# General Report — Session 2: Wave Propagation, Engineering Vibrations and Solutions, Vibrations of Machine Foundations, Blast, Traffic and Construction Vibrations, Vibration Absorption

M. Hesham El Naggar
*University of Western Ontario, Canada*

D. K. Baidya
*Indian Institute of Technology, India*

Dong-Soo Kim
*Korea Advanced Institute of Science & Technology (KAIST), Korea*

George M. S. Manyando
*URS Corporation, St. Louis, MO*

Nii K. Allotey
*University of Western Ontario, Canada*

## SESSION 2

### "Wave Propagation, Engineering Vibrations and Solutions, Vibrations of Machine Foundations, Blast, Traffic and Construction Vibrations, Vibration Absorption."

GENERAL REPORTER: Prof. M. HESHAM EL NAGGAR, Ph.D, P. Eng., University of Western Ontario, London, ON, Canada, N6A 5B9

CO-REPORTERS: Prof. D. K. BAIDYA, Ph.D., Department of Civil Engineering, Indian Institute of Technology, Kharagpur-721302, India

Prof. Dong-Soo Kim, Ph.D., Department of Civil Engineering, Korea Advanced Institute of Science & Technology (KAIST)

Dr. GEORGE M.S. MANYANDO, P.E. URS Corporation, St. Louis, Missouri, USA

Mr. NII K. ALLOTEY, M.Sc., University of Western Ontario, London, ON, Canada, N6A 5B9

INTRODUCTION

Twenty-four papers were submitted to this session covering wave propagation, problems of engineering vibrations caused by a wide range of activities and vibration absorption. These papers may be divided into the following general categories:

Construction Vibration: 5 papers (2.01, 2.08, 2.09, 2.17, 2.22)

Traffic Vibration: 4 papers (2.11, 2.21, 2.29, 2.32)

Foundation Vibration: 5 papers (2.02, 2.31, 2.33, 2.34, 2.36)

Wave Propagation: 4 papers (2.23, 2.28, 2.38, 2.39)

Soil Characterization and Ground Response Analysis: 3 papers (2.16, 2.20, 2.26)

Soil-Structure Interaction: 3 papers (2.10, 2.24, 2.40)

CONSTRUCTION VIBRATION

Five papers have been placed into this category. Three papers deal with vibration problems due to pile driving, one paper deals with vibrations due to dynamic compaction and the last paper deals with vibrations due to blast loading.

**A Few Considerations About the Property of Ground Vibration Generated by Pile Driving and Its Isolation Methods (2.01): by Kani and Hayakawa**

The authors have investigated the characteristics of ground vibrations induced by pile driving. Vibration measurements were taken at two sites and pile driving was performed using either a vibro pile-driver (electrical and hydraulic types) or a diesel pile hammer. The authors showed that vibration level was almost independent of soil type, depth of penetration, and type of driver and the attenuation characteristics were attributed to the wave propagation of combined body and surface waves. However, it would be more interesting to show the frequency characteristics of monitored vibrations, in-depth vibration measurements, and vibration characterization using 3 component vibration measurements. Also, they have investigated the effectiveness of various isolation methods using the wave penetration theory and the previous data. Types of barriers include concrete, EPS, steel sheet pile, composite of EPS and concrete, open trenches, and PC wall-piles. However, the simulation conditions were not clear and it would be better to explain the effectiveness considering the wave length and depth of barrier. Figures 8 and 9 in the paper need to be exchanged.

**Ground Waves Generated by Pile Driving, and Structural Interaction (2.08) by Ramshaw, Shelby, and Bettess**

The authors have investigated the vibration characteristics of pile head impact and vibratory driving, and the subsequent wave propagation into the ground using the combination of finite element, springs and a dashpot model. They showed the general agreement between measured and estimated peak particle velocities, but it would be nice to explain and include more detailed comparisons if more space allowed. The authors also showed the modeling tool used to investigate the response of simple structures such as a frame and in-plane wall together with the wave propagations in the ground using a 3D FE/IE wedge-shaped model.

**Analysis of Dynamic Compaction of Loose Soils Under Impact Loads (2.09) by Pan and Shelby**

The authors have investigated numerically the response of loose soils under dynamic compaction, using ABAQUS. The dynamic compaction was modeled as a rigid-body impact and the surrounding soil as axisymmetric elasto-plastic finite elements. To simulate the treatment area by 1st and 2nd impacts, a stiff plug was included in the analysis. As mentioned by the authors, mesh size is very important for the proper wave propagation simulation, and it would be better to show the detailed criteria of wavelength / mesh size ratio adopted in the study. Various comparisons were made in terms of the plug depth, peak vertical particle accelerations, and the mass penetrations. During dynamic compactions, however, the soil behaves extremely non-linearly, particularly near the compaction, and the decrease of modulus and the increase of damping with strain amplitude are important phenomena to consider. Also, the criteria for identifying depth of treatment zone using the vertical particle acceleration of 2g need to be explained more clearly and it would be nice to see the detailed comparisons with field case studies.

**A Case Study of Safe Blast Design with Vibration Analysis (2.17) by Shin, Bae, Lee and An**

The paper presents a case study on safe blasting design based on vibration analysis data. Test blasting was performed at two different sites with different bedrock conditions in South Korea. The characteristics of the sites are as follows.

Site A is located in a construction area of an expressway in a hilly district with rock outcrops. The rock at this site is gneiss of the Pre-Cambrian period. The rock is weathered and extremely stratified with irregular joints. The unconfined strength of this rock was about 512-658kg/cm$^2$. Gelatin dynamite 50m/m was used as gunpowder, and the blast pattern of the exploder was (ED, MSD) bench cut. Site B is located near a densely populated district. The geology at this site consists of granite bedrock of the Mesozoic Jurassic period. The bedrock is slightly weathered to some depth. The compressive strength varied from about 250 – 1200 kg/cm$^2$. The rock is estimated to be hard to extremely hard rock. Water-gel explosive was used as gunpowder and enforced moment blast and delaying blast side by side.

The resulting vibration data from test blasting were measured at the two sites. The effects of blasting vibration were analyzed as a function of distance, charging gunpowder capacity, surrounding conditions and measurement points. The square and cubic root site-specific scaling formulae for predicting vibration velocity were used.

$$V = Ks\{D/(w)^{1/2}\}^{-ns}$$

$$V = Kc\ \{D/\ (w)^{1/3}\ \}^{-nc}$$

where,

V: the velocity of a particle (cm/s)
D: the distance with blasting radius (m)
Ks:blasting vibration constant of sq. root scaling
ns: attenuation index of square root scaling
Kc: blasting vibration constant of cubic root
nc: attenuation index of cubic root scaling

Site specific scaling has been expresses as

$$V = KD^{-n}W^{b}$$

Here K: blasting vibration constant
n: attenuation index
b: gunpowder index

In these formulae, the attenuation characteristics of the blasting vibration velocity due to geotechnical properties and blasting conditions are dependent on the vibration constant and attenuation index.

The measured test results were used in a back calculation analysis to obtain best-fit formulae to predict the vibration velocity from test blasting activities. The obtained formulae were compared with available formulae based on research results presented by others from the same geographic region.

The results of the formulae presented by the authors showed good agreement with the results obtained by previous researchers. The square and cubic root formulae provided better predictions at Site B that is less weathered than at Site A that is more weathered and is highly jointed.

The following conclusions were made. Vibration intensity decreases with increased scaled-distance and also depends on the direction of bedrock joints. Vibration levels are higher for instance than for delayed detonation due to parallax. The attenuation index and blasting vibration constants are dependent upon geology and site subsurface conditions. Ground velocity data provide superior estimates of vibration intensity as a function of scaled distance than explosion pressure data. Valid blasting vibration prediction formulae can be obtained for any site based on results of the test blasting program. Safe blasting design should be based on predicted results and safety and not on safety considerations alone.

**Numerical Study on the Behavior of Structures in the Near-Field of Sheet-Pile Driving Work (2.22) by MeiBner and Becker**

The authors have performed numerical parametric studies on the behaviour of structures due to sheet-pile driving work using the finite element method. The parameters include the effect of piling depth, the depth of observation point, ratio of both base resistance and shaft resistance to total resistance during piling, excitation frequency, and foundation loading. They showed many interesting results, but the verification of finite element model is important by comparing the estimated results with various field monitored data. Also, as mentioned by the authors, it would be important to consider the elasto-plastic material behavior and nonlinear characteristics of modulus and damping of soil near the piling.

## TRAFFIC VIBRATION

Four papers fall in this category. Each paper deals with an interesting problem due to ground-transmitted traffic vibration. Two papers consider the characteristics of traffic induced vibrations and the factors that influence them. One paper deals with the liquefaction potential of rail track embankments due to rail-induced vibrations. The fourth paper deals with the response of vibration-sensitive equipment to ground transmitted vibrations due to traffic.

### Estimation of Ground-Borne Vibrations From Moving Trucks (2.11) by Siddharthan and El-Mously

The authors have investigated the vibration characteristics caused by moving trucks, particularly to compare the vibration response produced by wide-base and dual tires. The continuum-based finite layer model incorporates the visco-elastic behavior of an asphalt concrete layer, effects of vehicle speed, and complex 3D tire-pavement interface stresses. The responses of the two pavement systems (thin and thick) were computed and compared. However, the vibration characteristics induced by traffic are significantly affected by the roughness of pavement and the weight of vehicle, and it would be interesting to consider those parameters and also to compare with real field measurement data.

### The Modelling of Free-Field Traffic Induced Vibrations by Means of a Dynamic Soil-Structure Interaction Approach (2.21) by Lombeart and Degrande

The paper presents an interesting numerical model to obtain free field soil response due to the passage of vehicles on an uneven road using (i) derived transfer functions describing the dynamic interaction between the road and the soil; and (ii) the Betti-Rayleigh reciprocity theorem. They have also illustrated the model using a numerical example. Various parameters were studied with the help of numerical results. The most important result was probably the time history of the free field vertical velocity as a function of the distance to the center of the road. For the problem considered, free field vibration response was found to be negligible beyond a distance of 50 m. This distance, however, depends on type of soil, traffic, road etc. It would be of interest if the effect of the type of soil, traffic, roughness of the road etc. on this distance was highlighted.

### Liquefaction Potential of Railway Embankments (2.29) by Pando, Olgun and Martin

This paper presents the results of a numerical investigation of train-induced ground vibrations and discusses the liquefaction potential of railway embankments under this vibration. The liquefaction potential of railway embankments was evaluated using the cyclic shear stress approach. The dynamic shear stresses induced by the train loading were estimated by performing dynamic numerical analyses using the finite difference-based computer program FLAC. The train loading was modeled by an acceleration time history of sine wave with a frequency of 20 Hz and an amplitude of 0.25 g. The initial static horizontal shear stresses and vertical effective stresses were estimated from static numerical analyses using FLAC. The cyclic stress ratio (CSR) was then calculated accounting for the initial stress ratio using the approach proposed by Seed and his co-workers. The liquefaction resistance was characterized by the cyclic resistance ratio (CRR) using the approach proposed by NCEER (1997). The liquefaction potential was then evaluated by comparing the induced shear stresses in terms of CSR with the liquefaction resistance of the soil in terms of CRR. The results showed that the critical zone, where liquefaction potential is high, was located towards the toe of the embankment extending to a depth of about 5 m and over a length of about 10 m. The authors pointed out that the particle motion was elliptical with amplitude decreasing rapidly with depth similar to Rayleigh wave motion. The analysis was strictly linear elastic, and the nonlinearity was accounted for approximately by using adjusted soil properties to the expected strain level using an iterative procedure. However, the nonlinearity underneath the railway tracks is expected to be high and the equivalent linear analysis may not capture the essence of the nonlinear behaviour. Also, the numerical model did not account for the development of pore pressure that would have a significant impact on the liquefaction potential.

### Vibration of Synchrotron Foundation Due to Ground Transmitted Excitation (2.32) by El Naggar and Sparling

El Naggar and Sparling presented dynamic analysis of a foundation for the Canadian Light Source facility to predict the expected vibration amplitude due to the passage of loaded vehicles from nearby roadway. Recorded ground vibration data during traffic movement at two significant points [at the edge of the slab nearest to the roadway ($S_4$) & at the middle of the slab ($S_5$)] were presented. At $S_4$, energy concentration was observed in the frequency range 400-600 rad/sec and at $S_5$ it was observed in the range of 100-400 rad/sec. Using ground vibration recorded at $S_5$ as input motion, vibration analysis was carried out by the FFT method. Predicted amplitude was found to be within the permissible value. The analysis was repeated using recorded ground motion at $S_4$ as input motion and found predicted amplitude more than the limiting value. This, however, was discussed and stated to be satisfactory. At the beginning it was stated that there are three important steps in every design namely: (i) characterization of load (ii) characterization of soil; and (iii) dynamic response analysis. Soil characterization is, however, not included and the paper is somewhat incomplete without this.

FOUNDATION VIBRATION

This category includes five papers. Four papers report on experimental investigations to evaluate the impedance functions of the foundation. The fifth paper presents an analytical solution to the problem.

**Natural Frequency of Vibrating Foundations on Layered Soil System-An Experimental Investigation (2.02) by Baidya and Muralikrishna**

The paper presents an experimental study on the effects of layering on the resonant frequency of a vibrating footing on a different layered system. The natural frequency of a footing has been computed using available analytical methods and the computed results have been compared with experimental results. Sand and sawdust were used in different positions (top, bottom or middle) to form different layered beds. Typically, a two layered system consisted of a stiff layer of sand over a soft layer of sawdust and vice versa. A three-layer system consisted of a soft layer between two stiff layers and vice versa. In two layer systems, the thickness of $1^{st}$, $2^{nd}$, and total thickness was variable whereas in three layer systems $1^{st}$, $2^{nd}$, and $3^{rd}$ layers had a variable thickness while the total thickness was kept a constant. Dynamic loads were produced using a Lazan type oscillator with two different masses weighing 6.6 kN and 8.0 kN applied at three different eccentricities. Experiments were conducted in a concrete tank of size 1.7 m by 1.7 m by 1.35 m with a bottom concrete base as a rigid boundary. Amplitudes of vibration were measured using a vibration meter by Bruel & Kjaer. A speed control unit was used on the oscillator to avoid sudden application of high magnitude loads. The footing was subjected to vertical vibrations. The foundation response was measured in terms of frequency and corresponding amplitudes using a photo-tachometer and vibration meter, respectively. Amplitudes were recorded at a frequency interval of 25 to 50 rpm up to 1,400 rpm. The frequency at which a maximum displacement is obtained over that of a frequency sweep is the resonant frequency.

Results of experimental tests are consistent with theoretical expectations. However, we have noted that the symbols in Figure 3 are presented in reverse order, that is, the natural frequency should increase with increased thickness of the sand layer as pointed out in the text not the reverse. The authors have shown that the position and thickness of individual layers influence the natural frequency and magnitude of the amplitude of vibration. In addition, they have shown that the position of a rigid layer in the subsurface profile influences the natural frequency significantly especially when it is at depths within three times the footing width from the bottom of the footing.

The computed and observed natural frequencies were in good agreement. Computed values are within 10 percent of the observed values except for cases where there is a soft layer directly beneath the footing. For this case, the difference in the computed and measured values is about 30 percent which we concur is within acceptable limits.

The authors have shown that predictions of the natural frequency of layered systems using a static equivalent stiffness of the system based on equations by Baidya and Sridharan (1994) are useful for preliminary evaluations of footing response.

REFERENCES

Baidya, D.K. and Sridharan, A. (1994). The dynamic response of foundations resting on a stratum underlain by a rigid layer, Proc. Indian Geotech Conf. 1, 155-158, Warangl, India.

**Vertical Vibration of Block Foundations (2.31) by Puri and Das**

Prakash and Puri presented steady state vibration test results from two blocks of size 1.5mx0.75mx0.7m and 3mx1.5mx0.7m. Dynamic responses of the same foundations were predicted by (1) the elastic half space anlog method and (2) the impedance functions method and compared. Dynamic shear modulus 'G' was obtained by field (SPT) and laboratory (oscillatory shear test) methods. However, there was no mention of which method the shear modulus value referred to in the table. Also, other soil properties (density and Poisson's ratio) of the soil that are essential for the analysis using both the methods is not reported. Magnitude of dynamic force depends on excitation frequency, $\omega$ and eccentric angle, $\theta$. However, there is no such relation presented in the paper. How should $P_z$ be estimated to predict amplitude from equation 6 without having such a relation? Hence, it would be of interest to have more detail soil data and direct relation among dynamics force, $P_z$, $\theta$ and $\omega$ to make the test results more useful to future researchers.

The spelling of Gazetas is incorrect everywhere (written as Gazettas).

**Natural Frequency of Vertical Foundation Vibrations Evaluated From In-Situ Impact Tests (2.33) by Svinkin**

In this paper, the author proposes a new method for the evaluation of the damped natural frequency for vertical vibration of a foundation before it is installed. It is based on the relationship between the measured natural frequencies of the foundation and the natural frequencies of the soil deposit. From previous work by the author, the vertical damped natural frequency of a rigid foundation was shown to coincide with the dominant natural frequency of the soil profile. This is explained as being due to the foundation vibration response being highly damped in comparison to that of the site response. The paper outlines the steps involved in using this method to estimate the damped vertical natural frequency of the foundation and discusses two case histories that confirm the method. The paper does not discuss in detail any particular limitations or advantages of the method in comparison with already existing methods.

**Response of Circular Foundations Subjected to Dynamic Forces in Sandy Soils (2.34) by Uddin**

This paper highlights the results obtained from the field testing of the dynamic behavior of a circular foundation with a reinforced concrete cap-anchor foundation in sandy soil. The author shows results of the influence of the base-diameter of the cap-anchor on the resonant frequency of the foundation and the amplitude of vibration for eccentricities ranging between 0° and 42°. Further clarification of the term "eccentricity" used in the paper would be useful. The results showed increases in the resonant frequency of the foundation by as much as 27%, coupled with a decrease in the amplitude at resonance by as much as 64% for an embedment ratio of 30%, and an increase in the base diameter by 40%. The author noted that this foundation system performed better in terms of controlling vibrations, when compared to that of either a simple plain foundation, or that of a cap-anchor foundation. Empirical equations relating the increase in the resonance frequency and the decrease in the amplitude of the response with increase in the base diameter are also given in the paper for different eccentricities.

**Partially Embedded Rectangular Foundations: A Simplified Approach to Compute Dynamic Soil Stiffnesses (2.36) by Nogami and Chen**

The authors use Nogami and colleagues idealization of a continuous ground medium as a system of closely spaced vertical one-dimensional columns with horizontal springs interconnecting adjacent columns, to model a given layer of Novak and colleagues treatment of the soil at the embedment side of a foundation, as a Winkler model approximation. They provide closed-form expressions for computing the dynamic stiffness at the sides of a rectangular foundation. The results presented for the dynamic stiffness are similar to those of a circular foundation, but are affected by the aspect ratio of the foundation. The authors also provide an example application at the end of the paper, that shows the effect of the aspect ratio on the computed response. The authors state that the results obtained compared well with those computed by a more rigorous approach, however, the only comparison made in the paper is to that of Novak's solution. Since the present method is based on this solution, it would have been better to compare the result of the example application with results obtained from a totally different approach.

WAVE PROPAGATION

Four papers presented in this session investigate the characteristics of wave propagation in the soil. Three papers report on the analysis of field measurements and the fourth paper presents an analytical approach for the evaluation of soil damping from SASW measurements.

**Simple Power-Law Characterization of Transient Ground-Borne Vibrations (2.23) by Rucker and Holmquist**

The authors in this study attempted to characterize transient ground-transmitted vibrations in terms of peak particle velocity (PPV) using a simple power-law similar to the Gutenberg-Richter relationship for earthquakes. They examined the results of four monitoring programs of apparently random transient ground-transmitted vibrations: vibrations induced by playing children using the front door of a residence, traffic induced vibrations near the curb of an urban arterial street, an unidentified vibration interfering with a precision machining operation and vibrations induced by water transport in a pipeline. In each case, the PPV was collected in histogram-type format using an engineering seismograph that can monitor pre-selected time intervals over a period representative of the expected various stages of vibration activities. The PPV was then plotted vs. the cumulative event number (or rank) order in a log-log format. The resulting chart represented the simple power-law for the frequency-magnitude of PPV for that case. In each case, two distinct, nearly straight-line trends can be identified relating the PPV to the cumulative event number. The first trend line represented the small events and the second trend line represented the largest (extreme) events. To show the validity and limits of using the trend lines to predict future extreme events, the authors used the trend lines developed using the data collected during a limited period to establish the extreme event measured during the total observation period. The agreement was good between the predicted and measured PPV values, especially for the relatively periodic vibrations. The applicability of these power-law relationships to other sites and/or other sources of vibration is questionable. In spite of the simplicity of the approach, one could wonder about the practical value of such a tool given the rapid advancement and reduced cost of vibration monitoring devices, as the authors stated in their introduction.

**Surface Waves in Evaluation of Damping in Layered Systems (2.28) by Gucunski and Maher**

The authors have provided results of a parametric numerical study into the use of the Spectral Analysis of Surface Waves (SASW) and surface waves for the evaluation of the damping and attenuation characteristics of layered systems. The basis for this method is the direct relationship between damping and the complex phase velocity of surface waves. The damping and attenuation characteristics are evaluated from the decay factor which is a function of the complex phase velocity, and is defined as the attenuation per wavelength. The results of their numerical study were based on four soil stratification cases representing the case of regular stratification (increase in shear modulus with depth), the case of a surface layer underlain by a softer layer and the cases of a trapped soft and stiff layer, respectively. Their results showed that for low frequency components, attenuation properties of the system are controlled by the damping characteristics of deep layers, while for the case of high frequency components, the attenuation properties are controlled by the damping properties of the surface layer. For irregular stratification in which high Rayleigh modes dominate the wavefield, they showed that the damping characteristics of the system followed similar patterns to that of the phase velocity. Results for Cases 3 and 4 were noted to follow similar trends to the other cases, however, it would have been good if a reference to the results for these cases was cited, or if mention was made as to any important differences or similarities between these, and the results of the cases provided.

**Evaluating the Response of Soils to Seismic Tremors by Recording Background Noise (2.38) by Rabah and Nadir**

In an attempt to provide a more economical method for macro-zoning for earthquakes, especially in developing countries where resources are limited, the authors have proposed a method based on the recordings of a few minutes of seismic background noise, which are then used to establish the spectral ratio between the horizontal and vertical directions. The paper gives a short summary of the method and then concludes by discussing the use of the method in two different areas: Nice and Monaco situated on the Eurasian Plate, and Tunis situated on the North African Plate. The method is reported to be stable in both time and space and requires relatively light equipment. The paper is quite difficult to follow and no real quantitative comparison is made, to show its advantages.

**Influence of Seismic Noises Background Intensity on Waves Propagation Speed (2.39) by Kerimov**

The author seeks in this paper to show analytically that the speed and direction of waves in a ground medium depend not only on the ground skeleton but also on the initial existing stress and strain conditions. The author notes that this contributes significantly to the difference that arises between measurement of the ground wave speed in the field and in the laboratory. Solving a system of partial differential equations of motion using an elastic model of the ground medium, and assuming an orthotropic initial stress state, the author arrives at a solution that depends on choice of the sign of a parameter $c_o$, that depends on the initial stress conditions. The numbering and setting out of equations in the paper could have been handled better.

## SOIL CHARACTERIZATION AND GROUND RESPONSE ANALYSIS

Three papers fall in this category. Two papers address the ground response to dynamic loading and the third paper focuses on the soil characterization, for ground response analysis.

**Site Response Analysis Using Forced-Vibration Tests on Hydraulic-Filled Soil Deposits (2.16) by Kim and Lee**

The authors provide a case study of the site assessment of the resonant frequencies of an experimental site on Yong-jong Island, the location of the Inchon International Airport in Korea, using forced-vibration testing. The forced-vibration test was conducted using a combination of hydraulic hammer compaction and dynamic compaction. Measurements were taken by three 4.5 Hz velocity transducers installed in the three directions in a down hole array, as well as on the ground surface. From the spectral analysis of the particle velocity records, natural frequencies of 5, 7 and 9 Hz were obtained. Using a one-dimensional linear ground response analysis, the authors determined that the results of the spectral analysis were in good agreement with those obtained from the linear response analysis, except for peaks in the latter at 1 and 3 Hz, representing the first and second natural frequencies of the soil deposit. They attribute this phenomenon to restrictions on the transducer and vibratory source. It would have been helpful if the paper had gone a bit more into detail to explain the cause of this discrepancy.

**Deformation Characteristics of Hydraulic-Filled Cohesionless Soils in Korea (2.20) by Kim and Choo**

In this paper the authors present results from resonant column tests on seven representative samples of hydraulically-filled soil samples obtained along the coastal region of Korea. They present results for the deformation characteristics of samples at small to medium strains. Using the Hardin model for the small strain shear modulus, the various dimensionless constants of the Hardin model are evaluated for the different soil samples. They also show representative modulus reduction curves, that were found to be independent of density for five different confining pressures. They then fit the data obtained with a Ramberg-Osgood model, and showed a comparison with that of Seed et al. (1986) and Idriss (1990). The proposed curves lie on the right of the above, and shift further to the right with an increase in the confining pressure. To enable a better comparison, the authors should have stated the confining pressure(s) for which the chosen curves from the literature apply. They also estimate the small-strain damping ratio for the different samples and use a Masing Model with some modification to derive an expression for the damping ratio based on the computed Ramberg-Osgood parameters of the different confining pressures. This model is seen to overpredict the damping ratios at high strains, and the experimental curves themselves suggest that. This paper adds to the existing database of modulus reduction curves and hysteretic soil material damping ratio curves available in the literature.

**Vertical Earthquake Response Analysis of Xiolangdi Earth-Rock Dam with 3-D Shear Wedge Model (2.26) by Shen and Xu**

The authors present a simplified method for the evaluation of the vertical earthquake response of China's highest non-homogenous earth-rock dam, based on a three-dimensional shear wedge model. They obtain the displacement, velocity, acceleration and stress responses in the dam using the first three modes of the dam. The dynamic properties of the dam and their variation with strain are obtained from previous laboratory tests on the dam materials. Three earthquakes with peak accelerations ranging from 0.16 g – 0.5 g are used for the response analysis. These are: a distant earthquake; a near earthquake; and an earthquake at the dam site. The authors, however, do not mention anything about the frequency content of each ground motion. From the results they obtained, they show that the fundamental natural period of the dam in the vertical direction is 0.803 s, and the corresponding maximum acceleration response is 0.976 g. The paper also gives a summary of all the maximum response values for the different response quantities.

## SOIL-STRUCTURE INTERACTION

The soil structure interaction of three different structural systems is investigated three papers. The first papers uses the probabilistic approach to assess SSI effects on the response of tall structures. The second paper addresses the SSI of rail track systems in both frequency and time domains. The third paper addresses the classical SSI problem of elevated machine foundation experimentally and numerically.

### Probabilistic Analysis of Wind Response of Tall Structures Supported by Flexible Foundations (2.10) by Halabian and El Naggar

This paper looks at the effect of the variation of the basic properties of a soil-structure system under a wind loading regime, on the various response quantities of tall structures; in this case a R/C TV-tower. In modeling the system, the authors employ a substructure approach, using a sway-rocking stick model, based on the assumption of a homogenous visco-elastic halfspace. Assuming a response dominated by the fundamental mode, the authors investigate the sensitivity of the fundamental frequency to the elastic modulus and soil shear wave velocity and fit an empirical expression to the data obtained that is a function of both quantities. They show that based on the gust factor the effect of the foundation flexibility is to increase the dynamic component of the structure's response to the wind loading regime. Based on all the above, the bending moment at the base of the structure, which is an important design parameter, is then noted to be a function of elastic modulus, soil shear wave velocity and the mean design wind velocity. Using a second moment approximation, the authors then develop differential expressions for the mean value and variance of the base bending moment. From an example calculation using a normal distribution for the soil shear wave velocity, and a Gumbel distribution for the mean wind speed, the authors showed that base bending moment decreased as the mean shear wave velocity increased. For practical ranges of the soil shear wave velocity, this decrease was found to be as much as 20%. Even though the base bending moment was shown also to be a function of the elastic modulus, no mention is made of it in the example calculation.

### Dynamic Interaction Between Rail Track Systems and the Subsoil-Solution in the Frequency and Time Domin (2.24) by Savidis et al.

Savidis et al. studied dynamic behaviour of the track and the subsoil using finite element program ANSYS. An interaction problem was solved in frequency domain and Green's function representing subsoil was determined in the time domain. Although the method developed was substantially efficient, the results presented in the paper are only for homogeneous, linearly elastic and isotropic half space. They have also illustrated the developed method by a numerical example. Although the graphical visualization of the results presented is very good, a set of numerical results in tabular form may be better for readers (particularly for Fig. 7). Seventeen ties were considered in the frequency dependent flexibility analysis whereas only eleven ties were considered for simulation of moving wheel set. An explanation in this regard is desirable.

### Mathematical Modeling and Experimental Dynamic Investigation of an Elevated Foundation Supporting Vibration Machinery (2.40) by Vlad

In this paper, the author seeks to fill the gap existing between present sophisticated techniques available for the design of engineering structures, and the existing lack of use of these techniques in the design of elevated foundations supporting vibrating machinery; in this case a turbogenerator. The author develops two mathematical models of a 150MW turbogenerator foundation using two computer programs: one of medium complexity, using the program KONMAN 96; and another of high complexity, using the program SOLVIA 95. In verifying the accuracy of the two models, the dynamic characteristics of the two models are compared with measured estimates obtained from a spectral analysis of recordings obtained from selected points on the foundation, with the machine running at operating conditions. After initial calibration of the models using the measured data, the two models were reported as giving results that were in good agreement with those measured. The author went further to compute the response of the turbogenerator foundation to an imposed free-field motion, which the paper does not say much about. Dynamic stiffness coefficients of the foundation for both the lateral and rocking motions are shown in the paper, however, nothing is said about how these are taken into account in the two different computer models in which the foundation flexibility is taken into account. This is in contrast to the detailed explanation given for the manner in which the foundation itself was modeled. The author drew several inferences at the end. The author notes that non-structural elements could affect the response of the machine-foundation system, but says nothing about how non-structural elements were taken into account in both models. A comparison of this work with similar work done at the University of Western Ontario, Canada, would be of interest.