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General Report — Session 5

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A: SOIL-STRUCTURE INTERACTION UNDER DYNAMIC LOADING FOR BOTH SHALLOW AND DEEP FOUNDATIONS

B: SOIL-FOUNDATION INTERACTION TRIGGERED BY SEISMIC FAULTING

GENERAL REPORT ON SESSION 5

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INTRODUCTION

Session 5 includes an ensemble of fifty four papers that may be broken down as follows

A) In terms of general content:

– Forty-nine that deal with Soil-Structure Interaction (SSI) under Dynamic Loading, both for Shallow and Deep Foundations, and
– Five that deal with Soil-Foundation Interaction Triggered by Seismic Faulting

B) In terms of country of origin: 12 are from the USA, 10 from Iran, 7 from Greece, 7 from India, 5 from Italy, 3 from Japan and France, 2 from the UK and 1 from the Netherlands, Ireland, Australia, Korea, New Zealand, Russia, Serbia, Germany, China and Bangladesh.

A significant portion of the papers represent important contributions to the subject of SSI, both from an experimental as well as an analytical viewpoint.

PAPER REVIEWS

In what follows, the papers are briefly summarized and their conclusions discussed. The listing of the papers is based on their code number for this session.

<u>5.01a</u>

Chatterjee and **Basu** in "*Non–Stationary Soil-Structure Interaction Analysis of a SDoF System Subjected to Joint Horizontal & Vertical Seismic Excitations*" present a formulation for obtaining non-stationary response of a single-degree-of-freedom system resting on a single homogeneous soil layer medium subjected to simultaneous horizontal and vertical seismic excitations. The system equations are solved in the wavelet domain and closed-form solutions are derived for the response of the structure and the foundation. The goal is to accurately estimate the non-stationary response in cases where seismic excitation is active simultaneously in both horizontal and vertical directions. Nevertheless results are presented for horizontal seismic excitation only.

<u>5.02a</u>

In *"Seismic analysis of pile group using pseudosatic approach"* **Elahi**, **Moradi, Poulos** and **Ghalandarzadeh** propose a simple approximate pseudostatic method for estimating the maximum internal forces and horizontal displacements of a pile group subjected to lateral seismic excitation. The pseudostatic method pioneered by Tabesh and Poulos is extended to account for pile group effects and is modified to handle soil non-linearity. The piles are modelled as Euler-Bernoulli beams, discretized using the finite difference method. The soil is modelled as an elastoplastic material with its elastic part to follow Mindlin fundamental solution, so that an arbitrary pile element can influence elements of all piles in the group. The analysis is divided in two main parts: Firstly, the earthquake induced free-field motion is computed; since vertically propagating SH waves comprise the seismic excitation, the free-field response is obtained using wave propagation software such as SHAKE or ERLS. Secondly, the maximum values of the free-field motion obtained are applied to each pile as an external static soil displacement profile. A static analysis is then carried out to obtain the maximum bending moment and shear force developed in the pile due to earthquake loading. Displacement compatibility is enforced between the soil and the pile in the elastic regime. When soil yielding occurs at pile-soil interface, the condition is that pressure at all interface elements equals the ultimate lateral pressure of the soil.

Data obtained from dynamic centrifuge tests of pile-supported structures in soft clay over dense sand (base accelerations from 1995 Kobe and 1989 Santa Cruz records) and from the instrumented pile-supported Obha-Ohashi bridge in Japan which experienced a real earthquake are used to evaluate the performance of the proposed pseudostatic model. With reference to the centrifuge tests, the calculated and measured results are in reasonable agreement for both pile head moment and horizontal displacement. The computed results are in acceptable agreement with the field data for vertical piles and in good agreement for batter piles. Also, it is demonstrated that the inertial effects are relatively small, contrary to dominant kinematic effects. In this case group effects are considered as beneficial. Additionally, ignoring group effects may result in unrealistic determination of pile moments. Finally, a practical question arises as to the appropriate conditions to rely on the pseudostatic approach.

5.05

In an article titled "*Nonlinear Soil-Pile Interaction under Vertical and Coupled Motion*", **Manna** and **Baidya** present experimental results of the response of a single pile and of a 2x2 group of piles subjected to vertical and combined horizontal-vertical dynamic loading. The test results are compared to the corresponding theoretical ones from Novak and Sheta (1980) approximation. According to the latter the pile is represented as an embedded cylindrical body surrounded by a linear viscoelastic medium composed of two parts: an outer infinite region, and an inner "weak" layer that accounts for soil inelasticity at the near field. By matching the measured and theoretical results through a trial-and-error optimization technique, the authors result to closed-form expressions that relate the length of 'post-holing' to the maximum applied vibration amplitude.

5.08

In "*Estimation of Lateral Load Capacity of Short Piles under Earthquake Forces*", **Chowdhury** and **Dasgupta** present an analytical procedure for calculating the seismic response of pile-column systems. The developed procedure is based on a beam-on-Winkler foundation theory and can be easily implemented into a spreadsheet (such as MS Excel) for design purposes.

5.09

Prowell, **Elgamal** and **Lu** present a detailed 3D finite element model to investigate the influence of soil-structure interaction on the seismic response of a 5 MW wind turbine. Analyses are carried out in both the time and frequency domains with the computer code OpenSees (Mazzoni et al. 2006), assuming linear elastic behavior of the soil and the superstructure. The reported results indicate that SSI effects are of rather minor importance for relatively stiff soils, and of moderate importance for softer soils. Nonetheless, the design of the turbine is usually controlled by serviceability limit state criteria which overshadow the SSI effects. The authors conclude, however, that with current trends towards taller and more massive turbines (Wiser and Bolinger 2008), it is important to conduct further SSI research as an integral component of seismic response studies.

5.10

In "*Seismic Performance of Double EPS Geofoam Buffer Systems*" **Trandafir** and **Bartlett** present the results of a dynamic finite-element analysis addressing the effectiveness of a double expanded polystyrene (EPS) geofoam buffer system in reducing the peak seismic loads on a rigid, non-yielding retaining wall during an earthquake.

Contrary to the conventional isolation approach, a double EPS geofoam buffer system involves two vertical EPS panels, one placed against the rigid wall face and another installed at a specific distance away from the first panel in the backfill soil. Sensitivity analyses of the seismic performance of the double EPS geofoam buffer system in relation to the spacing between the EPS panels indicate that there is an optimum EPS panel spacing at which the seismic isolation efficiency of the double geofoam buffer system is maximized. Additionally, a comparative numerical study of the seismic response of double and single EPS geofoam buffers revealed that a double geofoam buffer system with an optimized EPS panel spacing is more efficient than a single panel EPS geofoam buffer for the same total thickness of EPS. The study is intriguing and could be of great practical value if issues related to installation of such double systems are addressed.

5.11a

Yang, Kwon, Choi and Kim report findings from a combined analytical-experimental study focusing on calculation of natural frequencies of pile-soil systems subjected to earthquake loading. The article is titled *"Natural Frequency Calculation of a Pile-Soil System in Dry Sand under an Earthquake loading"*. To this end, a simple mass-spring model is employed consisting of a diagonal 4 x 4 mass matrix for pile inertia and a corresponding stiffness matrix. Soil stiffness is represented by concentrated springs at different elevations. Encouraging results are obtained though comparisons against results from 1-g shaking table tests. In some cases the discrepancies between theory and experiment did not exceed 5%.

5.12a

In their paper "*Effect of uplift modeling on the seismic response of shallow foundations"*, **Wotherspoon** and **Pender** present the development, but mostly the response of a numerical model for the simulation of uplift and re-attachment of shallow foundations during seismic loading. Firstly, a comparison of existing numerical models simulating the uplift response of shallow foundations using spring elements shows significant differences in the moment-rotation response with the progression of uplift. Hence, a modification of the Ruaumoko non-linear element is introduced, that consists of making the vertical loads carried by the foundation control the rotational and horizontal characteristics, leading to reduction of stiffness of all DOFs as the footing progressively uplifts. Combining shallow foundation models with a simple frame model under seismic loading (4 different time histories scaled at 0.5g) shows that uplift modeling has a significant impact on the shear and moment actions carried by the footings. Hence, the distribution of actions across the structure becomes non-uniform, and in some cases the peak column base actions of the outer columns increased significantly. These indicative results show that ignoring soil-structure-interaction as beneficial (when applying code spectra in design) may prove non-conservative if uplift is ignored.

5.13a

Zhai in his paper *"Numerical modelling of soil-pile interaction in liquefying soils for a water crossing bridge"* presents a practical methodology for developing p-y curves for pile foundations in liquefying soils. For this purpose, the excess pore pressure ratio r_u developed during seismic loading is required and is estimated for various depths using 2D non-linear analyses with FLAC. In particular, a user-defined-model in FLAC is used that employs a pore-pressure-generation model combined with a Mohr-Coulomb non-linear model. Then, the p-y curves with depth are estimated, as: a) by retaining static curves when $r_u < 0.2$, b) by using clay curves with liquefied residual strength when r_u approaches 1.0 and c) by using a reduced friction angle on the basis of r_u for intermediate values of r_u. For analyzing the pile foundation, a FLAC SSI model was built including the prescribed pile and equivalent masses from the superstructure to capture the inertia loads, while retaining the foregoing p-y curves for the pile-soil connections. It is shown, that the computed pile bending moments and shear forces show reasonable resemblance with more "traditional" analyses using LPILE with the same p-y curves and same permanent soil-pile differential movements. This type of analysis is considered useful before considering ground improvement, especially for deep-seated liquefiable layers as the one considered in the real-case study presented in the paper.

5.15a

In their paper "*Effect of liquefaction on pile shaft friction capacity"* **Stringer** and **Madabhushi** present experimental data from two dynamic centrifuge experiments of a 2x2 pile group in two layer profile of a dense sand overlaid by a layer of loose sand. The piles were axially loaded and the models were loaded with 20 cycles of roughly sinusoidal motion of 0.18g (prototype). The difference between the 2 tests is that one is performed for saturated soil, and the other for unsaturated soil conditions. The analysis of the test results aims at depicting how axial loads are carried by piles during earthquake loading. In particular, the dry sand experiment shows that the piles mobilize additional shaft friction to carry the seismically induced axial loading with little load being transferred to the base of the pile and very small observed settlement. On the other hand, the saturated sand experiment shows that the pile group undergoes large settlements due to loss of skin friction in the overlying liquefied layer, which resulted in an attempt to mobilize additional end bearing capacity. Dissipation of excess pore pressures follows the end of shaking and is complemented with soil settlement, which results in significant drag down forces that counterbalance the skin friction and lead to another attempt of mobilizing additional end bearing capacity.

5.16a

Eisenberg presents a review of methods pioneered in Russia and former Soviet Union for the seismic protection of structures on the basis of modification in vibrational characteristics via "switch-off" elements and other adaptive control measures. Although only a general overview of the methods is provided and most of the references are from Russian or Soviet sources, the discussed approaches appear to be interesting, especially given that have been developed independently of corresponding approaches in the West.

5.17a

In the study titled "*Seismic soil-pile interaction: physical processes and analytical models*", **Malhotra** presents a discussion of available models and modifications to p-y relations used to model soil response under seismic conditions. The aim of this study is double: In the first part, the physical processes that occur when a pile-supported structure is subjected to seismic loads is described and the individual effect of each process on the lateral response of piles is elucidated. In the second part, available p-y based analytical models are employed to evaluate piles subjected to seismic loads in liquefiable soils. The predictions of the models are compared to data obtained from actual load tests at two sites. The main conclusion of the study is that further research is needed to quantify and predict gap formation, the stress strain behaviour of liquefied soils and to accurately evaluate non-linear bending resistance of steel encased concrete sections.

5.22

Anoyatis and **Mylonakis** in paper titled *"Dynamic Winkler Modulus for Axially Loaded End-Bearing Piles"*, exploiting the concept of the dynamic Winkler foundation in conjunction with a simple wave propagation model, showed that depth-dependent Winkler springs and dashpots may faithfully describe pile-soil interaction, contrary to common perception that the Winkler model is always approximate. The results are obtained in closed-form solutions for: (i) the displacement field in the soil and along the pile; (ii) the impedance coefficients (stiffness and damping) at the pile head; (iii) the depth-dependent Winkler moduli along the pile; (iv) the average, depth-independent, Winkler moduli to match the impedance coefficient at the pile head. The predictions of the model compare favourably with established solutions from the literature, while new results are presented. Their analysis leads to the following interesting conclusions: (1) Dynamic Winkler modulus, like its static counterpart, is depth-dependent even in homogeneous soil; (2) pile-soil interaction is mainly governed by wave propagation in the soil, not on the pile; (3) reducing soil stiffness (a conservative assumption in the realm of static analysis) leads to an increase in radiation damping, thereby it may result to non-conservative estimates of dynamic pile response; (4) In the high-frequency range, storage stiffness of Winkler springs is independent of pile slenderness. They remark, however, that the applicability of the model is limited by the assumptions of linearity in soil and the pile material, as well as perfect bonding at the pile-soil interface.

5.23

In paper *"Influence of Dynamic Soil-Structure Interaction Analyses on Shear Buildings and Towers"*, **Renzi**, **Mylonakis**, **Vannucci** and **Madiai** present a study which explores the influence of soil-structure interaction on the seismic response of shear buildings. The shear-type structure is modeled as a generalized Single-Degree-of-Freedom (SDOF) system using the principle of virtual displacements.

The foundation consists of surface square foundations resting on different types of soil, consistent with the provisions of EC8. Finite element analyses are performed in time domain through the use of recorded acceleration time histories, with reference to a set of idealized shear-building configurations. Key characteristic dimensionless parameters are utilized to describe the seismic response of the studied soil-structure systems, with due consideration of their geometrical and mechanical properties. Their results reveal that the effective fundamental period of the soil-structure systems increases with increasing depth to bedrock and size of the footings, and that significant changes in seismic demand are observed for softer soils, stiffer and taller structures.

5.26a

Ghadimi investigates the 3-dimensional dynamic response of pile groups embedded in transversely isotropic media subjected to multi-axial harmonic loading in a paper titled "*Dynamic Response of Pile Groups Embedded in Transversely Isotropic Media Using Hybrid Numerical Method"*. A promising method is presented treating the problem as a superposition of finite-elements for the piles and radiation disks for the wave transmitting soil. The method appears to be efficient and could be of practical value for groups containing a large number of piles. A systematic validation of the method against existing solutions would be desirable.

5.27a

In "*Experimental soil-foundation-bridge pier interaction: towards a reversal of capacity design*" **Anastasopoulos, Georgarakos, Drosos** and **Gazetas** present the experimental data from a series of shaking table experiments of a simplified physical model of a bridge overlying a layer of very dense sand (85% relative density). The aim of these tests is to experimentally verify the potential effectiveness of a new seismic design philosophy, in which soil failure is "utilized" to protect the superstructure. For this purpose, the response of an under-designed foundation of the bridge pier is compared to that of an over-designed foundation (conventional practice) under a series of real accelerograms and artificial sinusoidal motions. The results show that for moderate seismic shaking, both design alternatives lead to acceptable performance (minor flexural cracking in the latter, tolerable deck drift and settlement in the former "novel" approach). On the contrary, for large intensity motions (that exceed the design earthquake) the conventional design leads to bridge pier collapse, whereas the "novel" approach survives the shaking at the cost of significant deck drift and settlement.

5.30a

In their paper "*Centrifuge tests and simple analyses for seismic soil-structure interaction"* **Tamura, Adachi** and **Tokimatsu** present the results and simplified analyses of experimental data from dynamic centrifuge tests performed on a superstructure-footing model that was placed on a very dense (90% relative density) dry sand layer and underwent two earthquakes, one of 0.06g and another of 0.25g. The experiments were performed at 40g centrifugal acceleration and the soil model was placed inside a laminar box. The dry sand site amplification was successfully modelled with SHAKE91 and shear modulus and damping ratio curves from the literature. Similarly, the response of the simple superstructure-footing model (1-DOF for the superstructure and 2-DOF for the footing mass) was modelled successfully given the input motions estimated by SHAKE91. Yet for the high intensity (0.25g) motion test, and in order to accurately model the superstructure response, the soil nonlinearity must be much larger than originally depicted by SHAKE91 for the free-field response. This intense non-linearity is also depicted by relative displacement and base friction measurements of the footing response in this test.

5.31a

In *"Investigation of Vibration Caused by Traffic and Railway Load"* **Gordana** and **Stanko** present two examples related to investigation of vibrations in civil engineering structures. In the first example it is shown how it is possible to reduce vibrations caused by moving trains in underground structures with the use of special elastomers. It is shown by means of dynamic analyses that the use of polymers is important in engineering practice to reduce structural vibrations. The second example refers to foundations for special equipment such as electronic balances, which are very sensitive even to small displacements. Simple dynamic analyses are employed to determine the vibrations caused by heavy traffic loads and obtain optimum foundation solutions. The results of the investigation show that under carefully performed designs, maximum dynamic motions transmitted to the foundation can be lower than the maximum allowed.

5.32

In *"Seismic Response of Barrage Raft Floor under Heterogeneous Soil Medium"*, **Venkatesh**, **Pandey** and **Samadhiya** present finite-element analyses of a barrage raft floor resting on homogeneous and heterogeneous soil subjected to earthquake excitation. Significant differences were observed on the raft floor between homogeneous and inhomogeneous soil conditions. Differences were also observed between the downstream and the upstream section.

5.33

Daniela, Maugeri, Ernesto and **Erminia** report a study titled *"A Parametric Study on Soil-Pile Kinematic Interaction in Layer Soils"*. The article presents an interesting numerical study of the behavior of single piles to kinematic excitation, generated by the passage of waves through the soil surrounding the pile, which impose bending strains on the pile element even in the absence of a superstructure. The authors concentrate on kinematic bending moments generated at an interface separating two layers of sharply different stiffness (described by shear moduli G_1 and G_2), by employing a convenient yet realistic Winkler model. The variation of bending moments with G_1/G_2 is investigated. An important conclusion is drawn: bending moments obtained when G_1/G_2 is greater than 1 seem to be much more severe than those obtained when the above ration is lower than 1. Frequency effects are shown to be important.

5.37a

In *"Effect of Elastic & Inelastic DSSI on Seismic Demand of SDOFS Structures"* **Sáez, López-Caballero** and **Modaressi-Farahmand-Razavi** report an investigation conducted to define the role of pure elastic DSSI effects in the perfectly inelastic DSSI problem. In this regard, a comparative analysis of elastic and inelastic soil behavior is conducted.

Two generic types of inelastic SDOF structures, as proposed by seismic provisions, are examined, resting on a shallow rigid foundation in homogeneous medium dense sand under both dry and saturated conditions. It is shown that inelastic soil behavior may play a decisive role only for saturated soil. For dry soil conditions, an elastic DSSI approach appears to be sufficiently accurate to take into account the modification of structural response due to DSSI. Differences in dynamic response of the structure relate to pore pressure generation induced in the inelastic case, and are neglected when elastic behavior is assumed. Experimental verification of such important results is badly needed.

5.39a

In their paper *"Fixity of piles in liquefiable soils"* **Lombardi, Durante, Dash** and **Bhattacharya** present the results of parametric numerical analyses regarding the fixity of single piles due to loss of lateral support originating from sand liquefaction. The length of fixity of the pile is investigated numerically using the FEM platform SAP2000, in which the soil is modelled using Winkler springs, while its buckling load is estimated using the eigenvalue analysis. The employed simplified analysis is verified against previous analyses based on empirical, analytical and numerical methods. The results show that the fixity of a pile embedded in liquefied soil is affected mainly by the depth of liquefaction and the soil stiffness degradation ratio. These results are valuable and of significant practical interest.

5.40a

Vijaya and **Gaugadhara** in "*Experimental study on the performance of reinforced sand beds under repeated loads in presence of water"* present the results of experiments designed to study the performance of geogrid reinforced sand beds under footings, which undergo repeated loads in the presence of different levels of water. The experiments are performed in 1g model tests and the emphasis is put on the relation between number of loading cycles and settlement. The results show that the reinforcement is beneficial regardless of the water level. In addition, the presence of water in the reinforced sand increases the cyclic resistance ratio and reduces the settlement ratio making the response much more favorable, with the optimal response not related to fully but to partially inundated conditions.

5.41a

In "*Interaction between Superstructure & Substructure in Railways*", **Giannakos** presents a parametric investigation of the stiffness of the substructure of the railway track and of the elastic pads of the fastenings. A methodology is suggested for calculating the actions and stresses on the layers of the track structure as well as for the mean pressure on the seating surface of the panel and the total settlement of the structure. Basic measures to minimize the actions and permanent deformations of the superstructure and the substructure are proposed. These include: use of resilient fastenings and pads compatible to the clips, grinding the rail running table normally, reducing the non-suspended masses of the vehicles, use of ballast of high quality and hardness, use of high-quality substructure of the permanent way.

5.43a

Saeidi and **Nikkhah-Bahrami** in "*The Effect of Step Load Moving on the Surface of a Cylindrical Cavity Using Neural Networks*", employ potential functions and Fourier series methods in a cylindrical coordinate system to address the problem of moving loads on the surface of a cylindrical bore in an infinite elastic and isotropic medium. The authors uncouple the steady state dynamic equations of the medium by applying potential functions. The medium response is then obtained by using an appropriate numerical method of Laplace transform inversion. As the solution is of an integral form, they design a feed-forward back-propagation neural network which consists of two nonlinear hidden layers, successfully estimating the response of the medium subjected to moving load. The neural network was trained using the response evaluated numerically in a finite set of random points to approximate stress and displacement components in the medium, using the Levenberg-Marquardt back-propagation method. It is shown that because of the super seismic nature of the problem, two mach cones are formed and opened toward the rear of the front in the medium. Also the computational effort decreased considerably in comparison with numerical methods which are extremely time-consuming. The authors show that soft computing methods such as neural networks can be used as powerful tools in estimating the response of the infinite medium and spatial structures subjected to moving loads.

5.44

Gandomzadeh, **Avila**, **Semblat**, **Lenti**, and **Bonilla** present the results of a parametric finite element analysis regarding the influence of soil nonlinearities on dynamic soil structure interaction. Soil behaviour is described through a constitutive model based on the theory of plasticity. The model was originally proposed by Iwan (1967) and was subsequently extended by Fung (1965) to account for stress paths in 3 dimensions. It was found that the energy dissipation due to soil inelasticity might substantially decrease the response amplitude of the structure, and that the total mass of the structure is a very important factor that significantly influences the fundamental frequency of the soil-structure system. The authors remark that the effect of soil non-linearity on the structure response becomes more profound when the effective fundamental period of the systems is close to the natural frequency of the soil.

5.46a

Amini and **Shadlou** in "*Effects of Recorded Free-field Motion on the Response of Buildings considering Soil-Structure Interaction Effects*" revisit the issue of little known or misunderstood aspects of SSI in the response of building on soft ground. Detailed numerical analyses using a substructure approach are performed to investigate the importance of SSI on multi-storey buildings as function of the characteristic shear wave propagation velocity of the site, under an ensemble of 32 motions from the Imperial Valley (1979) earthquake. The Authors report that the equivalent-single storey models commonly employed in SSI analyses, instead of more realistic multi-degree-of-freedom models, may generate significant discrepancies in seismic response – often underestimate seismic demand.

5.47a

In "*Seismic performance of soil-mix panel reinforced ground*" **Olgun** and **Martin** present results from 3D nume rical analyses of the seismic performance of soil-mix panel reinforced ground of a lattice type. The analyses are performed using the FEM, and pertain to 30m deep soil site with $V_{s,30}$=192m/s overlying bedrock (V_s=750m/s), that has been improved at replacement ratios of 24% and 36% for a depth of 10, 15 and 20m. The soil-mix is modeled as to have an unconfined compressive strength of 1.5MPa. A grid pattern of 180-cm thick soil-soil mix panels with 9m center to center spacing was employed. The base shaking is earthquake-like, purely horizontal and the analysis compares the spectral acceleration at the surface of the improved ground to the pertinent response of the un-improved soil layer. The results show that soil-mix reinforcement can significantly reduce ground motions (up to 40%), especially for structural periods less than 1.0sec. The amount of ground motion reduction increases with replacement ratio, but is not significantly affected by improvement depth if that exceeds 10m. The generalization of the authors' results suggests that lower seismic design motions and more favorable Code (e.g. NEHRP, EC8) Site Categories may be achieved using such ground treatment. As the authors point out, additional research is need to explore certain aspects of the problem such as panel strength, stiffness and replacement ratio. A set of useful conclusions are drawn on the applications of soft computing to such problems.

5.48a

In their paper "*Earthquake input motions and seismic site response in a centrifuge test examining SFSI effects*" **Mason, Bray, Jones, Chen, Hutchinson, Trombetta, Choy, Kutter, Fiegel, Montgomery, Patel, Reitherman, Bolisetti** and **Whittaker** present the ground motion selection procedure for the testing program and preliminary results from a dynamic centrifuge test studying soil-foundation-structure and structure-soil-structure interaction effects in urban environments. Regarding the ground motion selection procedure, of interest is the fact that near-fault ground motions lead to enhanced soil non-linearity as compared to "ordinary" ground motions. The dynamic centrifuge test compared the soil and structure response of two structures far from one another depicting a three-story frame-based structure on spread footings and a nine-story frame-based structure on a three-story basement lying on dry, dense Nevada san (80% relative density). Comparing the near-field and the free-field ground response of the nin-story building highlights the kinematic interaction effects caused by the basement, and as such structure-soil-structure effects could be important if a smaller structure (e.g. the three-story building) was situated adjacent to the nine-story one with the embedded foundation. This paper is accompanied by 5.49a.

5.49a

Building on their related paper 5.48a, **Chen, Hutchinson, Trombetta, Mason, Bray, Jones, Bolisetti, Whittaker, Choy, Kutter, Fiegel, Montgomery, Patel** and **Reitherman**, in "*Seismic performance assessment in dense urban environments: evaluation of nonlinear building-foundation systems using centrifuge tests*" present the design, experimental program and results from a series of dynamic centrifuge tests with focus on structure-soil-structure interaction (SSSI) effects. The dynamic centrifuge tests compared the response of two structures far from one another depicting a three-story frame-based structure on spread footings and a nine-story frame-based structure on a three-story basement lying on dry, dense Nevada san (80% relative density). Their response is investigated during progressive earthquake shaking, while nonlinear behavior of the buildings is achieved either through nonlinear soil-foundation compliance or via designed inelastic fuses placed in the superstructures. Earthquake shaking caused yielding of both model structures, while measurement of accelerations depict that for the taller model building higher model effects are found to contribute significantly to its response.

5.50

Suzuki and **Tokimatsu** in "*Effects of Soil-Structure Interaction on Stress Distribution within a Pile Group under Multi-Dimensional Loading*", present the results of a series of physical model tests conducted at E-Defense, one of the largest shaking table facilities in the world located in Kobe, Japan. The study focuses on the response of a 3x3 steel pile group supporting a foundation with a superstructure. It is observed that pile stresses are mainly controlled by inertial forces when the natural period of the superstructure is shorter than - or close to - that of the supporting soil. In this case, the pile group effect is of major importance with the leading pile row being much more distressed than the trailing one. On the contrary, the kinematic loading dominates the response when the natural period of the soil is smaller than the effective fundamental period of the superstructure. In this case, the pile group effect is practically negligible. These finding complement and extend previous research efforts in the subject.

5.53a

In "*Soil-Structure Interaction of Soft Clay Using Prefabricated Vertical Geodrains Under Seismic Stresses*" **Shah** & **Shroff** present experimental data on the consolidation characteristics (settlement, excess pore pressure dissipation time histories) and the undrained shear strength (via lab vane measurements) of soft kaolinite clay, that is improved using prefabricated vertical geodrains. The measurements are performed in a modified hydraulically pressurized oedometer, that is mounted on a 1D shake table in order to also measure the pertinent response after seismic shaking. The results show a decrease in undrained shear strength of the clay following the shaking, and the beneficial effect of the geodrain in effectively decreasing the consolidation time of the clay layer. The effectiveness of the geodrain is not shown to be affected (e.g. clogging) by the shaking. A variety of findings is reported, both of classical geotechnical and of soil dynamics nature.

5.55

Cheng, **Law** and **Jiang** present a case study on the seismic response of a bridge pier supported by caisson foundation, focussing on soil-structure interaction effects. The aim of the paper is twofold: (a) to develop a methodology for computing depth-varying ground motions along the height of the caisson by taking into account kinematic soil-caisson interaction (combining the results from SHAKE and SASSI analysis), and (b) to calibrate the spring moduli of a beam on a Winkler foundation–based modelling of the caisson, by matching its response to lateral loading to the corresponding one from a 3D finite element analysis (using ADINA) with full consideration of soil and interface nonlinearities.

5.56a

In "*Structure–to–Soil–Structure Interaction Analysis: A Case Study*", **Anderson,** and **Elkhoraibi** present a case study demonstrating the importance of explicit modelling for structure-to-soil structure interaction (SSSI) analysis of the Hanford Waste Treatment Plant Pre-treatment Facility Complex. The SSSI effect is illustrated through comparison of seismic member forces and acceleration response spectra obtained by means of the established elastodynamic computer software SASSI. The authors highlight the importance of explicit modelling for SSSI in certain cases involving the seismic response of a small structure located close to a larger one. They stress the need for lucid guidelines in this regard.

5.57a

Grassi and **Massimino** in *"FEM Modeling of a 3D Soil-Pile System under Earthquakes"* report an interesting numerical study of the kinematic response of a pile to earthquake loading. An ensemble consisting (mainly) of Italian ground motions were employed and bending moments as well as displacements along the pile and the soil were determined. The conclusions reported by the authors include: (1) bending moments along the pile can be particularly severe and may inflict failure on the pile at least at cross-sectional level; (2) frequency effects can be particularly important; (3) soil and pile displacements may be significantly different during seismic response; (4) Pile length (in long piles) does not seem to be a factor. These conclusions are important. This is especially so with (3) and (4) as they are not part of current simplified solutions in the subject.

5.58a

In "*Dynamic Soil Structure Interaction Analysis of Pile Supported High Rise Structures*" by **Sushma** and **Kumar** presents a numerical study of the dynamic SSI of a high rise structure in viscoelastic half space in the presence of neighbouring pile supported structures. It is shown that the group effect of neighbouring pile supported structures is crucial in dynamic analysis.

5.59

In their paper titled "*Analysis of Soil Nailed Walls under Harmonic Dynamic Excitations Using Finite Difference Method*", **Sheikhbahaei** and **Hashemolhosseini** present a numerical analysis of a 9m high soil nailed wall subjected to harmonic base excitations taking into consideration nonlinear hysteretic soil behavior in order to explore the influence of key parameters such as; input motion frequency, nail inclination angle, nail length and soil strength properties. To this end, a three-dimensional model has been developed in the finite differences code FLAC3D. The failure criterion for the soil used in dynamic analyses is the Mohr-Coulomb shear failure criterion coming together with a nonlinear hysteretic constitutive behavior under cyclic loading conditions. The numerical model is excited at foundation level by a variable-amplitude harmonic motion with frequency close to the fundamental frequency of the reference structure. Dynamic analyses are conducted with a fully non-linear approach, under an explicit calculation scheme. Following a comprehensive parametric study of the performance of soil-nailed walls, the results show that horizontal displacements at the wall crest, peak horizontal displacement along the wall facing and maximum tensile force along nail bars decrease as the frequency of input motion increases as well as with increasing nail angle in the range 0^o to 15^o with respect to horizontal plane.

5.61

In their paper titled "*Numerical Analysis of Disconnected Spread Footing on Soft Soil during Strong Earthquake*", **Richter** and **Cudmani** present a case study of the foundation design for the Golden Ears approach bridge in Vancouver (Canada). The authors analyze the seismic response of a disconnected spread footing (DSF), in which footing and piles are separated by a layer of coarse grained material, as alternative to a conventional pile foundation. Calculations are performed with a 3-D finite element analysis using a (visco-) hypoplastic constitutive law for the stress-strain relation of soil. The results compare to those of a conventional pile foundation. It is shown that the internal forces in the piles of a DSF are significantly smaller as compared with those of a conventional pile foundation, particularly in the upper part of the pile. It is also remarked that the bending moments and shear forces in the piles are practically not influenced by the thickness of the gravel layer, and that the pile spacing in a DSF has a more pronounced influence on the internal pile forces.

5.62a

In their paper "*Lateral response of bridge pile groups in liquefiable soil with surface non-liquefiable layer using shaking table test*" **Liang, Xianzhang, Pengju** and **Xia** present experimental data on the seismic response of low-cap pile groups founding a bridge structure, in a soil profile consisting of a liquefiable sand underlying a non-liquefiable clay crust. The measurements are performed via 3 shaking table tests on the same soil-foundation-superstructure model (constructed in a laminar box), whose differences were in the amplitude and the frequency content of the purely horizontal earthquake-like base motion. Free-field response showed that low frequency and high intensity shaking produced more intense excess pore pressure build up. Measurements of peak moment along the depth of a pile show that the more intense the excess pore pressures, the higher the peak moments all along the pile depth. Qualitatively, in all tests, there is an abrupt change in the peak moment at the soil-clay interface, yet, the maximum values of the peak moment appear at the pile cap, whereas the lowest at the tip of the floating piles. In addition, it is shown that the amplitude of the input shaking and the inertial effect of the superstructure control the moment response of the pile, only at low excess pore pressure regimes.

5.64

In "*Evaluation of Deformation Behavior of Quay Walls under Earthquake Loading*", **Khodabakhshi** and **Baziar** present the results of a numerical investigation into the mechanism of damage on quay walls and the influence of soil properties on the residual deformation of gravity quay walls during an earthquake. A model of Kobe Port Island quay walls damaged during the 1995 Hyogoken-Nanbu (Kobe) earthquake is used as a case study.

The finite element software PLAXIS was used for the analyses under plane strain and undrained conditions. Horizontal acceleration was applied to the model and the results referring to horizontal and vertical displacements were compared with observed field measurements of seaward displacement, tilting and settlement. The results of the numerical analysis show good agreement between the numerical simulations and the observed data.

The results indicate that the observed damage was caused mainly by deformation of the loosely deposited foundation soil beneath the caisson wall, due to liquefaction and lateral spreading. On the other hand, the influence of the retained soil on the behavior of the wall is smaller.

5.65a

Gerolymos, **Gazetas** and **Drosos** address the issue of performance-based design for pile foundations. Their paper, titled "*Seismic Response of Pile Foundations*", shows that while seismic codes do not allow for plastic deformation in the piles, some observations have demonstrated that limited structural yielding and cracking in piles may not be always detrimental for the structure and the pile. A numerical finite-element study is then presented focusing on the influence of soil compliance, pile-to-pile interaction, intensity of seismic excitation, pile diameter, above-ground height of the pile, and location of plastic hinges on the seismic response of a pile-supported bridge pier. Two major conclusions are drawn: *First* that ductility demand of a bridge generally decreases with increasing soil compliance and below-ground location of plastic hinges. *Second* that allowing for pile and soil yielding force potential plastic hinges to develop in the foundation instead of the structure leading to lower ductility demand on the superstructure. This leads to a new performance-based design methodology which appears to be promising provided that damage below ground surface can be repaired without excessive cost.

5.69a

In a paper titled "*A Simple Numerical Tool for Dynamic Soil-Structure Interaction Analyses, including Non-linear Behavior of both Structure and Foundation*", **Figini, Chatzigogos** and **Paolucci** present a simple model to investigate non-linear dynamic soil-structure interaction phenomena on an elastic-perfectly plastic SDoF superstructure using a 3DoF macro-element foundation described by two sources of non-linearity in the soil-foundation interface: a) material nonlinearity, due to the irreversible elastoplastic soil behavior and b) geometric nonlinearity, due to possible foundation uplift. The earthquake motion is modelled by means of the 1999 Kocaeli earthquake record. The global model entails: a) the coupling between foundation and superstructure when one or both enters the non-linear range, b) energy dissipation by either foundation and superstructure, c) prediction of peak and residual displacements in both foundation and superstructure, d) modelling of structural isolation effects due to non-linear behavior of the foundation, e) the possibility for the superstructure to reach a particular level of ductility demand. The proposed model aims at serving as a numerical tool towards development of performance – based design approaches incorporating non-linear SSI effects.

5.75a

In their study "*Influence of concentrated mass on pile response under vertical earthquake excitation*" **Ghavazi** and **Madhoushi** present an analytical solution to determine the kinematic and inertial response of a vertical pile embedded in a homogeneous soil layer over rigid rock, subjected to vertical seismic excitation due to earthquake loading. Perfect contact is assumed between pile and soil. The kinematic pile response is obtained considering a stress free condition at pile head and soil surface. A concentrated mass at the pile head, which stands for the weight of the superstructure, produces the inertial pile response. The total displacement at the pile head is determined as a superposition of kinematic and inertial displacement. The displacement corresponding to kinematic response is calculated using the equations derived from the solution of Mylonakis & Gazetas (2002). The displacement due to inertial effect is based on dynamic plane strain model introduced by Novak (1977). The results are presented in terms of the dimensionless inertia and kinematic response factors. It is shown that the effect of the concentrated mass at the pile head has an insignificant effect on pile response, implying that the inertial response of the pile is negligible compared to kinematic response. In other words, the inertia effect can be safely neglected in pile design and only the kinematic effect is worth considering.

5.76a

In their paper titled "*Analytical Method for Seismic Bearing Capacity of Stone-Column Reinforced Shallow Foundations*" **Nazari Afshar, Ghazavi** and **Hemmati** present an analytical method to determine the seismic bearing capacity of a stone-column reinforced shallow foundation. To this end a simple failure surface is assumed for characterizing the failure stage of the stone column and soil materials using the concept of lateral active and passive earth pressures. The Mononobe-Okabe approach is employed to account for seismic effects on lateral earth pressures. The influence of geotechnical data of stone column material, foundation geometry, native soil specification, and earthquake details is examined. The authors show that an increase in seismic force can cause the ultimate bearing capacity of the stone column to decrease. In addition, with increasing the friction angle of the stone column material, the bearing capacity of the column increases particularly at low to moderate seismic intensities. This effect is shown to be insignificant at higher seismic intensities. The authors also show that an increase in diameter of the stone-column is more efficient than an increase in friction angle of the stone-column material, or with a decrease in center-to-center distance of stone columns.

5.77a

In their paper "*An analytical solution for pile-soil-pile interaction with unequal embedded lengths under vertical harmonic vibrations*", **Ghazavi** and **Ravanshenas** present a simple closed-form solution for determining the interaction effect between two closely spaced piles of unequal length embedded in homogeneous soil with inclined surface, subjected to vertical harmonic excitation at the top. Both soil and pile are assumed to be elastic. The dynamic displacement field around an individual pile is described by an asymptotic cylindrical wave expression. The source pile induces displacements to the soil and the soil induces displacements to the receiver pile. Two cases are investigated. In the first case the source pile is fully embedded in the soil, whereas only a part of the receiver pile is embedded. The second case refers to the opposite setup. It has been found that the interaction factor is different in the two cases, as pile-pile interaction is greatly affected by the embedment length of the source and receiver pile. The results also indicate that the distance between the two piles and the soil type greatly influence the response.

5.78

In their paper "*Investigation of non-uniform pile behaviour under torsional harmonic vibration*", **Ghavazi** and **Afzalirad** develop a method to account for the effect of taper angle on the response of an individual vertical tapered pile of circular cross-section subjected to torsional harmonic vibrations in the realm of elastodynamic theory. The pile is embedded in a linear isotropic viscoelastic soil medium characterized by hysteretic damping while no slippage is allowed at the pile-soil interface. The finite difference technique is employed to solve the governing differential equation of the problem. The pile is socketed into a stiff soil layer, thus the pile-tip condition is considered fixed. The main conclusions of the study are: the twist angle of the pile decreases with increasing the taper angle while pile length and volume are kept constant. An increase in soil shear wave velocity causes the twist angle of the tapered pile to decrease. In other words, it is shown that tapered piles perform better as foundation systems than straight-sided piles of the same length and volume.

5.79

"*Times-History Finite Element Dynamic – Soil Nail Wall – San Manuel Casino – Highland, California*" by **Barrar** and **Liu** presents the design and the performance analysis of a soil nail wall constructed in the highly seismic region of Southern California, about 100ft away from San Andreas fault, against seismic action. The main objective of this analysis was to determine the maximum deformation the wall will undergo during an earthquake so that an adequate separation could be defined between the wall and the nearby structure, thereby eliminating the exertion of static and seismic lateral earth pressures on the structure.

Soil Nail length and spacings were selected based on the results of a limit equilibrium procedure, calculating the factor of safety against the most critical failure plane that should satisfy the value of 1.50 or better in the permanent static and 1.1 for seismic condition. A pseudo-static seismic coefficient of 0.40g was used as part of seismic limit equilibrium analyses. In addition, vertical soil nails (V-Nails) were to be installed directly behind the shotcrete facing of the wall to provide localized surface stability during construction, the effect of which was neglected in the limit equilibrium analysis.

Finally, time-history dynamic analysis were conducted on a plane strain finite element numerical model of the above design, by means of the commercial finite-element code PLAXIS. The results of the latter analysis demonstrate that the soil-nailed wall will remain stable during the prescribed earthquake events.

5.80a

In "*Analysis of Tunnel Behaviour Under Seismic Loads by Means of Simple and Advanced Numerical Aproaches*" **Boldini, Amorosi** and **Palmisano** investigate numerically the dynamic behaviour of circular tunnels in the transverse direction, referring to a shallow tunnel built in an ideal soft clayey deposit by using: a) one-dimensional (1D) numerical analyses modelling the soil as a single phase viscoelastic non-linear medium, the results of which are then used to evaluate the input data for selected analytical solutions proposed in the literature (uncoupled approach), and b) 2D fully coupled Finite Element simulations adopting viscoelastic and viscoelasto-plastic constitutive assumptions for the soil and the lining (coupled approach). The results are presented in terms of increments of seismic-induced loads in the transverse direction of the tunnel lining. The different constitutive hypotheses adopted in the coupled numerical approach appear to play a significant role on the results. In particular, the plasticity-based analyses indicate that a seismic event can produce a substantial modification of the loads acting in the lining, leading to permanent increments of both hoop force and bending moment. The Authors point out that further research is needed towards constitutive modelling for soil and tunnel lining, to more realistically represent the behaviour and interaction of these systems under dynamic loading.

5.81a

Tazoh, Sato, Jan, Taji and **Gazetas** report results from centrifuge tests to investigate the behavior of batter-pile foundations in a study titled "*Seismic Behavior of Batter Pile Foundation: Kinematic Response*". The article presents an interesting comparison of the behavior of a vertical pile and a batter pile foundation without the presence of a superstructure installed in parallel to each other in a soil container filled with dry sand. The results indicate that the batter piles respond much less than the vertical piles to the input motion imposed at the bottom of the box. Also the rotational response of the pile cap is opposite in the two cases, with the batter pile foundation responding in a counterclockwise fashion to motion to the right, thereby reducing foundation input motion to a hypothetical superstructure. On the other hand, the "aseismicity" of the batter pile foundation comes at the expense of larger bending and axial strains along the piles. The paper elucidates the urgent need for experimental investigation of batter pile foundation behavior.

5.02b

In their paper "*Numerical modeling of buried pipeline crossing a fault*" **Govind** and **Kumar** present results from 3D numerical analyses of the stress-strain response of a buried steel pipeline crossing a fault. The analyses are performed using the FEM, and pertain to an 80m long pipeline model consisting of with 8-noded isoparametric brick elements. The pipeline corresponds to an 18 inch diameter steel cross section of API-5L Grade X65 steel, buried at 1.5m below the surface (from center), that is perfectly bonded to the surrounding soil. Different soil types are considered, but the emphasis of the analyses is on the fault angle and fault displacement effects on the normal and shear stresses along the longitudinal axis of the pipe. It is shown that normal stresses along the longitudinal axis are the most prominent and decrease with increasing angle between pipe and fault. The location where the peak value of normal stresses along the pipeline route appears depends on the angle between pipe and fault and the fault displacement, and is different for compression and extension. The latter effect is dependent on local buckling, which reduces the peak value in compression but distributes it over a wider length. Similar analyses show that the stresses along the pipe depend on various secondary parameters, like pipeline diameter, wall thickness, embedment depth and soil conditions (type and stratigraphy).

5.03b

Anastasopoulos, **Georgarakos, Kourkoulis** and **Gazetas** present a paper entitled "*Design of bridges against seismic faulting: methodology and applications*". In accordance to its title, this paper presents a numerical methodology for the design of bridges against seismic faulting. The problem is decoupled in two analysis steps: a) the response of a single pier undergoing fault rupture-soil-foundation-structure interaction with the superstructure modeled in a simplified manner to capture its kinematic constraints, and b) the response of the superstructure, taking the output of the first step as input differential displacements of the bridge pier foundations. The numerical analyses of the first step are conducted in 3D utilizing the FEM code ABAQUS and a modified version of the Mohr-Coulomb model to simulate strain softening of soil. Parametric analyses are performed for various foundation types and bridge types. Of special interest is the conclusion that piled foundations are found to be vulnerable to faulting, with floating piles performing better, especially if combined with hinged pile-to-cap connections. On the contrary, caisson foundations show advantageous response to faulting. In addition, statically-determinate superstructures are shown to be less sensitive to faulting, but care should always be taken to avoid fall of the deck due to excessive relative displacements. The authors also present an example of the methodology for an actual bridge in Greece that may experience normal faulting.

5.04b

In their paper "*Soft Soil Effect on Soft Storey Response*" **Al-Hussaini** and **Khan** present a numerical study on the significant effect of soft soil sites on the seismic response of soft-storey buildings. One-dimensional wave propagation analysis using SHAKE code is performed for selected soil profiles at the city of Dhaka in Bangladesh. In the absence of measured shear wave velocity data, empirical relations were used in this regard. Four US and Japanese strong motion records of were used as input motion due to lack of local data. Two-dimensional FE models for 6- and 10-storey reinforced concrete frame buildings with and without infill walls were subjected to elastic transient time history analysis using ETABS computer program. Infill walls were modelled through equivalent strut actions. Energy dissipation in the structural elements was obtained by dividing seismic response be the reduction factor R as specified in the building code. Results indicate that the analysis of soft-storey building on soft soil should be carried out by means of site-specific motions.

5.05b

Svinkin discusses the use of a variable damping coefficient in the classical wave equation method for capacity predictions of driven piles in his paper titled "*The Variable Damping Concept in Pile Capacity Prediction by Wave Equation Analysis*". The author stresses that classical wave equation analyses cannot predict time-dependent changes in soil-pile behaviour. A modified approach based on a time-dependent damping coefficient for the energy-dissipating mechanisms along the pile is discussed. Some encouraging results are presented, originally reported by the Author in a 1995 publication. In his concluding remarks, Svinkin points out that additional research is needed to examine the results of variable damping computations obtained from wave equations back-analysis. Yet, the method appears promising in alleviating limitations of pre-driving wave equation analysis in predicting pile capacity.

5.06b

Tezcan, Cheng and Hill, investigate the applicability and efficiency of support vector machines in estimating the earthquake response spectra through the Fourier amplitude spectra of a ground accelerogram in "*Response Spectrum Estimation using Support Vector Machines*". Two methods are commonly used for this purpose: time domain simulations, which offer high accuracy at a high computational cost, and random vibration theory which, although not computationally intensive, requires knowledge of the statistical distribution of the response amplitudes. The authors treat this task as a nonlinear regression problem and construct a supervised machine learning algorithm with minimal sensitivity to noise and outliers Pairs of vectors consisting of Fourier amplitude spectra and pseudo-velocity response spectra are transformed into a high dimensional feature space where the nonlinear relationship between them can be represented as a line. No assumptions regarding the probability density function of response amplitudes are required. Through a practical application using artificially generated accelerograms, it is shown that the support vector machines can predict the response spectra for a wide range of vibration periods.

Table 1: Summary of papers submitted to this session

Paper No. & Authors	Title of Paper	Field of Application	Summary of Content	Approach	Country
SESSION 5a					
"Soil-Structure Interaction under Dynamic Loading, for both Shallow and Deep Foundations"					
#5.01a Chatterjee, Basu	Non-Stationary Soil-Structure Interaction Analysis of a SDOF System Subjected to Joint Horizontal and Vertical Seismic Excitations	Building Response	Estimation of non-stationary response in cases where seismic excitation is active simultaneously in both horizontal and vertical directions.	Analytical	Netherlands, Ireland
#5.02a Elahi, Moradi, Poulos, Ghalandarzadeh	Seismic analysis of pile group using pseudostatic approach	Pile Foundations	Estimation of displacements and maximum internal forces of pile groups subjected to lateral seismic excitation	Numerical	Iran, Australia
#5.05a Manna, Baidya	Nonlinear Soil-Pile Interaction Under Vertical and Coupled Motion	Pile Foundations	Response of a single pile and of a 2x2 group of piles subjected to vertical and combined horizontal-vertical dynamic loading.	Experimental	India
#5.08a Chowdhury, Dasgupta	Estimation of Lateral Load Capacity of Short Piles Under Earthquake Forces	Pile Foundations	Analytical procedure for calculating the seismic response of pile-column systems	Analytical	India
#5.09a Prowell, Elgamal, Lu	Modelling the Influence of Soil Structure Interaction on the Seismic Response of a 5 MW Wind Turbine	Turbine Structure	3D finite element model to investigate the influence of soil-structure interaction on the seismic response of a 5 MW wind turbine.	Numerical	USA
#5.10 Trandafir, Bartlett	Seismic Performance of Double EPS Geofoam Buffer Systems	Retaining Wall	Investigation of the effectiveness of a polystyrene (EPS) geofoam buffer system in reducing the peak seismic loads on a rigid, non-yielding retaining wall during an earthquake	Numerical, Physical testings	USA
#5.11a Yang, Kwon, Kim	Natural Frequency Calculation of a Pile-Soil System in Dry Sand under an Earthquake Loading	Pile Foundations	Report of a combined analytical-experimental study focusing on calculation of natural frequencies of pile-soil systems subjected to earthquake loading.	Analytical - Experimental	Korea
#5.12a Wotherspoon, Pender	Effect of Uplift Modelling on the Seismic Response of Shallow Foundations	Shallow Foundations	Numerical simulation of uplift effects on the seismic response of shallow foundations	Analytical Spring-Dashpot approach	New Zealand
#5.13a Zhai	Numerical Modeling of Soil-Pile Interaction in Liquefying Soils for a Water Crossing Bridge	Pile Foundations	Proposal of a practical methodology for developing p-y curves for pile foundations in liquefiable soil	Numerical and p-y analysis	USA

#5.15a Stringer, Madabhushi	Effect of Liquefaction on Pile Shaft Friction Capacity	Pile Foundations	Measurement of pile shaft friction and settlements in seismic loading of dry and saturated sand	Experimental (centrifuge testing)	United Kingdom
#5.16a Eisenberg	Pile-In-Tube Foundations with Reserve Switch-Off Elements and Other Systems for Seismic Response Adaptive Control	Isolation and Protective Systems including Piles	Review of methods pioneered in Russia and former Soviet Union for the seismic protection of structures on the basis of modification in vibrational characteristics via “switch-off” elements and other adaptive control measures.	Review	Russia
#5.17a Malhotra	Seismic soil-pile interaction: Physical processes and analytical models	Pile Foundations	Discussion of available models and modifications of p-y relations used to model soil response under seismic conditions.	Review of physical processes and analytical models	USA
#5.22a Anoyatis, Mylonakis	Dynamic Winkler Modulus for Axially Loaded End-Bearing Piles	Pile Foundations	Exploiting the concept of the dynamic Winkler foundation in conjunction with a simple wave propagation model. It is shown that depth-dependent Winkler springs and dashpots may faithfully describe pile-soil interaction, contrary to common perception that the Winkler model is always approximate.	Analytical	Greece
#5.23a Renzi, Vannucchi, Madiai, Mylonakis	Influence of Dynamic Soil-Structure Interaction Analyses on Shear Buildings and Towers	Building response	Exploration of the influence of SSI on the seismic response of shear buildings. Finite element analyses in time domain using recorded acceleration time histories, with reference to a set of idealized shear-building configurations.	Analytical-Numerical Analyses	Italy
#5.26a Ghadimi	Dynamic Response of Pile Groups Embedded in Transversely Isotropic Media Using Hybrid Numerical Method	Pile groups	3-dimensional dynamic response of pile groups embedded in transversely isotropic media subjected to multi-axial harmonic loading	Numerical	Iran
#5.27a Anastasopoulos, Georgarakos, Drosos, Gazetas	Experimental Soil–Foundation–Bridge Pier Interaction: Towards a Reversal of Capacity Design	Shallow Foundations–Bridge design	Experimental comparison of over-designed and under-designed bridge pier foundation on dry sand under seismic shaking	Experimental (shaking table testing)	Greece
#5.30a Tamura, Tokimatsu, Adachi	Centrifuge Tests and Simple Analyses for Seismic Soil-Structure Interaction	Shallow Foundations	Experimental and simplified analysis of seismic loading of a superstructure-footing system on dry sand	Experimental -Analytical (Dynamic centrifuge testing)	Japan

#5.31a Gordana Stanko	Investigation of Vibration Caused by Traffic and Railway Load	Man-induced vibrations	Investigation of vibrations in 2 civil engineering structures.	Numerical	Serbia
#5.32a Venkatesh, Pandey, Samadhiya	Seismic Response of Barrage Raft Floor Under Heterogeneous Soil Medium	Raft floor	Numerical Investigation of the Response of Raft floor to earthquake loading.	Numerical	India
#5.33a Ardita, Maugeri , Motta, Raciti	A Parametric Study on Soil-Pile Kinematic Interaction in Layered Soils	Pile Foundations Kinematic Bending)	Numerical study of the behavior of single piles to kinematic excitation, generated by the passage of waves through the soil surrounding the pile, which impose bending strains on the pile element even in the absence of a superstructure.	Numerical	Italy
#5.37a Saez, Lopez-Caballero, Modaressi-Farahmand Razavi	Effect of Elastic and Inelastic DSSI on Seismic Demands of SDOF Structures	Building Response	Investigation of the role of pure elastic DSSI effects in the perfectly inelastic DSSI problem.	Numerical	France
#5.39a Lombardi, Bhattacharya	Fixity of the Pile in Liquefiable Soils	Pile Foundations	Parametric numerical analyses of the fixity of single piles due to loss of lateral support originating from seismic liquefaction	Numerical analyses by Winkler springs	United Kingdom
#5.40a Vijaya, Gangadhara	Experimental Study on the Performance of Reinforced Sand Beds Under Repeated Loads in Presence of Water	Shallow Foundations (on reinforced soil)	Experimental study on the number of load cycles versus settlement of shallow foundations on geogrid reinforced sand beds (dry, saturated, partially saturated)	Experimental model testing	India
#5.41a Giannakos	Interaction Between Superstructure and Substructure in Railways	Surface Foundations (of railways)	A parametric investigation of the stiffness of the substructure of the railway track and of the elastic pads of the fastenings.	Parametric design application	Greece
#5.43 Saeidi Nikkhah-Bahrami	The Effect of Step Load Moving on the Surface of a Cylindrical Cavity Using Neural Networks	Dynamics	Application of potential functions and Fourier theory to solving the problem of moving loads on the surface of a cylindrical bore in an infinite elastic and isotropic medium via Neural Networks	Numerical-Analytical	Iran
#5.44a Gandomzadeh, Santisi d'Avila, Semblat, Lenti, Bonilla	Influence of Soil Nonlinearities on Dynamic Soil-Structure Interaction	Building Response	Parametric finite element analysis regarding the influence of soil nonlinearities on dynamic soil structure interaction. Soil behaviour is described through a constitutive model based on the theory of plasticity.	Numerical	France

#5.46a Amini, Shadlou	Effects of Recorded Free-Field Motion on the Response of Buildings Under Considering Soil-Structure Interaction Effects	Building Response	Detailed numerical analyses using a substructure approach to investigate the importance SSI effects on multi-storey buildings under earthquake loading.	Numerical	Iran
#5.47a Guney Olgun, Martin II	Seismic Performance of Soil-Mix Panel Reinforced Ground	Free-field Response	Parametric numerical analyses of soft soil improved with soil-mix panels of lattice type. Study of beneficial effects on seismic ground response	Numerical	USA
#5.48a Mason, Bray, Jones, Chen, Hutchinson, Trombetta, Choy, Kutter, Fiegel, Montgomery, Patel, Reitherman, Bolisetti, Whittaker	Earthquake Input Motions and Seismic Site Response in a Centrifuge Test Examining SFSI Effects	Different Structure-Foundation Systems	Numerical analysis is employed for ground motion selection procedure for the testing program and preliminary results are presented from a dynamic centrifuge test studying soil-foundation-structure and structure-soil-structure interaction effects in urban environments (companion to paper 5.49a)	Numerical analyses – dynamic centrifuge testing	USA
#5.49a Chen, Hutchinson, Trombetta, Mason, Bray, Jones, Bolisetti, Whittaker, Choy, Kutter, Fiegel, Montgomery, Patel, Reitherman	Seismic Performance Assessment in Dense Urban Environments: Evaluation of Nonlinear Building-Foundation Systems Using Centrifuge Tests	Different structure-foundation systems	The presentation includes the design, experimental program and results from a series of dynamic centrifuge tests with focus on structure-soil-structure interaction (SSSI) effects (companion to paper 5.48a)	Experimental (centrifuge testing)	USA

#5.50a Suzuki, Tokimatsu	Effects of Soil-Structure Interaction on Stress Distribution within a Pile Group under Multi-Dimensional Loading	Physical Model Tests on Shaking Table	Results of a series of physical model tests conducted at E-Defense, Kobe, Japan. The study focuses on the response of a 3x3 steel pile group supporting a foundation with a superstructure.	Experimental	Japan
#5.53a Shah, Shroff	Soil-Structure Interaction of Soft Clay Using Prefabricated Vertical Geo-drains Under Seismic Stresses	Soft clay improvement with geo-drains	The setup and data of the consolidation characteristics and the undrained shear strength (pre and post-shaking) of soft kaolinite clay, that is improved using prefabricated vertical geo-drains	Experimental (1g shaking table testing)	India
#5.55a Cheng, Law, Jiang	Soil-Structure Interaction Analysis for Bridge Caisson Foundation	Bridge Caisson	Case study on the seismic response of a bridge pier supported by caisson foundation, focussing on soil-structure interaction effects.	Numerical	USA
#5.56a Anderson, Elkhoraibi	Structure-To-Soil-Structure Interaction Analysis: A Case Study	Building Response	A case study on the importance of explicit modelling for structure-to-soil structure interaction (SSSI) analysis of the Hanford Waste Treatment Plant Pre-treatment Facility Complex.	Numerical	USA
#5.57a Grassi, Massimino	FEM Modelling of a 3D Soil-Pile System Under Earthquakes	Pile Foundation (kinematic response)	Parametric finite-element analyses of kinematic response of a single pile in layered soil	Numerical	Italy
#5.58a Sushma, Kumar	Dynamic Soil Structure Interaction Analysis of Pile Supported High Rise Structures	Building Response	Numerical study of the dynamic SSI of a high rise structure in viscoelastic half space in the presence of neighbouring pile-supported structures	Numerical	India
#5.59 Sheikhbahaei, Hashemolhosseini,	Analysis of Soil Nailed Walls under Harmonic Dynamic Excitations Using Finite Difference Method	Retaining Wall	Parametric investigation of the factors affecting Soil nailed walls performance under Harmonic dynamic Excitations	Numerical	Iran
#5.61a Richter, Cudmani	Numerical Analysis of Disconnected Spread Footing on Soft Soil during Strong Earthquake	Surface Footing	Case study of foundation design for the Golden Ears approach bridge, Vancouver. Analysis of seismic response of a disconnected spread footing (DSF) in which footing and piles are separated by a layer of coarse grained material, as alternative to a conventional pile foundation.	Numerical	Germany

#5.62a Liang, Xianzhang, Pengju, Xia	Study on Lateral Capacity of Pile Groups of Bridge in Liquefiable Ground Using Shaking Table Tests	Pile Foundation	Setup and data on the seismic response of low-cap pile groups founding a bridge structure, in a soil profile consisting of a liquefiable sand underlying a non-liquefiable clay crust are presented	Experimental (Shaking table testing)	China
#5.64 Khodabakhshi, Baziar	Evaluation of Deformation Behavior of Quay Walls under Earthquake Loading	Retaining Wall	Back analysis of the deformation failure of Kobe Port quay walls during the 1995 Hyogoken- Nanbu Earthquake	Numerical	Iran
#5.65a Gerolymos, Drosos, Gazetas	Seismic Response of Inelastic Pile Foundations: New Design Philosophy and Applications	Pile Foundation	Performance-based design for pile foundations.	Numerical	Greece
#5.69a Figini, Chatzigogos, Paolucci	A Simple Numerical Tool for Dynamic Soil-Structure Interaction Analyses Including Nonlinear Behaviour of Both Structure and Foundation	Building Response	Development of a numerical model towards development of performance – based design approaches incorporating non-linear SSI effects.	Numerical	Italy, France
#5.75a Ghavazi, Madhoushi	Influence of concentrated mass on pile response under vertical earthquake excitation	Pile Foundation	Analytical study of pile response. Inertial effects appear to be negligible in pile design' only kinematic effects seem to be worth considering.	Analytical	Iran
#5.76 Nazari Afshar Ghazavi Hemmati	Analytical Method for Seismic Bearing Capacity of Stone-Column Reinforced Shallow Foundations	Shallow Foundation	Determination of seismic bearing capacity of a stone-column reinforced shallow foundation	Analytical	Iran
#5.77a Ghavazi, Ravanshenas	An analytical solution for pile-soil-pile interaction with unequal embedded lengths under vertical harmonic vibrations	Pile Foundation	Analytical study of vertical pile response. Pile-to-pile interaction appear to be greatly affected by the embedment length of the source and receiver pile	Analytical	Iran
#5.78a Ghavazi, Afzalirad	Investigation of non--uniform pile behaviour under torsional harmonic vibration	Pile Foundation	Analytical of study of torsional pile response. The twist angle of the pile appears to decrease with increasing the taper angle while pile length and volume are kept constant	Analytical	Iran
#5.79 Barar, Liu	Times-History Finite Element Dynamic – Soil Nail Wall – San Manuel Casino – Highland, California	Retaining Wall	Design and performance analysis of a Soil Nail Wall, against seismic excitation, in a high seismicity area in California	Numerical	USA

#5.80 Boldini Amorosi Palmisano	Analysis of Tunnel Behaviour Under Seismic Loads by Means of Simple and Advanced Numerical Aproaches	Tunnel	Investigation of dynamic behaviour of circular tunnels in the transverse direction referring to a shallow tunnel built in an ideal soft clayey deposit	Numerical	Italy
#5.81a Tazoh, Sato, Jang, Taji, Gazetas	Seismic Behavior of Batter Pile Foundation: Kinematic Response	Batter Piles	Results from novel centrifuge tests to investigate the behavior of batter-pile foundations. Comparison of the behavior of a vertical and batter pile foundations without the presence of a superstructure, installed in a soil container filled with dry sand.	Experimental (centrifuge model testing)	Japan, Greece
SESSION 5b					
"Soil-Foundation Interaction Triggered by Seismic Faulting"					
#5.02b Govind, Kumar	Numerical Modelling of Buried Pipeline Crossing a Fault	Pipeline	3D numerical analyses of the stress-strain response of a buried steel pipeline crossing a fault are presented	Numerical	India
#5.03b Anastasopoulos, Georgarakos, Kourkoulis, Gazetas	Design of Bridges Against Seismic Faulting: Methodology And Applications	Pile & Caisson foundation	A pertinent methodology is presented, that consists of 2 steps: a) the response of a single pier undergoing fault rupture, and b) the response of the superstructure, taking the output of the first step as input differential displacements of the bridge pier foundations	Numerical	Greece
#5.04b Al-Hussaini, Khan	Soft Soil Effect on Soft Storey Response	Building Response	A numerical study on the significant effect of soft soil sites on the seismic response of soft-storey buildings.	Numerical	Bangladesh
#5.05b Svinkin	The Variable Damping Concept in Pile Capacity Prediction by Wave Equation Analysis	Pile Foundations	Discussion of the use of variable damping coefficient in classical wave equation method for capacity predictions of driven piles	Numerical	USA
#5.06b Tezcan, Cheng, Hill	Response Spectrum Estimation Using Support Vector Machines	Engineering Seismology	Investigation on the applicability and efficiency of support vector machines in estimating the earthquake response spectra through the Fourier amplitude spectra of ground accelerograms	Numerical	USA

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