive nonlinearity in the adjacent region, the actual computation of natural period (Equation 7) does not reflect this. Comparison with natural period of ground during the earthquake estimated from actual records may be helpful to validate this approach.
The authors have also evaluated the shear strain distribution along the ground section modeled and have concluded about the existence of permanent shear deformation. These are significant results, but it would have been helpful if attempt were made to compare the permanent shear deformation from the analysis with the extent of actual observations after the Kobe earthquake.

ESTIMATION OF DYNAMIC SOIL PROPERTIES FROM SEISMIC RECORDS

Paper 3.40 (Juan Carvajal U., Victor M. Taboada U., and Miguel P. Romo O.) Evaluation of Mexico City Clay Dynamic Properties Using A Parameter Identification Approach

The authors use results from vertical arrays of strong motion instruments to evaluate soil dynamic properties by solving the inverse problem. The model employed in the paper assumes a 1-D propagation of shear waves throughout homogeneous viscoelastic soil deposits. Defines soil properties in terms of fundamental parameters shear modulus G and viscosity. If the ground motions are known at various points within the soil deposit for different earthquakes, the equivalent properties of the materials may be estimated by solving the inverse (deconvolution) problem (system parameter identification). Procedure consists of comparing the experimental and analytical responses. Once the amplitude Fourier spectrum of the response is computed, it is compared with the corresponding spectrum of the measured response. The, an optimization procedure is activated that is based on the minimization of the overall error between both spectra. In doing this, sets of shear modulus (G) and soil viscosity () are varied until the minimum error is obtained. The corresponding values are the in situ equivalent properties. Methodology is compared to velocities measured by means of field studies using a P-S logging system.

- DPIS calculates the transfer function, considering the dynamic parameters constant with the frequency.
- Presented some evidence that for Mexico City clays G increases with ground motion frequency

Paper 3.33 (Mohammad R.Ghayamghamian and Masato Motosaka) Identification of Dynamic Soil Properties Using Vertical Recordings

Non-linear soil response and identification of dynamic soil properties were investigated using both frequency domain and time domain analyses for a vertical array site at Chiba in Japan. In the frequency domain analyses the frequency dependent transfer function of soil is calculated as the ratio of the spectrum at uphole to the spectrum at downhole (spectral ratio). Shear modulus and damping ratio are evaluated from peaks in the transfer function amplitude. In contrast, for the time domain analyses acceleration data from the site are processed directly to determine the shear stress-strain hysteresis curve. The shear modulus and damping ratio are evaluated from shear stress-strain hysteresis curve using equivalent shear modulus and damping ratio approach. Results indicated that both the frequency domain, time domain and laboratory results are in general agreement. However, the shear moduli inferred from hysteresis stress-strain relations in the time domain have higher values than those of the spectral ratio analysis.

Paper 3.09 (Makoto Kamiyama, and Masaru Yoshida) A Method for Estimating Non-Stationary Variation of Soil Rigidity During Strong Motion

This paper presents a method based on the "Complex Envelope" to inversely estimate soil rigidity and damping from the time histories of stress and strain induced in soils. The "Complex Envelope" transfers a time history into its corresponding imaginary number system. This method was used with strong motion records obtained by a vertical-array observation system at Port Island during the 1995 Kobe Earthquake, Japan. Results of shear modulus ratio versus absolute strain generated by this analytical method were compared against laboratory-derived values. These results indicated that the reductions of rigidity ratio (i.e. shear modulus) during the strong motions depend more strongly on strain and their degrees of reduction are much greater than the ones of the laboratory experiments. In addition, results from the analytical method showed that extreme reduction in rigidity, depending on strain, occurred in the superficial layers during the main-shock of the earthquake.

FAULT PROPAGATION

Paper 3.04 (Dimitrios Loukidis and George Bouckovalas) Numerical Simulation of Active Fault Rupture Propagation Through Dry Soil

A numerical simulation of fault rupture propagation through dry soil was performed using a finite difference scheme. Only dip-slip fault propagation is simulated. Soil behavior was simulated using a Mohr-Coulomb elasto-plastic constitutive model with strain softening. Looking at both the shear strain rate and the plastic shear strain contours delineated shear zones resulting from rupture propagation. Results indicated that (1) declination of the fault trace from the straight projection of the fault plane is higher in dilatant soils, (2) a graben is formed in cases of normal faults with relatively shallow dip-slip angle, (3) high values of the dilatancy angle tend to decrease the width of the ground surface that is distorted, and (4) local amplification of ground motion is possible near the fault trace in dense soils, especially in reverse faulting cases. The results also indicated that the analysis was not sensitive to the soil layer thickness. Unfortunately the authors did not indicate the model they employed to represent dilatancy. A second drawback was that the analysis was performed only for dry soil. Results of analysis were only compared against laboratory experiments reported in the literature.

OCCURRENCE OF LIQUEFACTION ON SEISMIC BEHAVIOR

Paper 3.16 (Jun Yang, Tadanobu Sato, and Xiang-Song Li) Motion Amplification in Horizontal and Vertical Components at Liquefiable Site

An analytical study using an effective stress based non-linear model has been presented to identify the characteristics of motion amplification in both horizontal and vertical components at a liquefiable deposit. The procedure uses a bounding surface hypo plasticity model, which characterizes incremental non-linearity of the stress-strain rate relations based on the postulation, that the stress-strain rate relationship depends not only on the current stress state but also on the stress rate itself. Results indicated that the vertical component of base excitation has a minor influence on the development of pore pressure and the potential of liquefaction except for causing some oscillation in the response of pore pressure. In addition, the transfer function for vertical component is likely to be independent of the intensity of shaking or non-linear soil behavior. Motion amplification in vertical component was also shown to differ considerably from that in horizontal component. Authors suggest that it would be possible to use the information of spectral ratios (H/V) to identify non-liner soil behavior and site liquefaction.

Paper 3.29 (Junichi Nishikawa, Takuya Egawa, Takaki Ikeda, Hirochika Hayashi, and Shigeru Miwa) Evaluation of the Seismic Behavior on Sandy Ground with Built-Up Pore Water Pressures by Effective Stress Analysis

Effective stress and total stress analysis were carried out which incorporated both strain dependent non-linearity and non-linear build up of pore pressure. These results were compared with observed records from Lake Utonai, Japan to evaluate the effect of excess pore water pressure on the seismic amplification of the ground. These records were the result of the 1993 Kushiro-oki Earthquake. Two different approaches were used for conducting effective stress analysis. Method one used the program FLIP which incorporates a strain stress plasticity model for cyclic mobility based on a multiple shear mechanism defined in a strain space. The second method employed the program YUSAYUSA that uses an effective stress path model. For both methods analysis was carried out with and without the effective pore water pressure rise to simulate both effective and total stress non-linear analysis. The non-linearity of shear stress and shear strain was modeled into a modified Hardin-Drnevich model, and the Masing rule was applied to the hysteresis rule. Liquefaction strength of undisturbed material from the site was determined using cyclic triaxial tests. These laboratory results were used to determine the parameters for the analytical models. Using these parameters in the models an analysis was conducted for the site. Results were presented showing the maximum response distribution of acceleration, relative displacement, shear stress, shear strain, and excess pore water pressure as a function of depth compared with both observed data and results from an equivalent linear analysis from a previous study. This comparison indicated the following:

- In general no marked difference were observed between the equivalent linear and non-linear analysis for pore pressure ratios less than 0.4.
- There were no significant difference between the results of effective stress and total stress analysis, though the amplitude was slightly different.
- Effective stress methods are considered by the authors to be sufficiently effective for seismic response analysis,
- Authors indicate that equivalent linear analysis is conservative for stress analysis, but care should be exercised for strain analysis because the results are not conservative.

CONCLUDING REMARKS

The papers contained in this session show substantial development in our discipline in recent years but also raise some very real challenges and opportunities for future research. A review of the papers indicates that real strides are being made in a number of diverse areas. These areas are the following:

- Dense, three dimensional strong motion seismograph arrays are providing excellent, high quality data to directly validate site response models and provide an opportunity to estimate dynamic soil properties in-situ.
- Development of non-linear dynamic response analysis methods is proceeding quickly. This development is being driven by an appreciation of the differences between the linear approach (i.e. SHAKE) and non-linear formulations. Their appears to be a real need to calibrate these new models against real case studies in addition to comparing against other existing codes.
- Realization that the lateral dimensions of faulting is important as well as the length of fault breakage.
- Development of soil models to account for the effect of large confining pressures on the strain dependent modulus degradation and damping in soil.
- Development of methods to treat intensity data objectively and reproducibly using computer generated

isoseismal maps employing Voronoi polygons. The inversion of this process to predict source geometry and kinematics show considerable promise.

- The development of microzonation techniques is continuing to show progress.