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General Report Session 5: Soil-Structure Interaction Under Dynamic Loading

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Soil-Structure Interaction Under Dynamic Loading

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Forty seven papers were submitted to this session, which can be grouped by subject as follows:

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SOIL-STRUCTURE INTERACTION: THEORETICAL ASPECTS
by J. Roesset

Although most dynamic soil structure interaction analyses are conducted in the frequency domain there have been in recent years an increasing number of solutions in the time domain using finite elements for the solution of nonlinear problems (nonlinear soil behavior or nonlinear contact problems) as well as boundary elements. For simplified structural analysis where the structure may behave nonlinearly it is convenient to be able to replace the soil by frequency independent springs, masses and dashpots, which can still reproduce the basic behavior. Excellent models of this kind were derived by Meek and Veletsos (1973), Verbic and Veletsos, and Veletsos and Nair. This last reference explained clearly the basis for the models, intended to reproduce the response of a rigid circular slab on a homogeneous half space. The case of a homogeneous soil layer of finite depth resting on a rigid base presents additional difficulties because of the existence of resonant frequencies and the absence of radiation below a threshold frequency. In their paper "*Lumped Parameter Model for Foundations on Layer*", Wolf and Paronesso present a method to derive lumped models with different degrees of complexity and accuracy for the case of a homogeneous soil layer. The simplest model has six parameters. Its agreement with the "exact" solution presented by the authors is excellent for the real part of the stiffnesses and dimensionless frequencies less than 1.25 in horizontal and torsional motion, 2.5 in rocking and 2 in the vertical mode. The imaginary part of the stiffnesses (damping coefficient) shows, however, radiation almost from the beginning and therefore is not so accurate. It is interesting to notice that when using more terms and, therefore, a much more complex model the agreement improves overall but there seems to be some negative damping for low frequencies. The significance of the errors committed by using these lumped models will depend, of course, on the particular problem considered. It may not be serious for seismic excitation but it could be very important for machine foundations with an excitation dimensionless frequency of 1.5, for instance. The authors apply the model to the study of the partial uplift of a rigid block on individual footings ignoring the coupling between the footings through the soil. This would seem to be a questionable assumption. Finally, in an appendix the general procedure is applied to model the water in a reservoir rather than a foundation. Although unrelated to the title of the paper this is another interesting application.

A considerable amount of research has been conducted during the last 20 years on dynamic soil structure interaction, from the derivation of new methodologies, to the implementation of computer programs and the development of a basic understanding of the nature of the problem and the significant parameters affecting it. It appears unfortunately, that most of this accumulated knowledge has failed to reach even the research community. It is surprising to find, for instance, that Sobath, Mahmoud, Gabr and Bahloul in their paper "*Nonlinear Seismic Analysis of Building Foundation Soil System*" are satisfied using frequency independent springs and dashpots, based apparently on suggested formulas for strip footings, to reproduce the foundation of a building on a soil layer of finite depth. They indicate that the depth of the soil layer is one of the parameters considered, but this seems to relate exclusively to the selection of the soil properties, based on the confining stress at middepth of the soil layer (in itself a rather poor selection criterion). The effect of the layer thickness on the foundation stiffnesses, their static values and their frequency dependence is otherwise ignored, as is the effect of the soil on the characteristics of the earthquake motion. It is always hard and dangerous to derive general conclusions in relation to soil structure interaction effects on the basis of the results of a small number of studies. This is the case here and the reader must be cautious to avoid being misled by some of the conclusions of this paper.

In their paper "*Dynamic Response of Foundations on Two Parameter Media*", Alvappillai, Zaman and Faruque attempt to use a two parameter Winkler foundation model which ignores inertia effects in the soil and simulates radiation damping by a parameter C_t (without any indication of how to select its value), to study the vertical vibration of a flexible circular plate under vertical loads. It is unfortunate that they do not compare their results to available accurate solutions as those presented by Whittaker and Christiano. An accurate solution of this problem can be obtained today at very reduced cost with many of the existing programs and formulations but if the authors prefer a mechanistic model to the use of the differential equations for the continuous formulation they should be aware that such a model has been developed by Nogami.

The vertical vibrations of one or more flexible circular mats are studied with a much better model of the soil by Lin and Adams in their paper "*A Hybrid Model for Soil Foundation Compliance*", using a substructure approach and Kausel's Green's functions to derive an influence matrix for the soil. The surprising factor in this paper is the use of linear expansion solid finite elements to model the mats. How a reduced number of these elements can reproduce accurately the flexural behavior of a plate is very unclear.

The vertical vibrations of flexible strip footings is the subject of the paper "*Dynamic Response of Flexible Foundations on Multilayered Medium*" by Wang Fuming. Plane strain, two dimensional problems, can be solved very conveniently by using the exact analytical expressions in the vertical direction for each layer, and expanding the solution in a Fourier series in the horizontal direction. (For a 3D problem in cylindrical coordinates one would have a Bessel expansion in the radial direction). This approach was used for instance by Gazetas to study the dynamic response of strip footings and rectangular foundations. More recently a similar formulation in which the exact solution is replaced by the name of the finite strip method. This is the formulation used by the author who assumes a smooth footing and tabulates the results of a series of studies.

Hybrid models combining boundary elements to obtain an absorbing boundary matrix and finite elements to model the core region have been successfully developed by Penzien et al, Tajimi and Lysmer among others and have been implemented in well known computer programs which can be applied to study three dimensional bodies of arbitrary shapes. Following the same basic idea of Penzien, Romanel and Knudu present in their paper "*A Hybrid Modelling of Soil Structure Interaction Problems*" the formulation for a much simpler two dimensional plane strain problem. The authors seem to be unaware of the more powerful hybrid models already developed. They are also unaware of the fact that consistent absorbing boundaries for layered media (rather than a homogeneous deposit) have been available for over fifteen years.

For the reader looking for a challenge the paper "*Deformation of Soil to Seismic Waves Reflected on Foundation*" by L. R. Stavnitser addresses the problem of one dimensional wave propagation in a bilinear elastic-plastic medium with complete reflection of the waves at the boundary, computing stresses and settlements. Although this is not really the case of a foundation and the paper is hard to read, the formulation is interesting.

Finally for the reader who has become tired of papers dealing with Soil Dynamics and Earthquake Engineering -the topics of this conference- the paper "*Nonlinear Analysis of Circular Plates on Nonlinear Foundations*" by Mahmoud, Gheith and Nassar, offers a change of pace since the problem addressed is unrelated to either subject. This paper addresses the large deflection analysis of plates (normally used for thin plates) with the horizontal displacement of the edges prevented by unspecified means, supported on a nonlinear but elastic Winkler foundation, and subjected to static vertical loads.

Many solutions to this problem (without the Winkler foundation) have been published in papers and books, using primarily finite elements. This paper uses instead a straightforward weighted residuals formulation with Galerkin's criterion.

SOIL-STRUCTURE INTERACTION: PRACTICAL ASPECTS
by A. Hadjian

The set of ten papers in this area come from the Soviet Union (2), Yugoslavia, Romania, Turkey, India and the USA (4). The central theme is the practical aspects of soil-structure interaction.

The paper by J.M. Ferrito ("*Interaction at the Waterfront*") is concerned with available constitutive models for porous media. Because of its waterfront mission, the Navy must site its fleet support facilities often on loose, saturated cohesionless soils with severe liquefaction potential. Therefore, to better understand the response of their structures to ground motions induced by earthquakes, the Naval Civil Engineering Laboratory undertook a review of material models to predict pore pressures and characterize soils in terms of effective stresses rather than simple total stress. Based on this review, it was concluded that the material model under development at Princeton (Prevost and colleagues) was capable to predict the behavior of cohesive and cohesionless materials. These models have been validated by centrifuge tests of a storage tank, a soil column and a footing. The paper gives comparisons of test and computed results which support the validity of the Princeton soil model. This model represents the soil as a two-component system, the soil skeleton and the pore fluid. The model is applicable to general three-dimensional stress-strain conditions, but its parameters can be derived entirely from the results of conventional triaxial soil tests. In addition to giving a theoretical background of the model, and comparisons of calculated and test results, the paper points out an important observation of practical importance: that directly under the structure, pore-pressure increase is slower and always remains lower than the pore-pressure in the free-field at the same elevation; thus, liquefaction predictions based on free-field data provide conservative estimates for what could occur under structures.

The measures being taken to protect historical buildings (churches, mosques, palaces, fortifications, etc.) against earthquake damage in Istanbul are reviewed by Nafiz Camlibel in the paper, "*Earthquake Damages Influenced by Soil Conditions in Historical Buildings in Istanbul*". Statistical records from 212 to 1967 show that the damage caused by earthquakes are more serious on buildings constructed on unstable soil than those on stable soil. The cracking of masonry structures is not considered a sign of imminent or eventual collapse, but rather a characteristic of masonry to adapt to its unstable environment. Structures, such as domed buildings that carry their load by compression, have survived numerous earthquakes, while those that have tensile stresses have cracked and collapsed several times during historical earthquakes. To protect historical structures against future earthquakes, a system of closely spaced piles around the structure is proposed. These piles are then connected with horizontal struts to the structure. An idealized single degree of freedom model using the lateral stiffness of the piles is formulated. Without showing any analytical or test results, it is claimed that "the seismic energy that would be absorbed by the structure can be reduced to zero according to the geometry of the piles, system dimensions and the absorbability of the piles". Since piles tend to enhance the high frequency components of ground motion, the effect on rigid masonry structures could be just the opposite. A more detailed evaluation of this solution is in order.

M.A. Klyachko and A.M. Uzdin present a discussion on the "*Peculiarities of Soil-Structure Interaction in Construction with Artificial Bases*". The Soviet code, "Construction in Seismic Regions," SNIP-11-7-81 allows the reduction of seismic design levels on high-compressible soils by two magnitudes, which is equivalent to a factor of 4 in ground motion accelerations, if a 5m deep artificial base is constructed with a modulus of 60MPa. Concern with a step wise change of a factor of four at 5m, led to a finite element study of the reduction of free-surface accelerations at the center of a circular pad relative to the free-field. A ground motion reduction curve, as a function of the thickness of the pad, is presented together with a curve for determining the horizontal extent of the pad. Thus, the effectiveness of a pad of any depth in reducing ground accelerations can be determined, eliminating the arbitrary 5m cut-off requirement. For example, for a 5m pad the free-field motion reduction factor is 0.63 and the extent of the required pad is 5.5 + B_o where B_o is the diameter of the foundation. A short discussion is given of a similar study for pile foundations without providing details or results.

Y. Ouyang, D.L. Allen, V.P. Drnevich are concerned with an "*Analysis of Bridges for Seismic Hazard Mitigation in Kentucky*". Bridges with at least on interior pier support with simple beam superstructures could collapse due to loss of support if the support length of the superstructure on the pier top is less than the sum of the maximum relative sliding displacement of the abutment and the maximum displacement at pier top during vibrations. To predict this type of collapse, the maximum resistance coefficient of the abutment is first developed as a function of the angle of internal friction and a dimensionless abutment weight based on the Mononobe-Okabi model. Using Newmark's energy balance method, the maximum relative sliding displacement of the abutment is calculated as a function of earthquake peak acceleration, peak velocity and resistance coefficient. The pier top displacement is calculated by a simplified single degree of freedom model and site specific response spectra. Using a spreadsheet computer program, 83 multiple span bridges with retaining wall type of abutment have been analyzed. Of these, 14 (17%) bridges may have the potential for support-loss type of collapse. Although no new grounds have been broken, the study is exhaustive and meticulous. All derived equations are presented in complete detail. This study is part of a larger study to determine whether about 300 bridges in western Kentucky might collapse during a recurrence of sizeable earthquakes in the New Madrid seismic zone.

Another paper concerned with bridges addresses the "*Soil-Structure Interaction Effects on the Response of Meloland Bridge*", by E.A. Maragakis, B.M. Douglas, S. Vrontinos and S. Abdel-Ghaffer. The experimental data obtained from two quick-release tests are used to develop a model of the Meloland bridge, including soil-structure interaction effects at both abutments and central pier foundation. The approach used was based on a system identification of the interaction springs and member properties. For the central pier foundation, the stiffness of the soil springs was also calculated using a finite-element model which provided acceptable results when compared to the values obtained from the system identification model. This paper could have been more useful if SSI effects had been quantified; the question is not whether there is soil-structure interaction but how significant it is. Nevertheless, the paper could be used as a vehicle for developing rules to construct models from basic structural data. These rules could then be applied to other bridges to perform blind response predictions of similar quick-release tests.

The results of a parametric study using the SASSI code are presented in the paper, "*Soil-Structure Interaction Analysis of a Deeply Embedded Reactor Silo*" by M. Longstreth, F.F. Tajirian and A. Appleford. Three sites are considered: stiff rock, linearly varying soil site (V_s 335 m/sec at grade to 762 m/s at the silo base) and soft site (V_s 335m/sec) overlying rock (2,438 m/s). The silo (18.3m diameter) is embedded to a depth of 48.9m. The top 9.1m of each silo is rectangular (22.9m and 40.8m). The results are as expected: as the free-field ground motion reduces with depth so does the response of the silo. For not very clearly stated reasons, the input to the silo at rock is assumed to be constant with depth. Irrespective of ground stiffness characteristics, ground motion reduces with depth and has its characteristic phasing with depth. As a result of this rather untenable assumption made for the rock site, any comparison of the response results of the soil sites with those of the rock site are misleading. It would have been interesting to compare the response of the silo walls to the free-field response at corresponding depths. This would have established the extent of the interaction effects for all three sites. Considering the rather significant depth of the silo, the implicit deconvolution results at large depths should have been verified by comparing with free-field parametric deconvolution results. Although the results of the structure-structure interaction are given qualitatively, it would have been useful to see some computed results. The problem with deeply embedded structures is not so much the acceleration response, but rather the imposed strains on the silo. The paper does not give any results on this problem.

The paper, "*Soil-Structure Interaction Effects Based on Recorded Strong Motions During Earthquakes*" by K. Talaganov and M. Curbrinovski presents results of the analyses of dynamic soil-structure interaction (SSI) effects for the Montenegro (Yugoslavia) earthquake of April 15, 1979 together with the results for one foreshock and four aftershocks. Three structures of essentially the same fundamental periods (obtained from ambient vibration measurements) but founded on three different sites are studied. Based on SSI models, free-field motions have been obtained for the two soft soil sites by dividing the building transfer functions by the recorded Fourier transformed foundation motions. By comparing peak accelerations and acceleration response spectra of the calculated free-field and recorded foundation motions, the effects of SSI on each building and each event were evaluated. In general, the recorded motions at foundations are larger for the entire range of periods, except for very low periods. Based on this observation it is concluded that records of strong earthquakes at foundations should not be considered as free-field motions and the need exists to consider the interaction effects incorporated in recorded ground motions.

Based on empirical data, the USSR Standard Building Code (Bridges and Pipes) provides a dynamic load factor for design loads on bridges. This load factor increases with the bridge span length, specially for metal structures, as a result of reduced damping with increasing span. In order to explain this effect, the paper "*The Soil-Structure Interaction in Bridge Dynamic Problems*" by E.V. Berezantsera, Yu. G. Kozmin and A.M. Uzdin proposes a model for the analysis of bridges considering soil-structure interaction effects of the pier foundations. The model of the base is composed of a two-mass system, including a reduced soil mass (m_1), and added soil mass (m_2) and two elastic-damping elements joined in series. Formulas are given to approximately calculate the parameters of the model. Numerical results show, similar to the experimental results, that the reduction of damping is associated with the increase of the span length, and hence increase of the period of oscillation, which results in a decrease of radiation damping at the base. A detailed analysis of the results also shows that the damping vs span relationship is mode dependent. The reduction of damping with span length occurs for the second mode (where the span structure and the piers oscillate in phase). For the third mode, where the span structure and the piers oscillate in antiphase, damping increases with span length. Similar trends in damping have been observed as a function of the increase of the foundation modulus.

The paper, "*Seismic Behavior of Bridges Considering Soil-Structure Interaction*" by S.K. Thakkar, P.R. Bose and D.K. Mazumdar, presents a comparative assessment of four different methods of soil-structure interaction analysis of two typical bridge substructures founded on alluvial soil. The coupled rocking-translation soil-springs used to represent the soil are frequency independent. The damping constants as provided by the different methods are not considered; instead, an equivalent stored strain energy weighted damping concept has been used. The four methods of analysis used are: Beredugo-Novak, Wolf, Bycroft-Parmelee and Terzaghi. System frequencies (periods) are comparable for Wolf and Bycroft-Parmelee models. Beredugo-Novak model gives slightly longer periods and the Terzaghi model gives significantly longer periods (about twice as long). These differences result in rather comparable responses for shear, moment, deflection and seismic equivalent coefficient for the first three methods. For the Terzaghi model, significantly less shear, moment and seismic coefficient are obtained, and deflections are significantly larger. In the absence of actual test data, the above results could only be used as a rough indication of the validity of the methods. More useful is the conclusion that the equivalent damping increases in the higher modes due to energy dissipation into the foundation material. A similar conclusion is made by Berezantscra et al.

The paper, "*Evaluation of Seismic Soil Structure Interaction (SSI) by Different Approaches*" by D.M. Ghiocel, T. Mauna and D. Ghiocel, presents results on two buildings using two different SSI analytical methods: 1) a general structural analysis program where the soil has been modeled only by its stiffness characteristics and inertial and radiation damping effects are missing; and 2) FLUSH Code. The buildings studied are a 9 story shear wall structure and a nuclear plant reactor building. For the latter case structure-structure interaction through soil (SSSI) is also evaluated. As expected, reduction of system frequencies and response due to SSI relative to fixed base models have been obtained. Also the influence of the heavier structure on the adjacent lighter structure during SSSI have been noted. Qualitatively these effects have been reported much earlier. Despite a rather detailed and meticulously performed study, the quantitative results should not be used as generic guidelines. With the existence of more sophisticated analytical tools (verified against actual earthquake data) that consider the inertial and damping effects of the soil (effects that Method 1 does not consider), 3D solution (FLUSH is 2D), input motions that consider the scattering problem, and the conservatism of structure-structure effects using 2D analyses, the reported results can only be viewed as qualitative trends for both SSI and SSSI.

The last two papers (Thakkar et al and Ghiocel et al) are similar to the extent that results obtained from different methods are compared. In the absence of test results the value of this type of comparisons is limited.

PILES
by J. Bielak

Fourteen papers in this session address issues related to pile foundations. They include theoretical and experimental studies, single piles and pile groups, and elastic and inelastic behavior.

Wu et al use a combined finite element and direct integral equation formulation to analyze the response of a single uniform or stepped floating pile embedded in a homogeneous elastic soil. They observe effects due to pile stepping but only at very high frequencies, corresponding to wave lengths comparable to the length of the pile. Bandyopadhyay employs a 3 x 3 x 3 finite element mesh to examine the forced axial response of a single pile-elastoplastic soil system, with a personal computer. In another study using finite elements to represent the pile and an integral equation method for the elastic soil, Ahmad and Mamoon study the response of a single floating pile due to obliquely incident plane SH-, SV-, and P-waves. At low frequencies, slender piles essentially follow the soil, while short piles tend to remain straight. At high frequencies, on the other hand, the motion of both slender and short piles can be reduced significantly. It seems, however, that these frequencies are too high to be of practical interest for a single pile.

Three separate papers, by Ilyichev and Shliakin, Babu, and Arya and Arya, are concerned with the development of methods for analyzing the steady-state axial and lateral response of groups of piles which are perfectly bonded to a linearly elastic soil. The first two papers use the theory of elastic wave propagation to deal with a set of point bearing piles in a layer while the third one combines the dynamic stiffness of a single pile with static pile-to-pile interaction coefficients. In a related work, Kagawa examines the effect of employing different levels of soil-pile compatibility conditions on the seismic response of axially loaded pile groups. He finds that representing a pile only by its axis in the study of pile-soil-pile interaction can lead to significant errors for very high frequencies of excitation, as may occur in problems of machine vibrations, but not for seismic response.

Kobori an his coworkers carry out a careful experimental and analytical investigation of the effect that soil backfill and grouting of the pile head and a superimposed base mass have on the dynamic response of a pile foundation. The study is limited to small vibrations so that test model and surrounding soil remain within the linear range. Grouting of the base mass to soil increases the resonant frequency and reduces peak response by about 50 percent. Addition of backfill effectively precludes the vibration of the mass. The analytical procedure is effective in predicting the lateral displacement but not the rotation of the mass.

Nagataki and Senno propose to use ground walls embedded on the periphery of a pile foundation to reduce the dynamic load acting on the piles during earthquakes. Small scale shaking table tests and a finite element analysis were conducted to demonstrate the feasibility of this technique. Results show a reduction of about 40 percent in pile head moment due to the presence of the ground walls.

A simple analytical procedure for evaluating dynamic response of soil-pile-structure system during liquefaction is presented by Nomura et al. The structure is supported on a single pile, idealized as a set of springs and lumped masses surrounded by a one-dimensional soil column which is analyzed using an effective stress procedure for free-field soil response. Results from the analytical model exhibit a remarkable agreement with results from shaking table tests. Since the actual pile-structure model is rather simple, this study provides an excellent verification of the effective stress analysis.

Purkaystha and Day carry out an experimental program of small scale model tests to study degradation effects in piles subjected to vertical cyclic loads. They examine the influence of several parameters in both displacement controlled and load controlled tests, including the number of cycles, loading rate, maximum load, and maximum displacement. All these parameters have a noticeable effect.

Authors of paper 5.51 untitled and anonymous (Nogami and Otani?) present an analytical model consisting of Winkler type foundation for calculating the response of one and two piles. The elastic impedance is represented by a set of spring-dashpot elements in series which are introduced to approximate the behavior of a plane strain model. While this model is formulated only in the frequency domain, the springs and dashpots allow calculations directly in the time domain. An inelastic element is added to the system in order to model slip and gapping between pile and the surrounding soil.

Nogami et al conduct a numerical study of the seismic response of a structure supported on a pile foundation embedded in a fixed-base layer, with a view toward examining the errors caused by frequently used approximations. They investigate, in particular, the effects of using frequency independent springs and dashpots for the Winkler subgrade model; neglecting the effect of piles on input base motion; and neglecting pile to pile interaction. The authors show the latter effect is extremely significant. It seems fair to state, however, that most pile group studies today take this effect into consideration, at least approximately. Authors find that errors due to the first two approximations can also be significant, especially if the shear wave velocity of the layer increases with depth.

Kobayashi et al present a detailed experimental and theoretical study of the inelastic dynamic behavior of a 3 x 3 point bearing pile group model under forced loading. Results of the dynamics tests demonstrate clearly the highly hysteretic nature of pile response. The compliance of a single pile in the lateral and axial directions is determined experimentally in the field from static loading tests with large enough loads to produce slipping and gapping of the pile, and plastic deformations in the surrounding soil. The experimentally determined compliance is combined with a conventional plain strain wave propagation theory for evaluating the interaction between two piles in order to develop an approximate procedure for obtaining the overall system compliance. A comparison between experimental and theoretical results due to dynamic loading indicates that purely elastic analyses cannot explain the observed pile group behavior. Only by introducing the nonlinear behavior into the mathematical model did it become possible to obtain a satisfactory agreement between experimental and analytical results.

From the papers on piles presented in this session and from the work of other investigators it appears that additional research is required in order to fully understand the effect of inhomogeneous deposits on the dynamic response of pile foundations. Experimental work is needed to better assess nonlinear effects on dynamic pile foundation response, including slip, gapping, and soil degradation; and work on simplified analytical techniques for incorporation these effects in design should be continued.

EXPERIMENTAL METHODS AND SOIL RESPONSES
by G. Martin

Kanatani, Nishi, Touma, Ohnami and Namita in their paper on "*Numerical Simulation of Shaking Table Tests by Non-linear Response Analysis Methods*" describe a finite element numerical simulation of site and soil structure interaction response on saturated sands. The analysis is based on Biot's theory for saturated porous materials coupled with elasto-plastic constitutive relations to simulate non-linear characteristics of soils. Shaking table tests were conducted on samples of saturated sand, and material constants for analyses were obtained from monotonic and cyclic loading triaxial tests. The authors were able to numerically model laboratory test results (expressed as variations of shear modulus with shearing strain amplitude and liquefaction strength curves) with a reasonable degree of accuracy. Shaking table tests were performed in a container whose width, height and depth were 6 m., 1 m. and 1 m. respectively. A structural model whose width, height and depth were 0.6 m., 0.6 m. and 0.8 m. respectively, was buried in the sand. Response during dynamic loading was measured with accelerometers, pore pressure gauges and displacement transducers. Whereas comparisons between computer and experimental results for time histories of accelerations at various locations are generally favorable, comparisons between computed and experimental results for time histories of settlement and pore pressure increase showed significant differences. This indicates either deficiencies in the numerical model used or difficulties in saturating the sand. Difficulties in correctly modelling the boundary conditions for the model test may also have been a factor.

In their paper on "*Seismic Effect Evaluation for Underground Space and Structures*" Wang and Li examine the causes of the observed lack of damage in underground tunnels versus the heavy damage to surface structures which occur during strong earthquakes. The following factors related to damage potential in underground structures are identified:

A. The geometry of the underground space or structure
B. Its depth of embedment
C. Its lining conditions
D. The lithology of the ambient geologic formations
E. The character of the input earthquake wave source

By performing regression analyses on over 105 underground structures damaged in earthquakes of varying intensities, methods for evaluating underground earthquake intensity versus surface intensity are established.

Mori and Kondo in a paper on "*Experimental Studies on the Dynamic Behavior of Soft Clay Ground Structures Supported by Friction Pile Foundations,*" present shaking table test results simulating a multi-storied structure founded on long friction piles in soft saturated clay. A large experimental tank containing a consolidated clay slurry was used for tests.

A four story building on friction piles was modelled using model similitude laws. Input accelerations at the base of the shaking table were up to 0.36g. Undisturbed samples taken from the tank were used to perform cyclic triaxial tests to characterize stress-strain behavior and pore pressure increases during cyclic loading. Time histories of accelerations, pore pressure increases and vertical and horizontal displacements were measured during shaking table tests. Excess pore pressures generated in normally consolidated clays were greater than those in over-consolidated clays as expected. However it is believed that interpretation of the test data with respect to both the magnitude of pore pressure increases and observed pile settlements is complicated by side effects from the tank. Side effects influence the shearing strain distribution within the tank which in turn will influence the magnitude and distribution of pore pressure increases and resulting pile settlements.

The paper by Luong on "*Dynamic Behavior of Slender Structures on their Pre-stressed Foundations*" presents an innovative experimental approach to the study of foundation systems for over head line or transmission towers. The paper presents a summary of the various foundation types used for transmission towers including concrete pedestal footings, pile foundations and pre-stressed foundations. Such foundations comprise anchorage elements driven or propelled into the ground and pre-stressed by a pre-stressing force applied between the anchoring device and a concrete slab founded on the ground surface. The advantage of this foundation system is that it ensures a quasi-elastic response to dead and live loads with higher modulus values and much smaller settlements than those of other foundation types. The paper outlines an experimental study using a centrifuge to examine the cyclic and transient response of pre-stressed pylon foundations, and also full scale vibratory tests on overhead line towers. The latter present the results of a series of cable slacking tests conducted on overhead line towers in France on 3 types of foundations. The technique which induces free vibrations, allows the development of a method for integrity control and inspection of foundation systems. Numerical simulations of the vibration modes are also described.

The paper by Inukai, Imazawa, Izumi and Tanimoto and that by Miyamoto, Izumi and Nasuda, both address "*Experimental Studies on Embedded Soil-Structure Interaction.*" Both address the problem of the earthquake response of partially embedded nuclear reactor buildings (rigid stiff structures) by undertaking forced vibration field test programs on 1/10 scale models (8m x 8m square foundations and 10m high structures, buried 5m in the ground). Sinusoidal forced vibration tests were performed with and without backfill. The response as a function of frequency, was measured by displacement transducers on the structure, by accelerometers in the backfill and surrounding soil, and by earth pressure gauges on the foundations. Test results (resonance curves, phase shifts and impedance functions) clearly show that embedment significantly reduces vibration amplitudes due to radiation damping. In the study by Inuaki et al, the model structure was founded on rock, and embedment had little effect on natural frequencies of vibration (about 10hz). In the study by Miyamoto et al, the model structure was founded on a soil layer, and embedment increased natural frequencies due to the increased lateral stiffness. In this study, theoretical analyses were also performed comparing elastic wave propagation solutions (for horizontal and rocking foundation vibration modes) with finite element solutions (incorporating transmitting boundaries). In both cases theoretical solutions compared well with experimental test results.

Hu and Xia in their paper on "*Seismic Response Analysis of a Thick Overburden Consisting of Loose and Soft Soil,*" present one dimensional site response analyses (assuming vertically propagating shear waves) of deep soft soil sites (300m to bedrock) representative of sites in the Shanghai area. Soft clay shear wave velocities range from 100 to 400m/s. Response analyses assume equivalent linear behavior, with shear moduli and damping ratios a function of shear strain. Analyses use a modified El Centro earthquake record (1940N-S) as input motion) peak accelerations = 0.1 and 0.05q) both at bedrock level and at depths of 50, 100 and 200m. It is not clear if a transmitting boundary was used for the latter cases. Results, expressed as acceleration response spectra, clearly show the effect of the deep soft site profiles in increasing spectral ordinates at longer periods (1-4 seconds).

Maher, Lacy and Venancio-Filho in their paper on "*Effect of Soil Treatment on the Dynamic Response of Machine Foundations*" present an analytical study on the effects of grouting a clean sand foundation soil (with fly ash cement, lime/cement or sodium silicate) on the dynamic response a specific machine foundation (10 ft high and 10 ft wide strip footing) and vibration system. The study first presents laboratory resonant column test data showing how dynamic shear modulus values increased with grout treatment. A finite element analysis using the computer program DYNAFLOW (coupled with viscous transmitting boundaries) was used to model the effect of grout type and extent beneath the foundation, on amplitudes of vertical, sliding and rocking vibration. Reductions in amplitudes of 50-76% were observed. However, as the natural frequency characteristics of the untreated soil-foundation system are not reported, it is difficult to draw generalized conclusions.

The paper on "*Seismic Fluidization and Foundation Behavior*" by Richards, Elms and Budhu, examines the question of bearing capacity of shallow foundations resting on dry sand foundation soils subjected to horizontal earthquake loadings. The study shows that due to horizontal inertial stresses acting on the foundation soil, active and passive slip lines form. Eventually horizontal slip lines form when acceleration amplitudes reach high critical values (a function of friction angle) a state of general "fluidization" is reached. Transient reductions in vertical bearing capacity and corresponding progressive accumulation of vertical settlement occurs. The phenomenon is illustrated by a series of shaking table test on a dry sand supporting a cylindrical foundation. The theory is used to derive classical Prandtl-type bearing capacity factors for foundation soils under seismic loading, as a function of maximum horizontal accelerations. If limiting coefficients are exceed in an earthquake, incremental vertical displacements will occur, which suggests a displacement control philosophy for seismic design of foundations. It is important to note that lateral inertia forces acting on foundations from structural loading, would reduce bearing capacity further.

Truong, in a paper on a "*Parametric Study of Horizontal Permanent Displacement on Sand*", describes an experimental laboratory study where model footings resting on a dry sand, were subjected to static and superimposed cyclic loads of varying intensities in a horizontal direction. The paper primarily addresses the question of long term cyclic loading and displacements arising from wind or vehicle loading. During tests, permanent horizontal displacements were recorded as a function of static and cyclic load conditions, level of rocking motions and frequency. Results were interpreted qualitatively in relation to a simple yield theory.

The paper by Musaev on "*Testing of Stressed State in the Structure-Base System under Non-Stationary Dynamic Effects*", describes the application of a finite element method for the solution of two-dimensional dynamic elastic and elasto-plastic problems. The method is illustrated with respect to underground openings and structural foundation systems.

PIPELINES
by E. Kausel

Akiyoshi and Fuchida ("*Anti-seismic Reinforcement of Pipelines in a Liquefied Ground*") propose a method for reinforcing pipelines so that they can withstand the effects of ground liquefaction. In their view, there are two methods for accomplishing this: either the ground is improved so that liquefaction effects are minimized or eliminated, or the pipeline is designed with protective or supportive devices such as flexible couplings, piling, and so forth. In the scheme proposed and analyzed by the authors, the pipeline is constructed with expansion joints and is stiffened with pipes of small diameter that are placed parallel to the pipeline, and are attached to it with metal plates placed at regular intervals. They conclude from their numerical analyses that the proposed scheme is effective in providing seismic protection to pipelines, and that it offers advantages over other competing methods. However, the mathematical model used by the authors -in essence a set of beams on a bilinear (elastic ?) foundation- is based on rather drastic simplifications of the problem at hand, and the validity of some of the parameters and idealizations may be questionable; hence, it analyses the seismic response of a pipeline using simple mechanical idealizations for this problem in the context of a random vibration approach. The ground motions used for these models were inferred from data obtained from the SMART-I instrument array in Taiwan. Loh observes that the differential ground displacements are due, in part, to phase delays associated with long period wave components. In his study, he ponders also the influence of local soil amplification, local inhomogeneities, spatial coherence of the ground motion, the input spectrum (motion on firm ground), and the epicentral direction. He concludes that soil inhomogeneities have a significant influence on pipe response, even over short distances; indeed, he believes these variations in local soil stiffness to have a more important effect on pipe response than the spatial variation of the ground motions, and that this response is sensitive to the epicentral direction of the earthquake.

Finally, Zhang and Wang ("*Lateral Stiffness and Damping Coefficient of Soils for Seismic Analysis of Buried Pipelines*") present the results of a study on the coefficients of subgrade reaction for a pipeline that is buried a certain depth in the ground. In the paper, the authors propose formulas for the complex coefficients of subgrade reaction that contain the embedment and Poisson's ratios as parameters, and which are linear in the frequency of excitation (i.e., they can be interpreted as frequency independent Winkler springs K and dashpots C). To arrive at their results, Zhang & Wang consider a homogeneous elastic halfplane (two-dimensional halfspace) subjected to a harmonic line load whose axis coincides with the axis of the pipeline, and which acts horizontally in a direction perpendicular to the axis. They then estimate the inverse of the coefficient of subgrade reaction (i.e. the dynamic compliance) as the average motion of the circumference that defines the pipeline-soil interface (but before the soil is excavated and the pipeline is installed). While the results presented are interesting, some comments are in order. First, the stiffness coefficient K cannot really be independent of frequency, because the halfplane does not have a static stiffness; this contradiction is perhaps due to limitations of the numerical model used. Second, K almost certainly does not attain a zero value when the depth of embedment is taken as zero; instead, it probably should approach a value that is half as large as that for a full space (i.e. half the asymptotic value for large embedment). Third, the compliance computed contains the inertia forces corresponding to the volume of excavated soil; these forces should have been subtracted. Finally, the authors include the effect of hysteretic losses in the soil by simply adding the material damping ratio to the radiation damping coefficient; this is not an appropriate procedure. Instead, a complex frequency and a complex shear modulus should have been considered.

TRANSMITTING BOUNDARIES
by E. Kausel

Transmitting boundaries are mathematical devices used at the edges of models of infinite media with finite elements or finite differences. The purpose is, of course, to simulate with a finite model an infinite one. The only paper in this group is that of Z. Wang ("*A Comparison and Study on Artificial Boundaries: Conceptual Aspects*"), who reviews some available alternatives for these devices. Unfortunately, this paper incurs in many serious misconceptions and errors. For example, the author states that artificial boundaries must be "frequency independent". This is not so; in fact, many are not, including the viscous boundary (whose impedance changes linearly with frequency). Elsewhere, he states that the transmitting boundary of Liao-Wong can perfectly absorb waves coming from any direction and is superior to other schemes, or that the consistent boundary of Lysmer-Waas involves substantial error and that it is based on a one-dimensional approximation; both of this statements are patently and demonstrably wrong. These, as well as other errors in the paper force me, unfortunately, to dismiss this work as unsuitable for further reference.

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